Christian Hahm and Kathryn Piper
CIS 5603 - Artificial Intelligence
Final Project Report

Creating 3D "Flyers" Using Genetic Algorithms

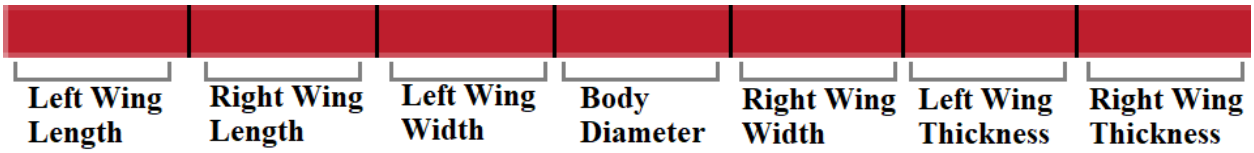
Introduction

Genetic algorithm is a type of evolutionary computation which is inspired by Darwin's "natural selection" to automatically generate increasingly optimal solutions for a task with a defined fitness function. Once the task is defined, an initial population of candidate solutions, each with various attributes or "genes", is generated to try and complete the task. The genetic algorithm consists of a loop where the best-performing candidates in the population, determined by a fitness function,"reproduce". This introduces new offspring into the population and replaces the worst-performing candidates. The genetic algorithm hopes to introduce better 'fit' candidates through reproduction of the best-performing candidates from the previous generation. The offspring's genes are inherited directly from their parent(s), but with slight differences brought about by "genetic recombination" or "crossover" (the choice of each parent's attributes) and the introduction of random mutations. The mutations may have a positive or negative impact on the candidate's performance on the task. After many generations, the population is a solution set that has evolved to optimize for the task at hand [3].

The Flyer Algorithm

For this project we implemented a genetic algorithm on a population of 16 "3D Flyers" which evolve to fly higher through each generation. Our code was written in C# and the Genetic Algorithm was run using Unity Game engine. Each Flyer consists of a spherical body with two rectangular- prism wings with the following 7 attributes:

1. Left/Right Wing Length (Wing area is proportional to the Wing's flapping force)
2. Left/Right Wing Width (Wing area is proportional to the Wing's flapping force)
3. Left/Right Wing Thickness (proportional to the Wing's flapping frequency)
4. Body Diameter (proportional to the # of flaps a Flyer can perform in its lifetime)



Each gene on the chromosome is in the range (0.0, 4.0]. All of the features are encoded as genes within a "chromosome" as an array of floats and are directly inheritable. Each body part (wing and body) has a mass proportional to its volume. The Top 4 Flyers survive to the next generation along with their 12 offspring, which are produced by exhaustive interbreeding. We tested 3 different types of crossover [2]: Single-Point Crossover, Two-Point Crossover, and

Uniform Crossover. After breeding and replacement each generation is considered to have passed and the next generation begins.

Every gene within each offspring has a chance to be mutated. When a new offspring is created, each inherited gene has a 20% chance of mutating and taking on a random value to encourage diverse Flyer characteristics. Lower values of mutation resulted in extremely homogeneous populations that plateaued early, whereas much higher values devolved the experiment into more of a random search where the inherited genes (and thus the generational information) were simply lost to mutations.

For each crossover type, we performed three trials where in each trial the algorithm ran for 25 generations. After each generation we recorded statistics about the maximum flight height and the Flyer attributes.

Results

We ran 9 trials total and from those 9 trials the best Flyer was able to fly to a height of 48.64 meters. This Flyer was created from the Two-Point mutation crossover. Of the Top 3 highest Flyers from all trials, two were created from the Single-Point mutation crossover model. The wing thickness and wing width seem to trend closer in value to each other. In 5 of the 9 trials the wing that is shorter is somewhat wider than the wing that is longer, however the difference in width is not very great. Wing length times wing width is proportional to the flapping force so it is possible that the width helped to balance out the lack of length. When examining the attributes of Flyers over the generations, we find that in 9 out of 9 trials one of the wing's length shrinks to become considerably shorter than the other wing in all of the trials. It could be that the difference in wing length creates a stable Flyer, and being oriented upward allows the Flyer to reach higher heights due to our fitness function. The other traits tend towards values in range [2.5,3.5] that optimize that specific Flyer configuration.

The average best height of all trials' best Flyers is 44.275 meters. The average best height from the Single-Point Crossover model is 43.689 meters, from the Two-Point Crossover model 45.063 meters, and from the Uniform Crossover model was 44.074 meters. This means Two-Point crossover had the best Flyers on average and produced the best Flyer overall. From this we might say that the Two-Point Crossover model was the best for the trials that we ran, but more trials would likely be needed to see if the differences are significant.

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Best Flyer from each Trial

Crossover	Trial	LW Length	RW Length	LW Width	Body Diameter	RW Width	LW Thickness	RW Thickness	Score (meters)
Single-Point	Trial 1	3.960963	1.672601	3.808132	3.023949	3.996559	3.079279	3.635968	47.28957
Single-Point	Trial 2	2.546351	3.026479	3.288517	2.883121	3.760251	3.025312	2.574933	45.70729
Single-Point	Trial 3	1.237751	3.838802	3.26551	2.755591	2.714379	3.803769	3.029102	38.07222
Two-point	Trial 1	2.53915	3.672182	3.686303	2.827985	3.090761	3.893079	3.453083	43.557
Two-point	Trial 2	1.619304	2.967868	3.961496	2.74494	3.511518	3.739878	2.856245	42.98876
Two-point	Trial 3	2.282935	3.598958	3.829222	3.606087	3.510516	2.643354	3.431449	48.64305
Uniform	Trial 1	2.389143	3.237123	3.252407	2.454668	3.681267	2.195402	2.232904	44.09472
Uniform	Trial 2	2.066612	3.048501	3.530656	3.340074	3.545026	3.830632	3.551865	45.38079
Uniform	Trial 3	1.637495	3.931123	3.315953	2.900353	3.325307	3.811975	3.298044	42.74664
Average		2.253304	3.221515	3.548688	2.948529	3.459509	3.335853	3.11817	44.27556

Table 1. A table of all of the highest Flyers from each trial and the values of their attributes.

Conclusions

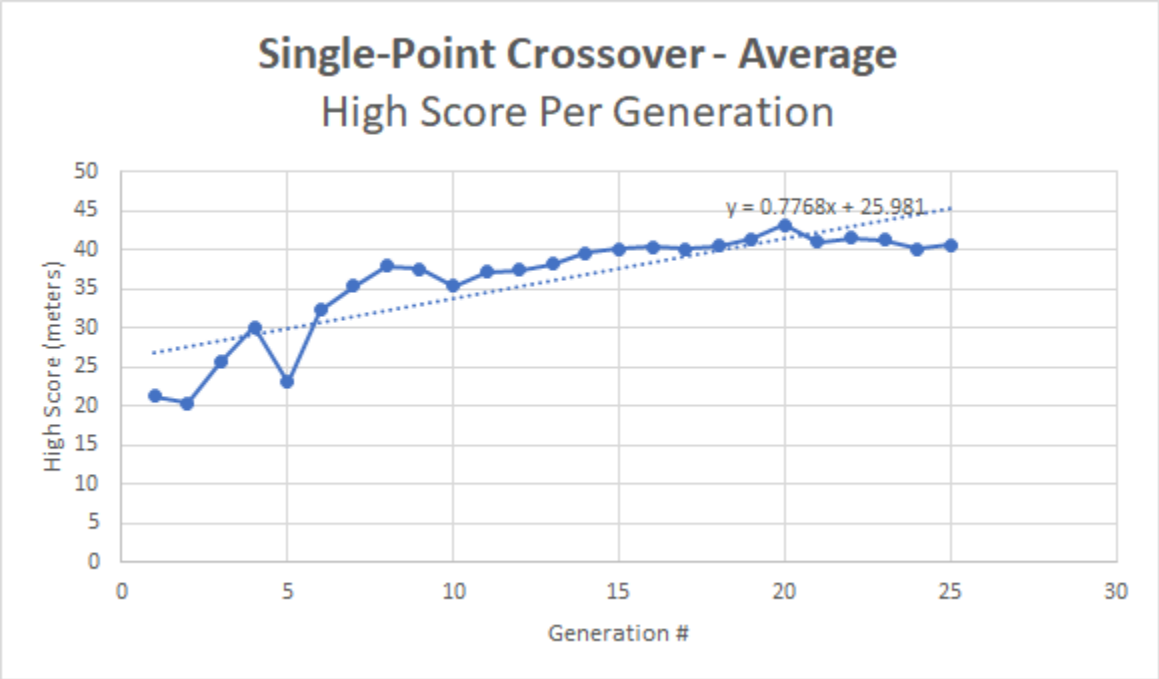
From our results we found that Two-Point crossover was the best method, producing the best Flyers on average as well as the best Flyer overall. We found across the trials, there is a genetic advantage to having one wing that is shorter than the other with the shorter wing value trending around [1.5,2.0]. Wing Thickness, Wing Width and the longer wing's Wing Length all tend towards the range [3.0,3.5]. Body Diameter tended to values in [2.5,3.0]. The best Flyer scores from each Trial have a range of 38m to 48m. We found that a 20% mutation rate on each gene, which at face value seems quite extreme, was necessary (in this particular simulation) for maintaining healthy genetic diversity such that the population doesn't plateau too early. Future directions for this type of project could be running more trials to test other mutation rates, improving the fitness function to account for other useful flying behaviors, and improving the simulation physics and Flyer anatomy.

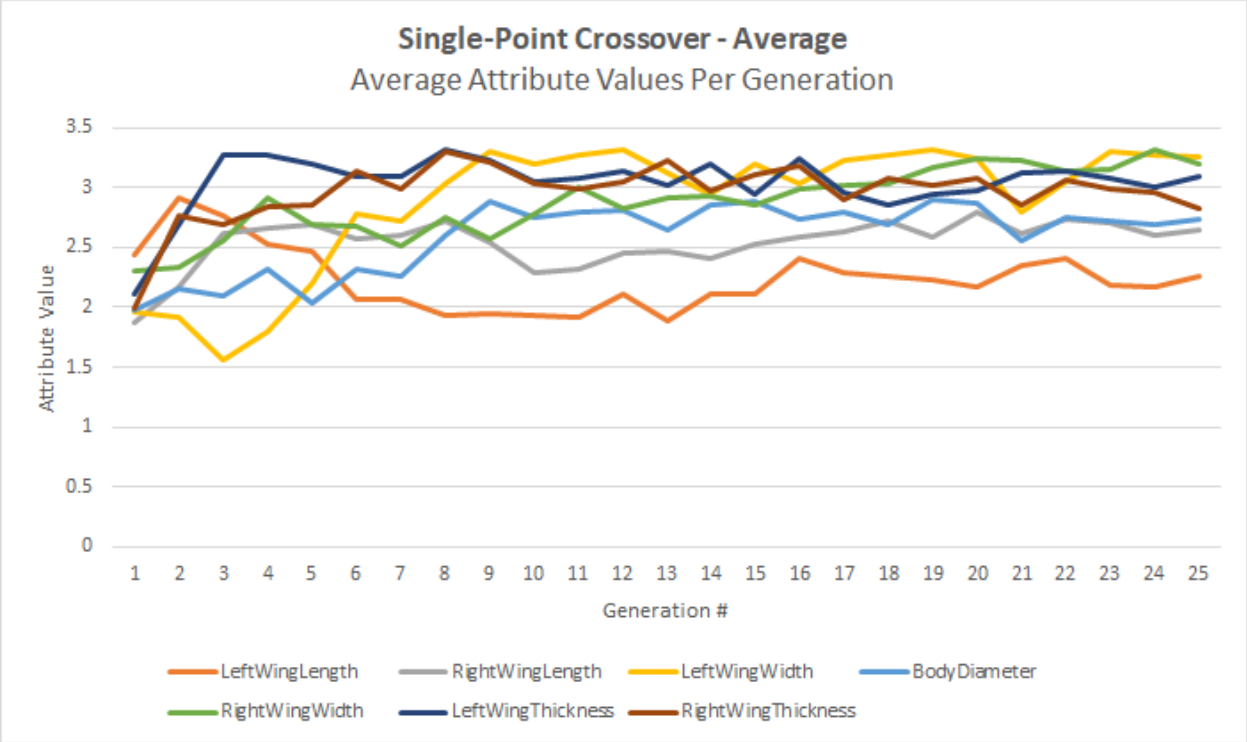
Appendix

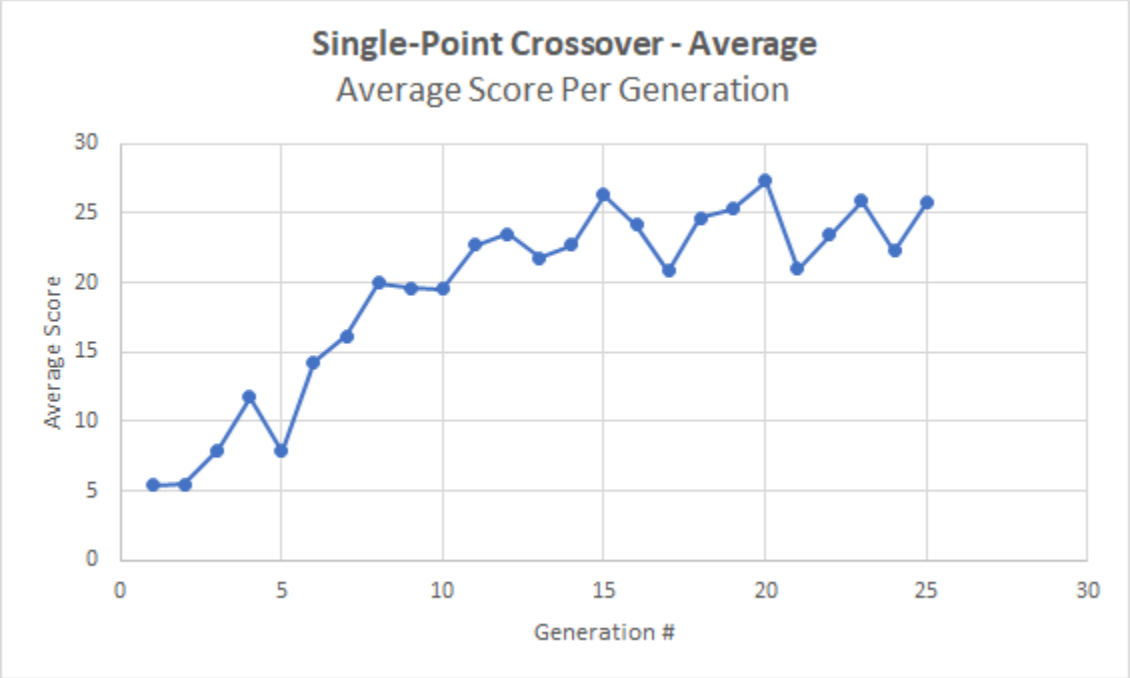
Table of Contents

Single-Point Crossover

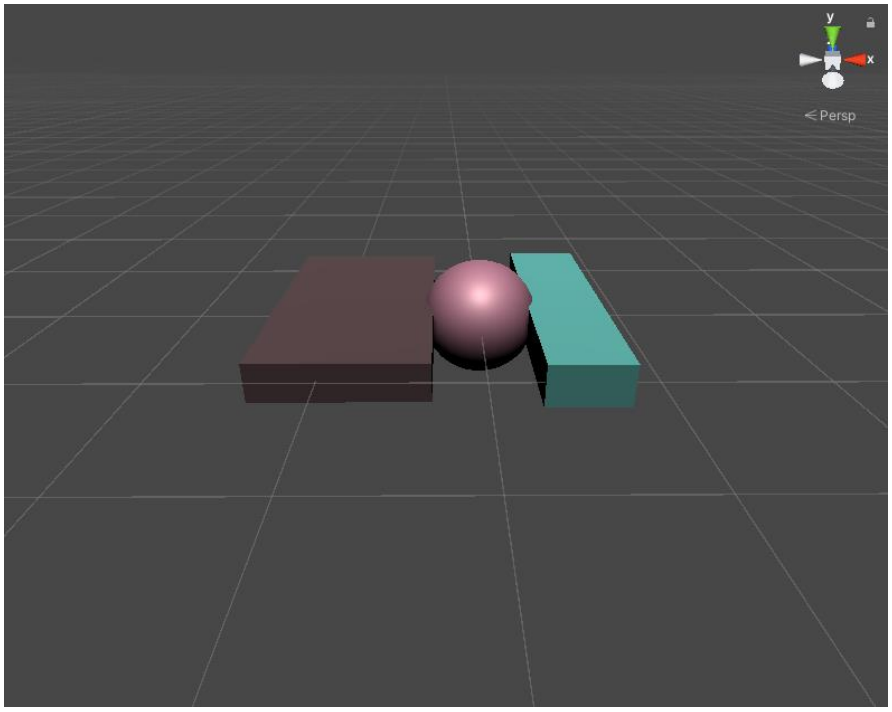
Overall average (per generation)





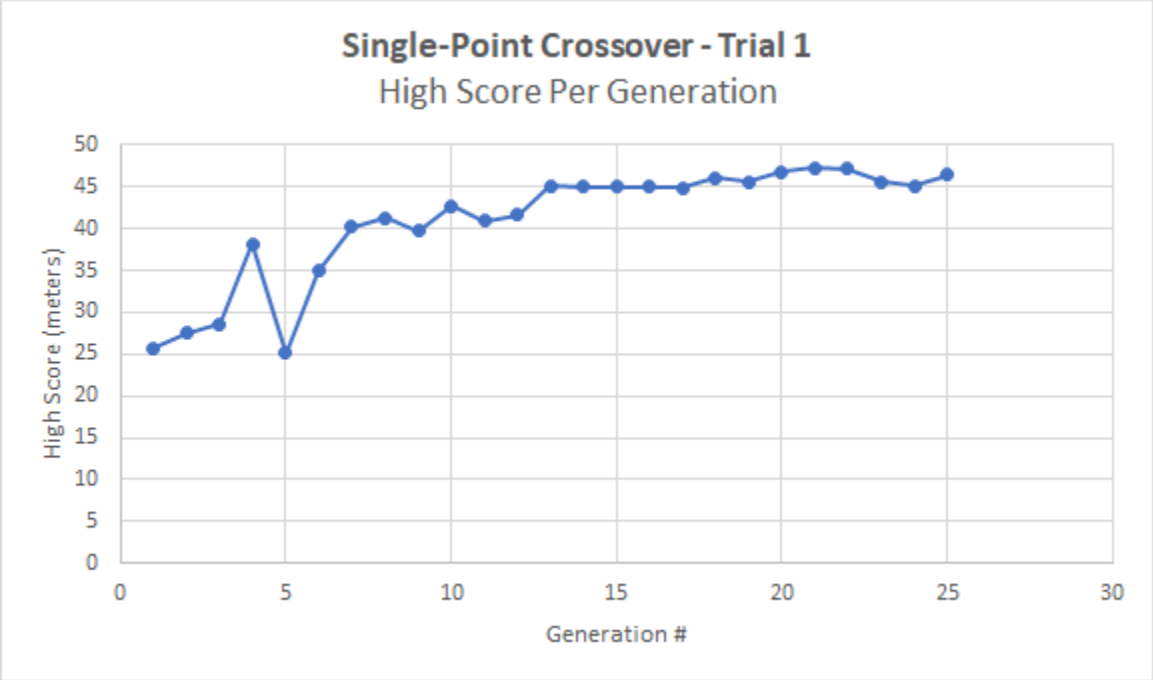


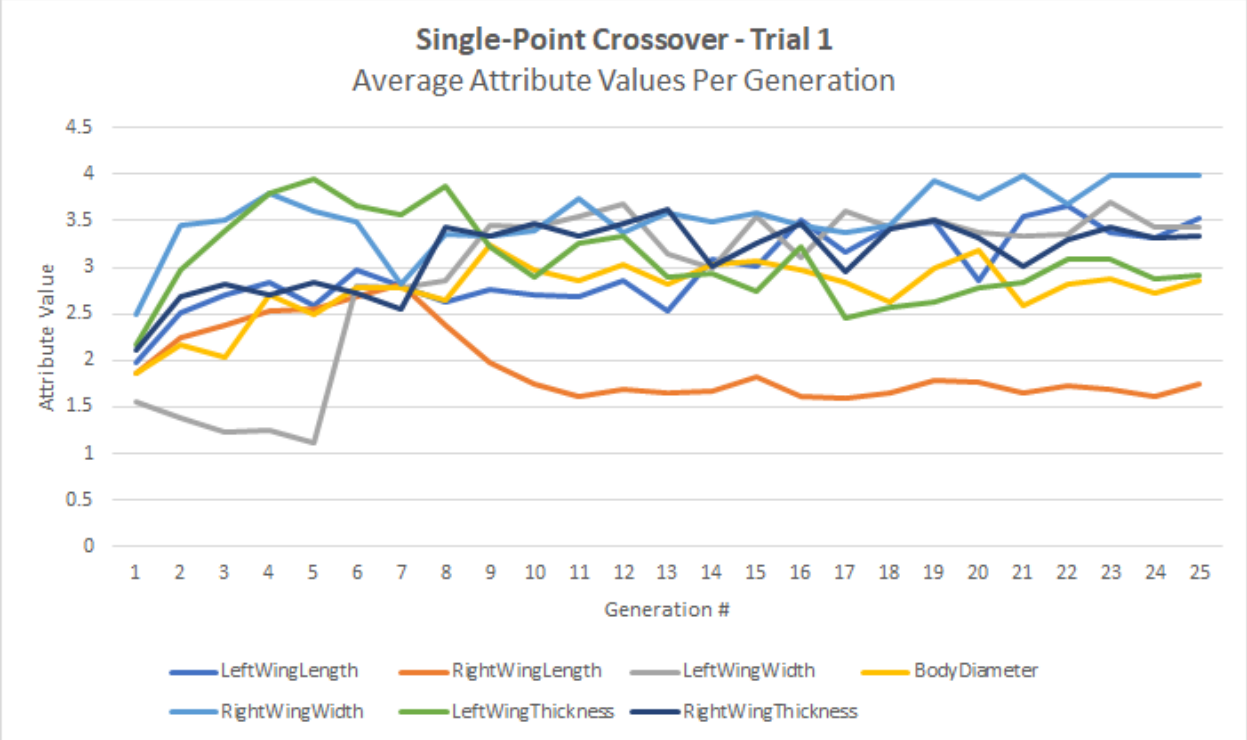
Average of all 3 trials' Highest Scores: 43.68969333 meters
Trial with the Overall Highest Score: Trial 1

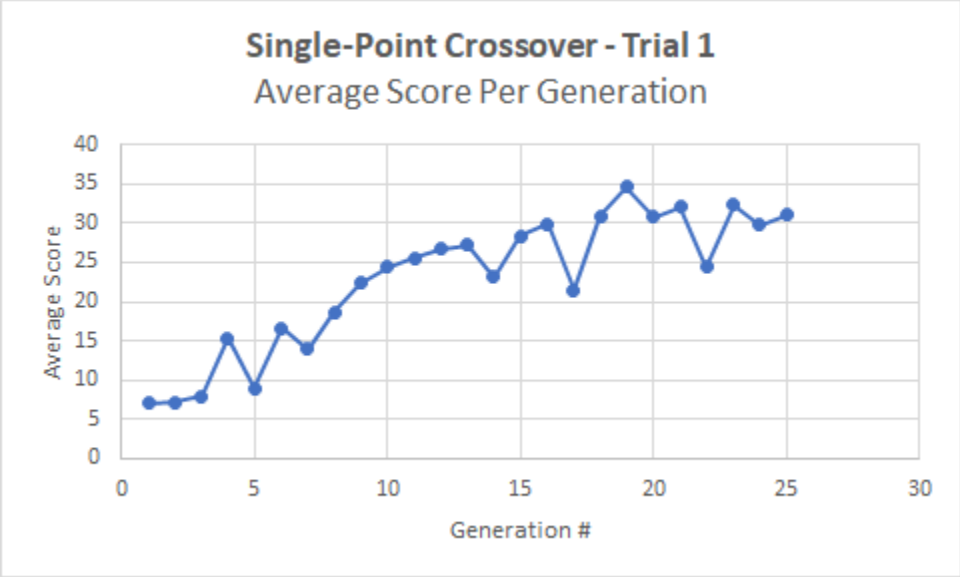


Best Flyer

Trial 1


Single-Point Crossover - Trial 1
High Score Per Generation
High Score (meters)
Generation #
0
5
10
15
20
25
30
35
40
45
50


Single-Point Crossover - Trial 1
Average Attribute Values Per Generation
Attribute Value
Generation #
LeftWingLength
RightWingLength
LeftWingWidth
BodyDiameter
RightWingWidth
LeftWingThickness
RightWingThickness

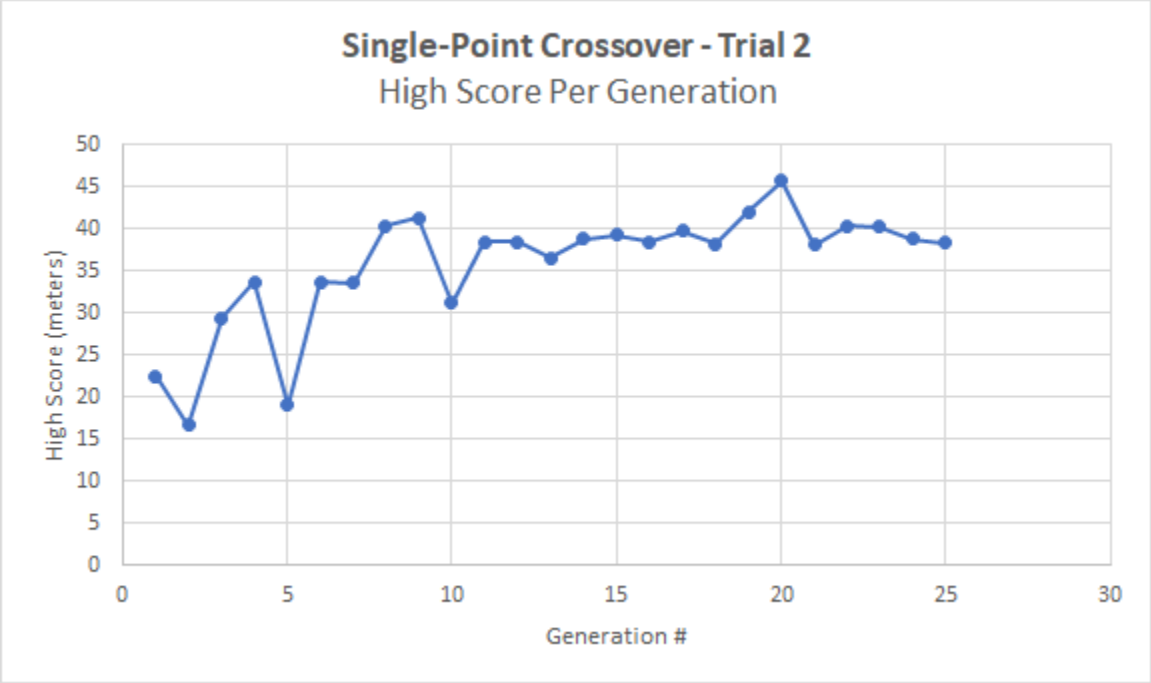


Highest Score: 47.28957 meters

Best Flyer Chromosome (Flyer that achieved Highest Score):

LeftWingLength	RightWing Length	LeftWing Width	BodyDiameter	RightWing Width	LeftWingThickness	RightWingThickness
3.960963	**1.672601**	**3.808132**	**3.023949**	**3.996559**	**3.079279**	**3.635968**

Trial 2


Single-Point Crossover - Trial 2
High Score Per Generation
High Score (meters)
Generation #
0
5
10
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35
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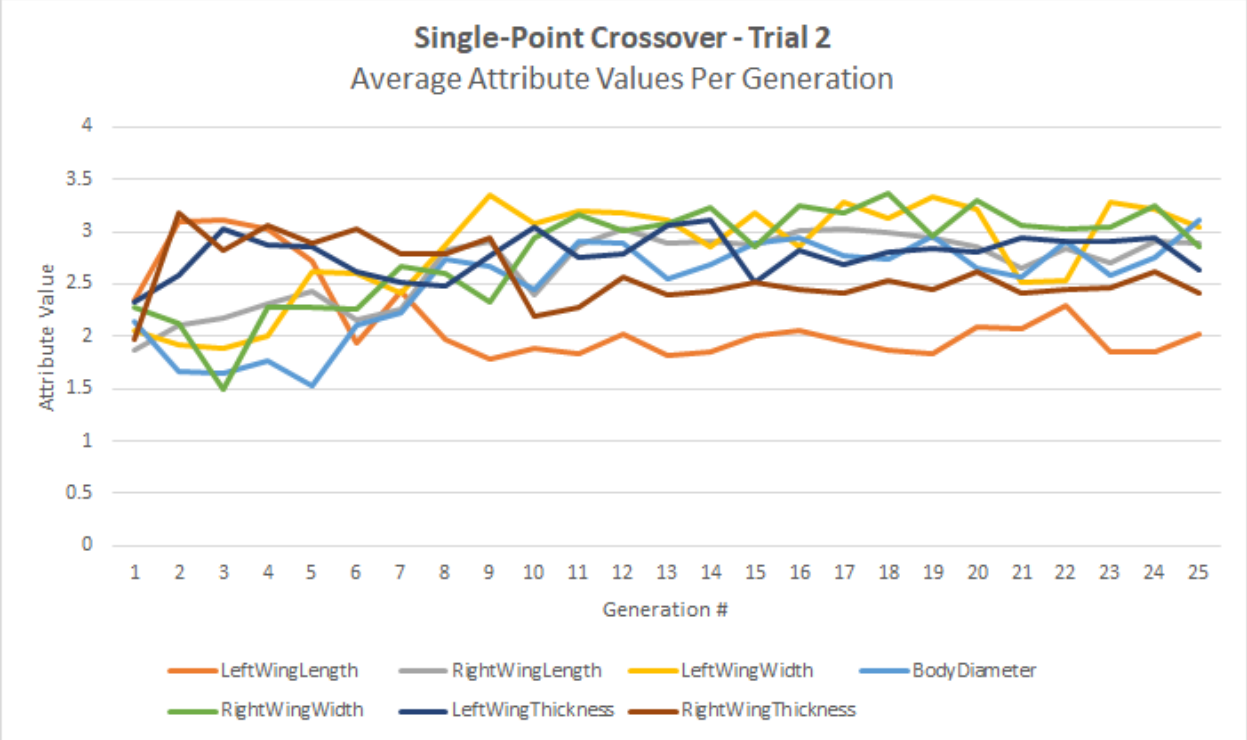
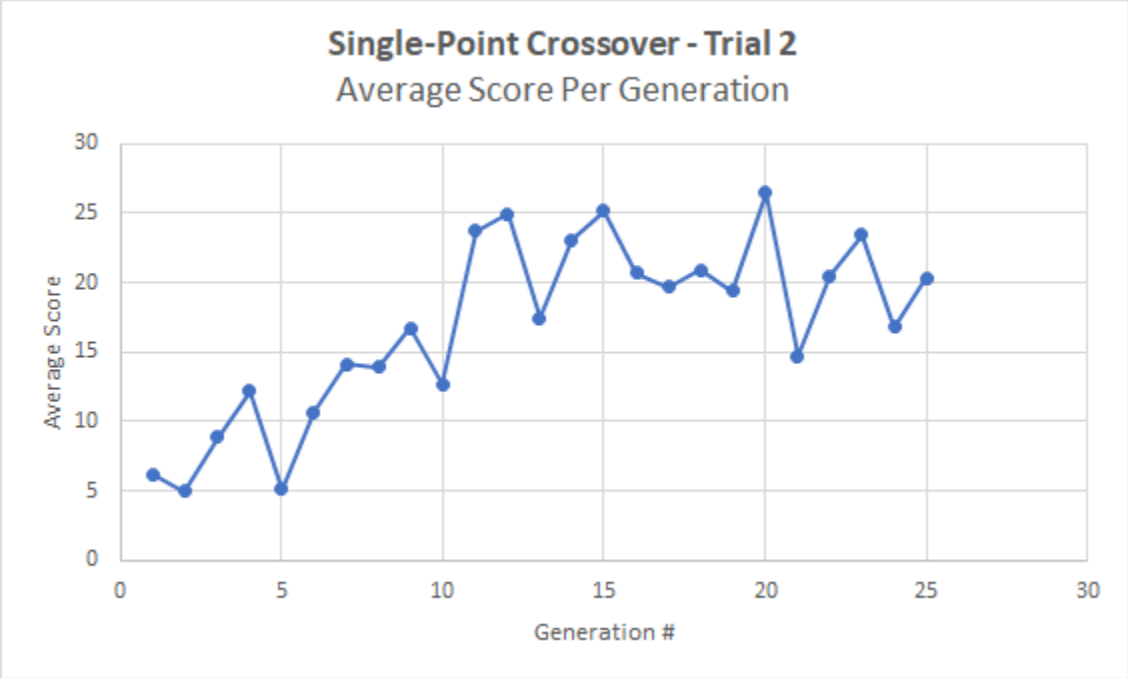

Single-Point Crossover - Trial 2
Average Attribute Values Per Generation
Attribute Value
Generation #
LeftWingLength
RightWingLength
LeftWingWidth
BodyDiameter
RightWingWidth
LeftWingThickness
RightWingThickness

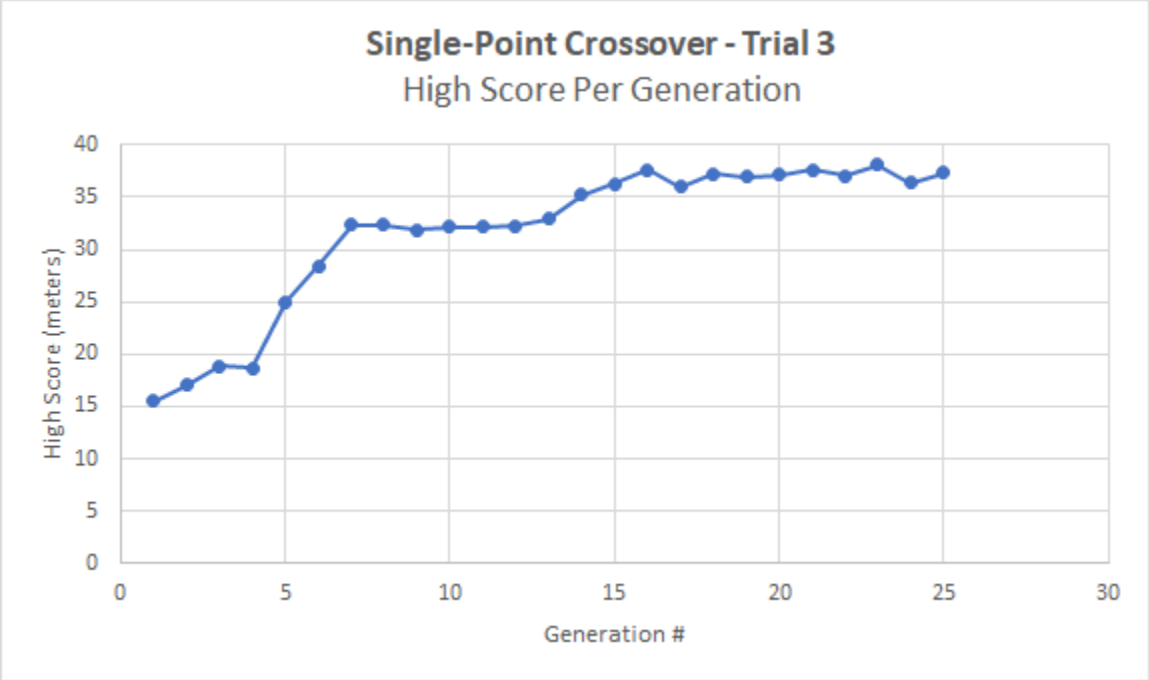


Highest Score: 45.70729 meters

Best Flyer Chromosome (Flyer that achieved Highest Score):

LeftWingLength	RightWing Length	LeftWing Width	BodyDiameter	RightWing Width	LeftWingThickness	RightWingThickness
2.546351	**3.026479**	**3.288517**	**2.883121**	**3.760251**	**3.025312**	**2.574933**

Trial 3


Single-Point Crossover - Trial 3
High Score Per Generation
High Score (meters)
Generation #
0
5
10
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25
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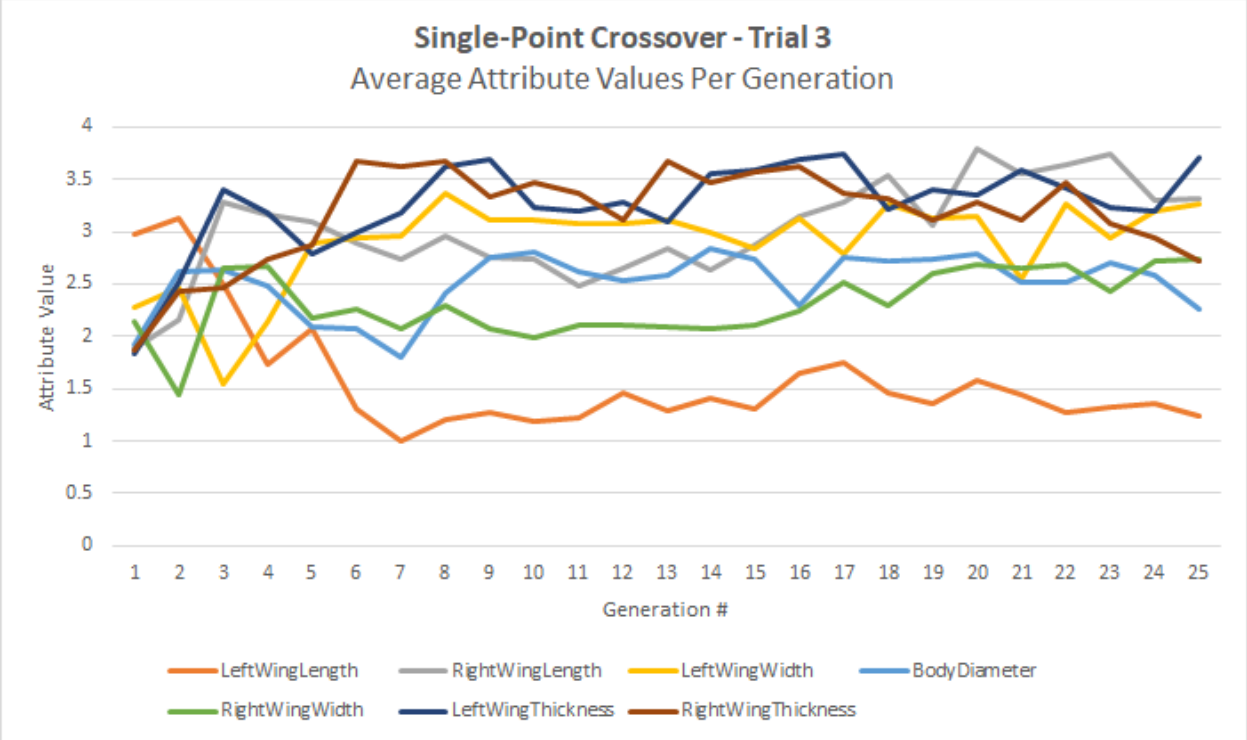
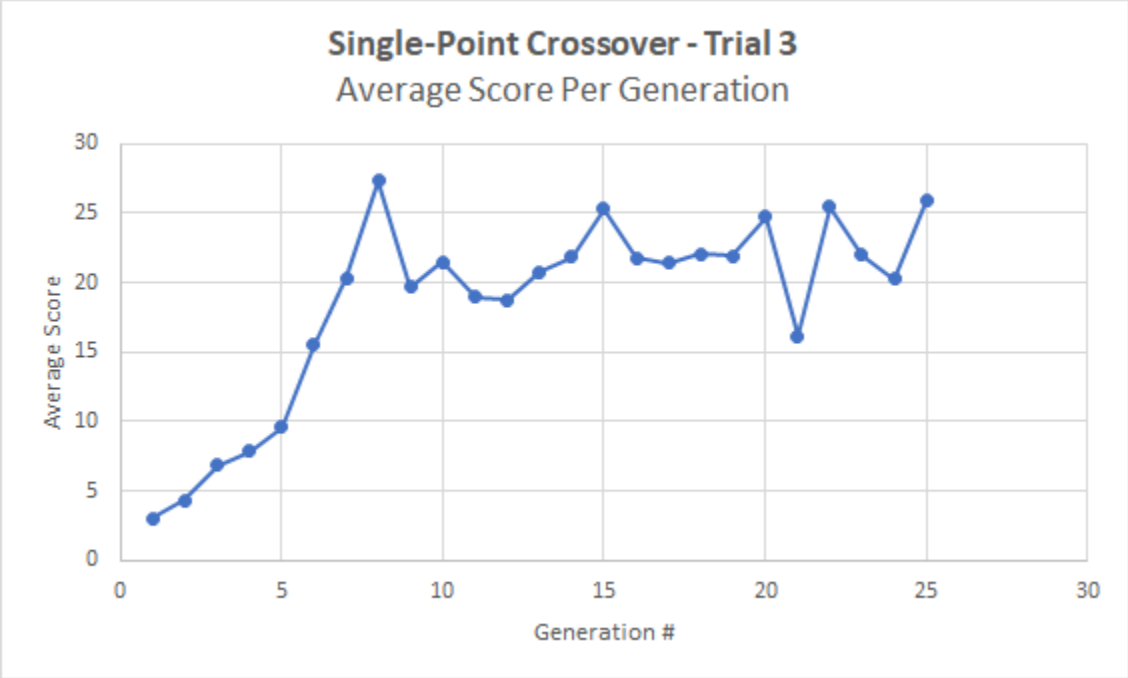
40


Single-Point Crossover - Trial 3
Average Attribute Values Per Generation
Attribute Value
Generation #
LeftWingLength
RightWingLength
LeftWingWidth
BodyDiameter
RightWingWidth
LeftWingThickness
RightWingThickness



Highest Score: 38.07222 meters

Best Flyer Chromosome (Flyer that achieved Highest Score):

LeftWingLength	RightWing Length	LeftWing Width	BodyDiameter	RightWing Width	LeftWingThickness	RightWingThickness
1.237751	**3.838802**	**3.26551**	**2.755591**	**2.714379**	**3.803769**	**3.029102**

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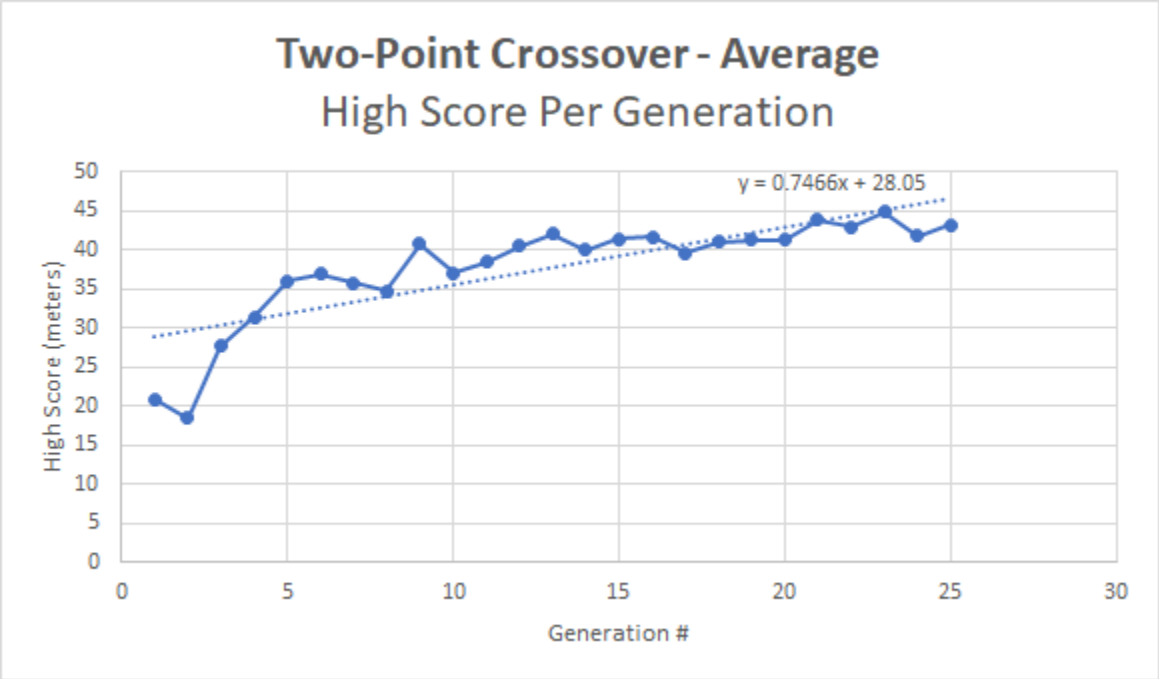
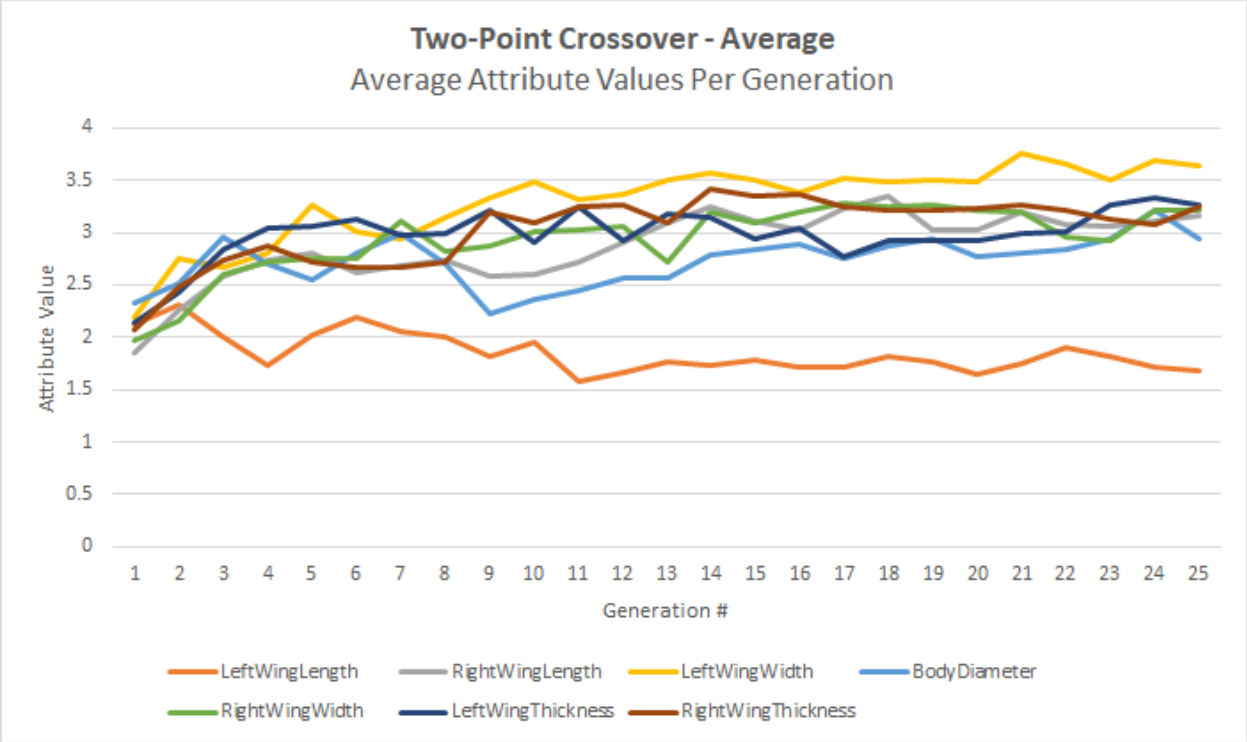
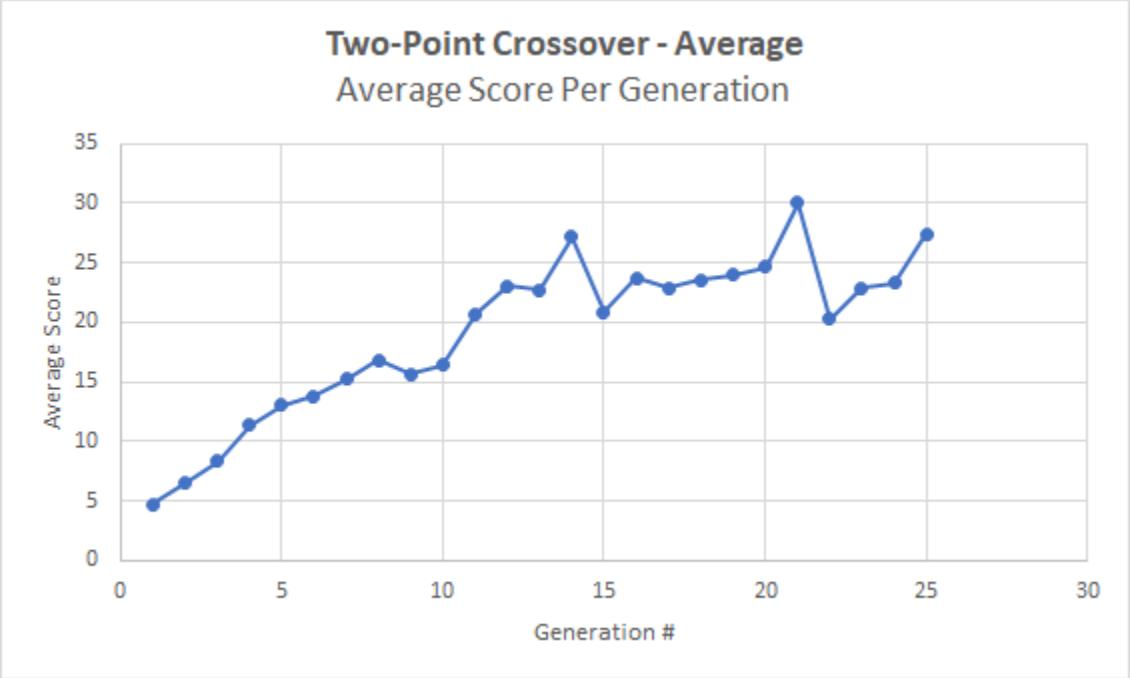
Two-Point Crossover

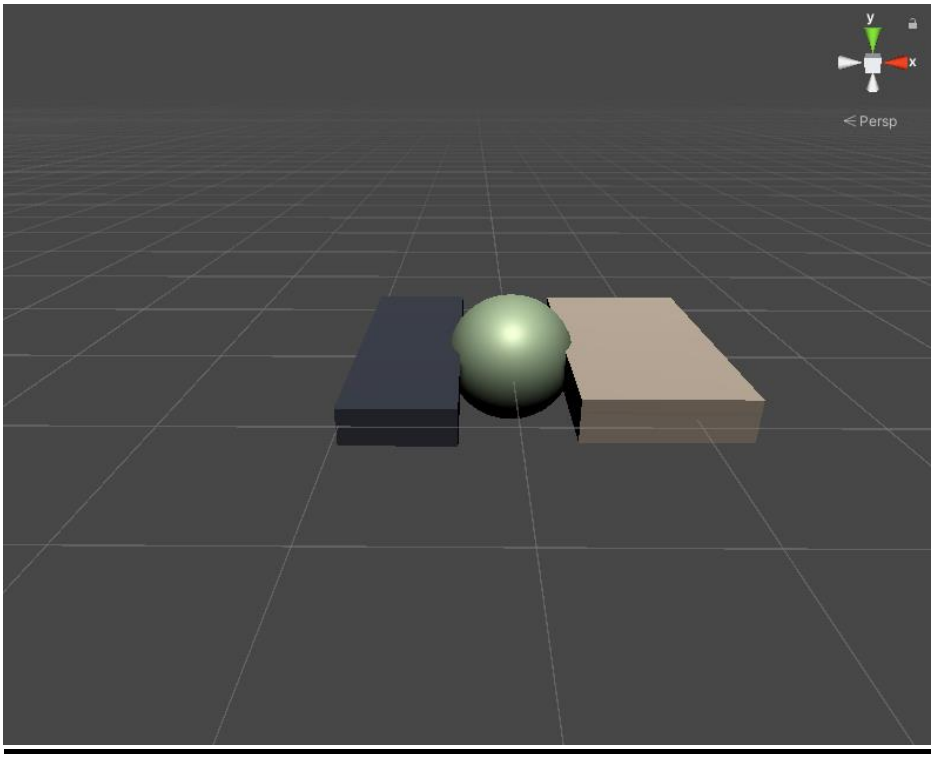
Overall average (per generation)





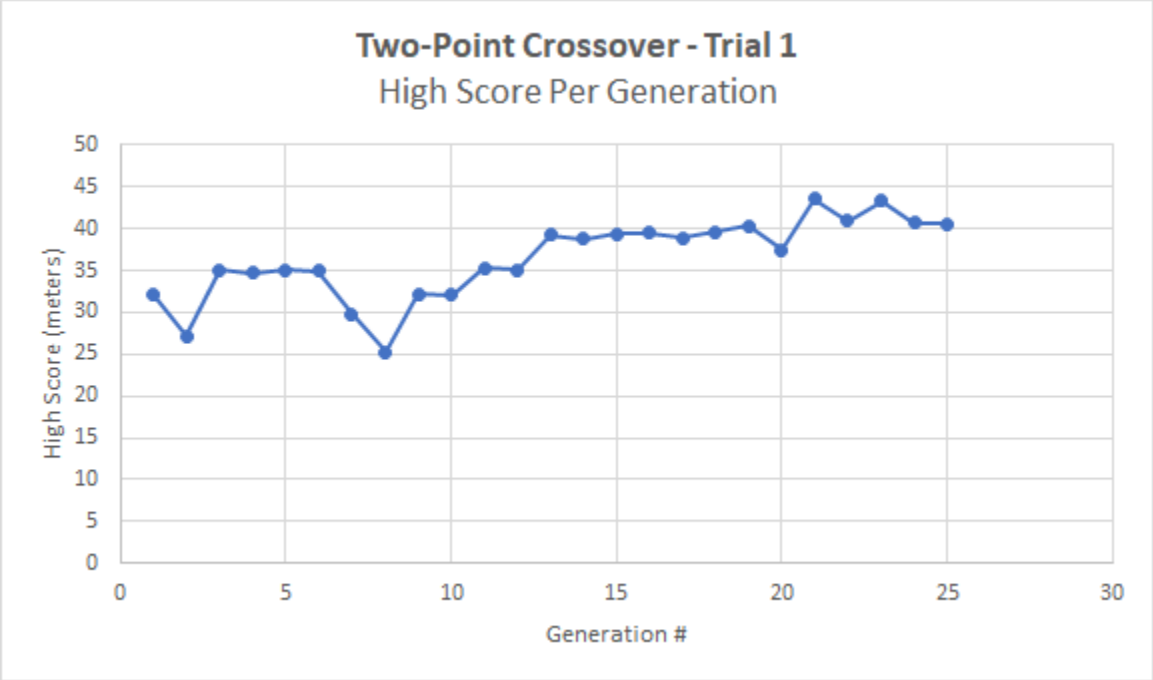


Average of all 3 trials' Highest Scores: 45.06293667 meters
Trial with the Overall Highest Score: Trial 3



Best Flyer

Trial 1


Two-Point Crossover - Trial 1
High Score Per Generation
High Score (meters)
Generation #
0
5
10
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20
25
30
35
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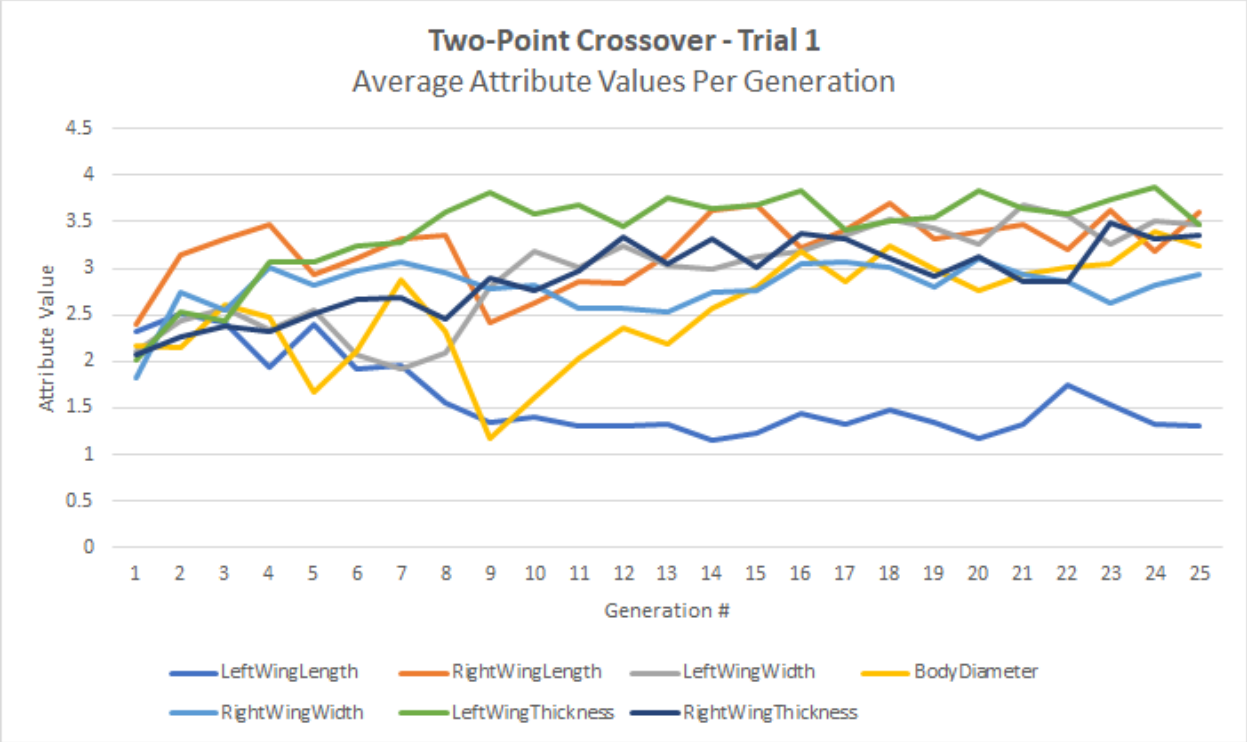
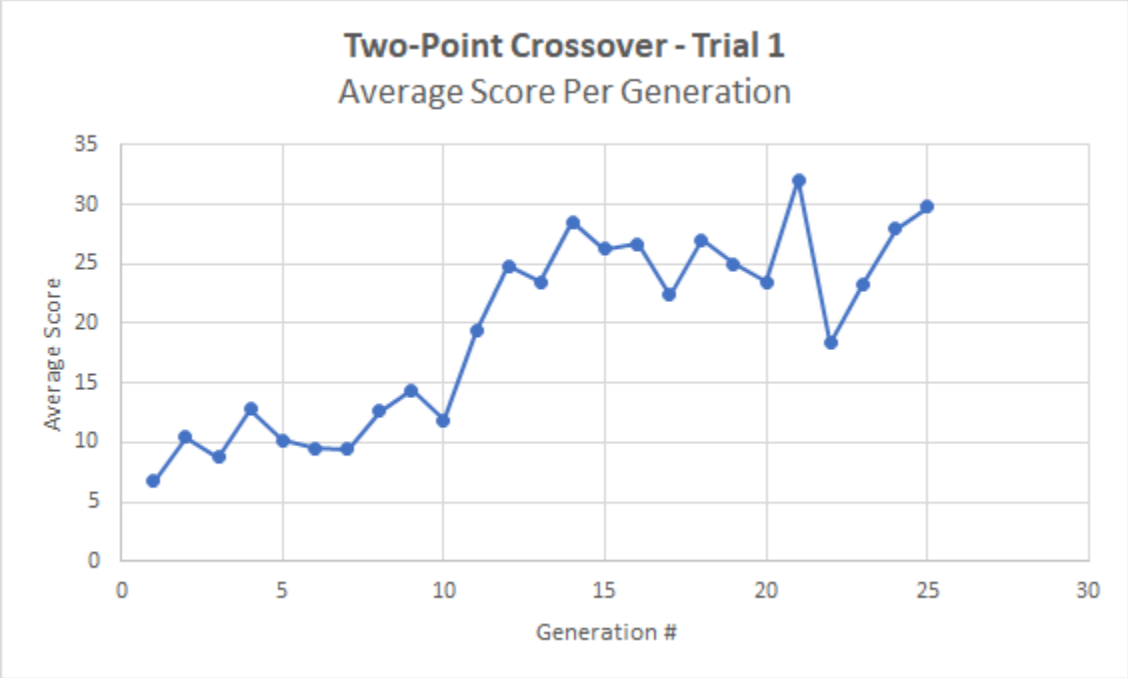
45
50


Two-Point Crossover - Trial 1
Average Attribute Values Per Generation
Attribute Value
Generation #
LeftWingLength
RightWingLength
LeftWingWidth
BodyDiameter
RightWingWidth
LeftWingThickness
RightWingThickness

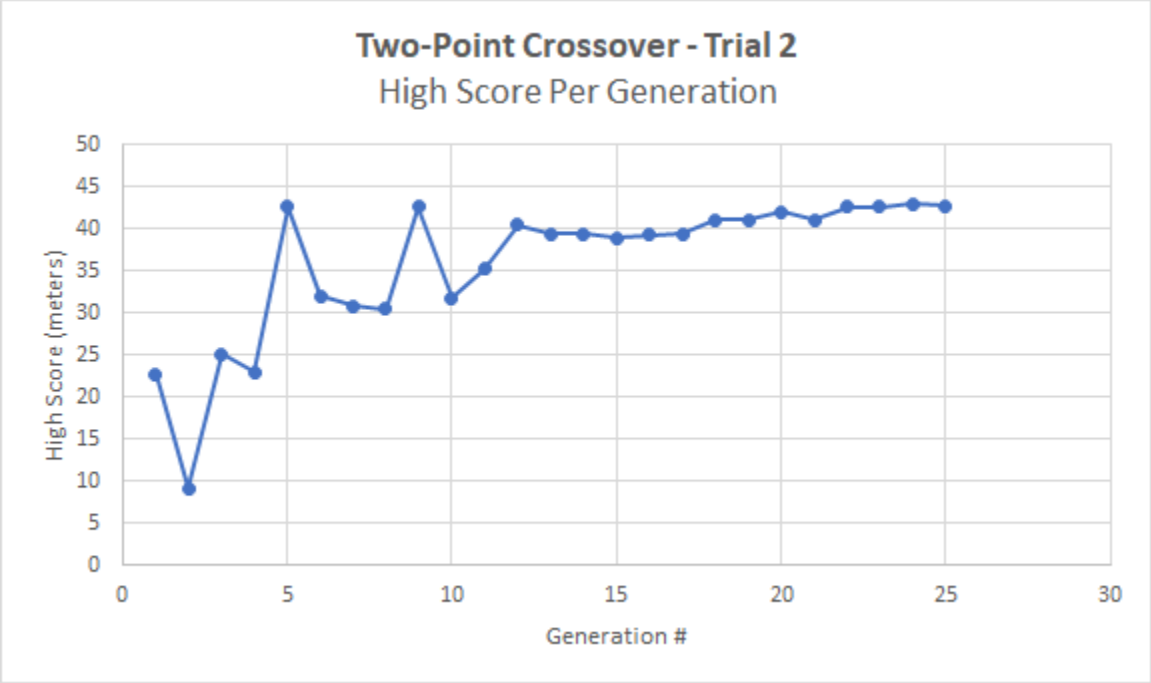


Highest Score: 43.557 meters

Best Flyer Chromosome (Flyer that achieved Highest Score):

LeftWingLength	RightWing Length	LeftWing Width	BodyDiameter	RightWing Width	LeftWingThickness	RightWingThickness
2.53915	**3.672182**	**3.686303**	**2.827985**	**3.090761**	**3.893079**	**3.453083**

Trial 2


Two-Point Crossover - Trial 2
High Score Per Generation
High Score (meters)
Generation #
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5
10
15
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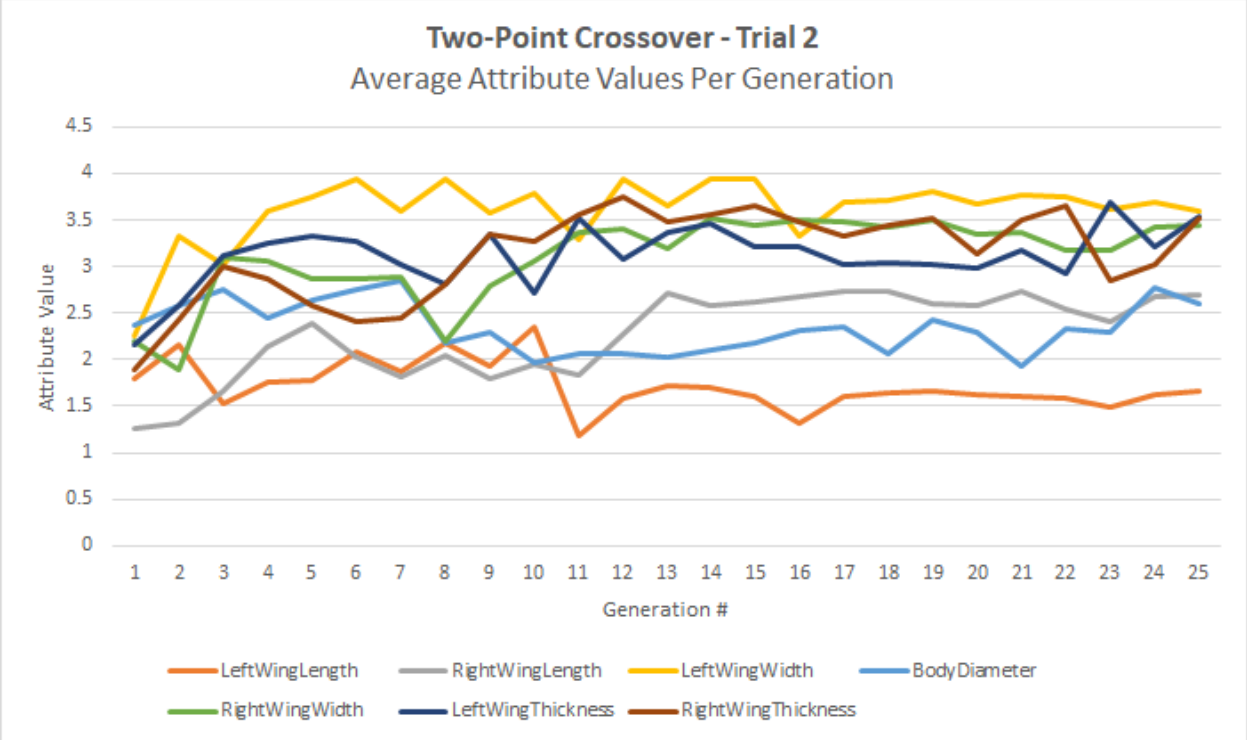
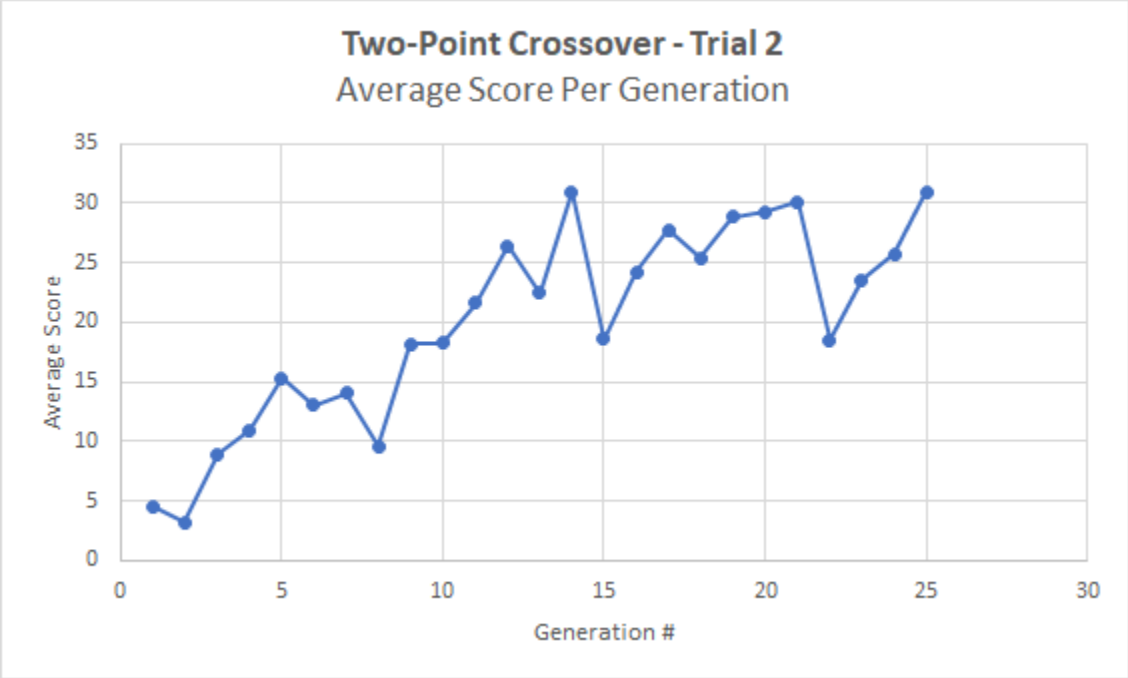
30
35
40
45
50


Two-Point Crossover - Trial 2
Average Attribute Values Per Generation
Attribute Value
Generation #
LeftWingLength
RightWingLength
LeftWingWidth
BodyDiameter
RightWingWidth
LeftWingThickness
RightWingThickness

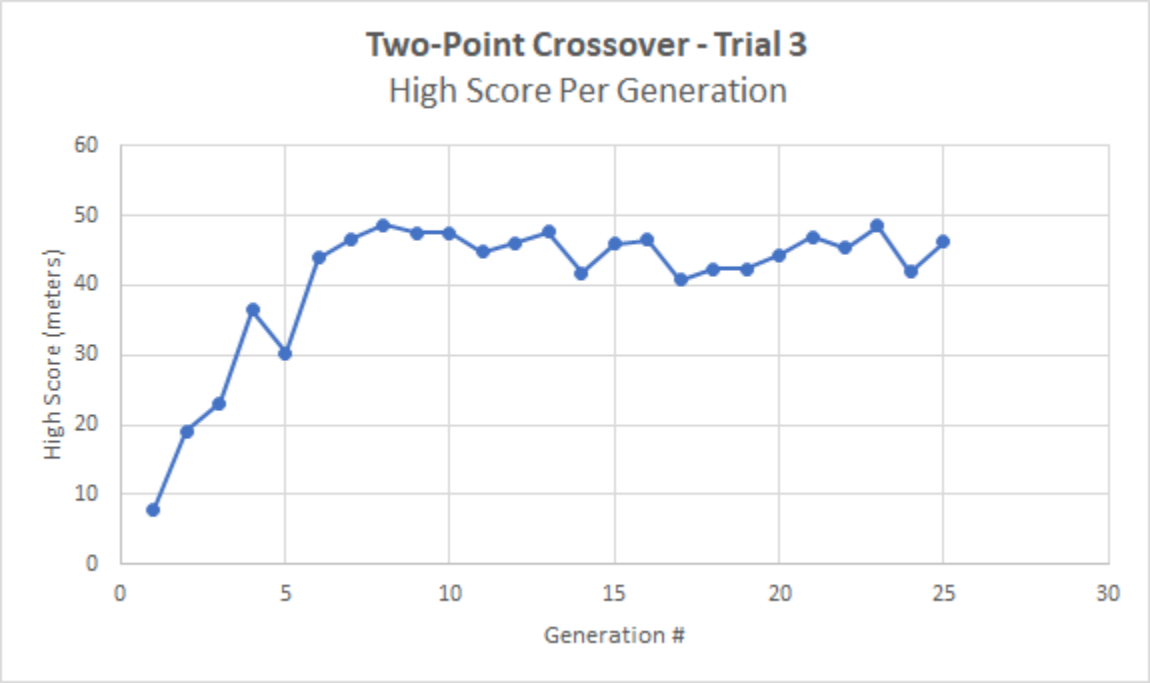


Highest Score: 42.98876 meters

Best Flyer Chromosome (Flyer that achieved Highest Score):

LeftWingLength	RightWing Length	LeftWing Width	BodyDiameter	RightWing Width	LeftWingThickness	RightWingThickness
1.619304	**2.967868**	**3.961496**	**2.74494**	**3.511518**	**3.739878**	**2.856245**

Trial 3


Two-Point Crossover - Trial 3
High Score Per Generation
High Score (meters)
Generation #
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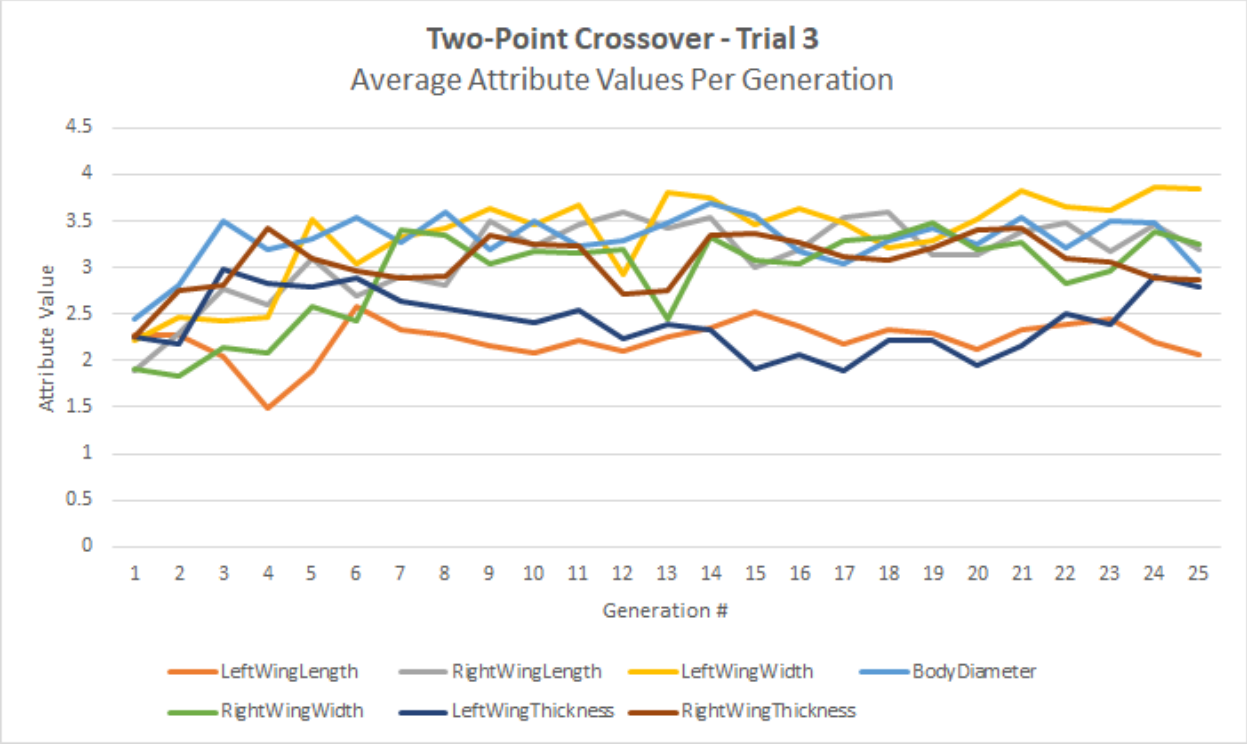
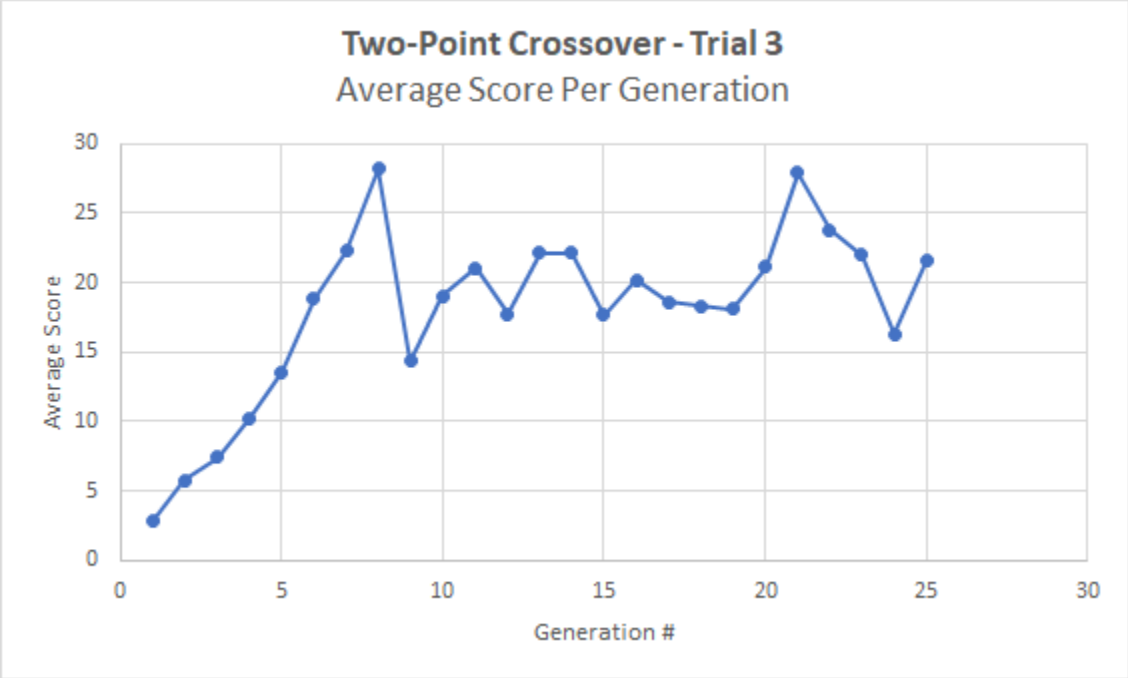
10
20
30
40
50
60
0
5
10
15
20
25
30


Two-Point Crossover - Trial 3
Average Attribute Values Per Generation
Attribute Value
Generation #
LeftWingLength
RightWingLength
LeftWingWidth
BodyDiameter
RightWingWidth
LeftWingThickness
RightWingThickness



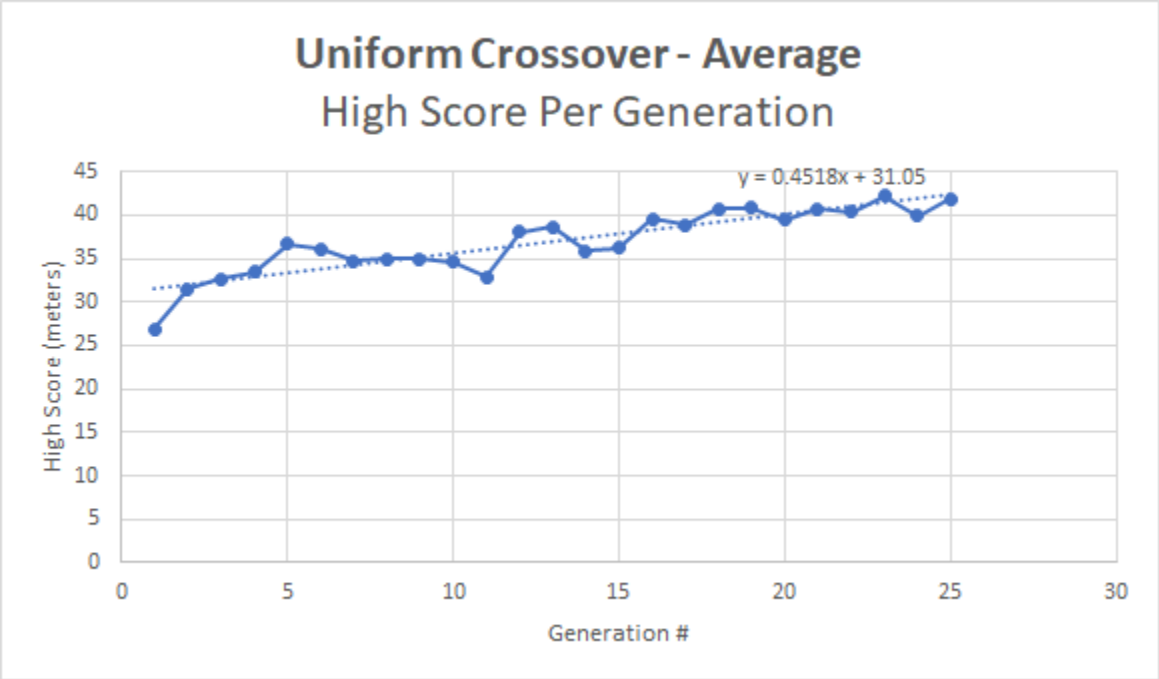
Highest Score: 48.64305 meters

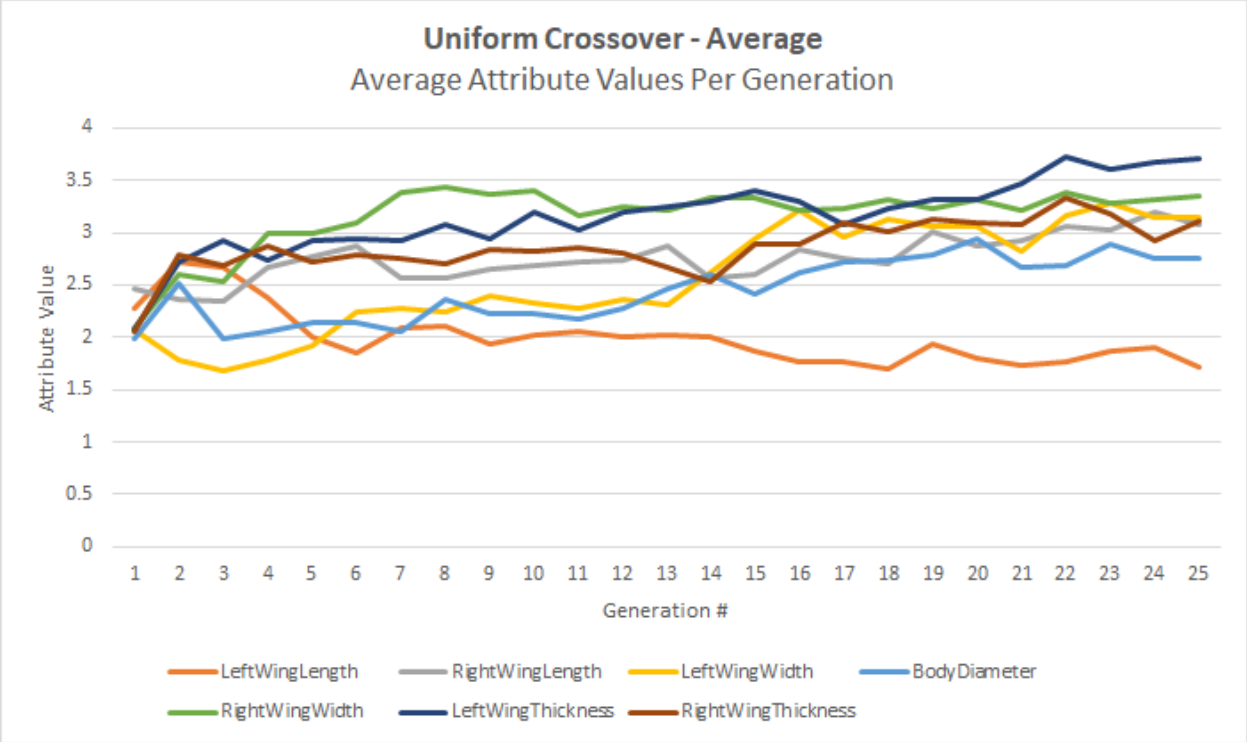
Best Flyer Chromosome (Flyer that achieved Highest Score):

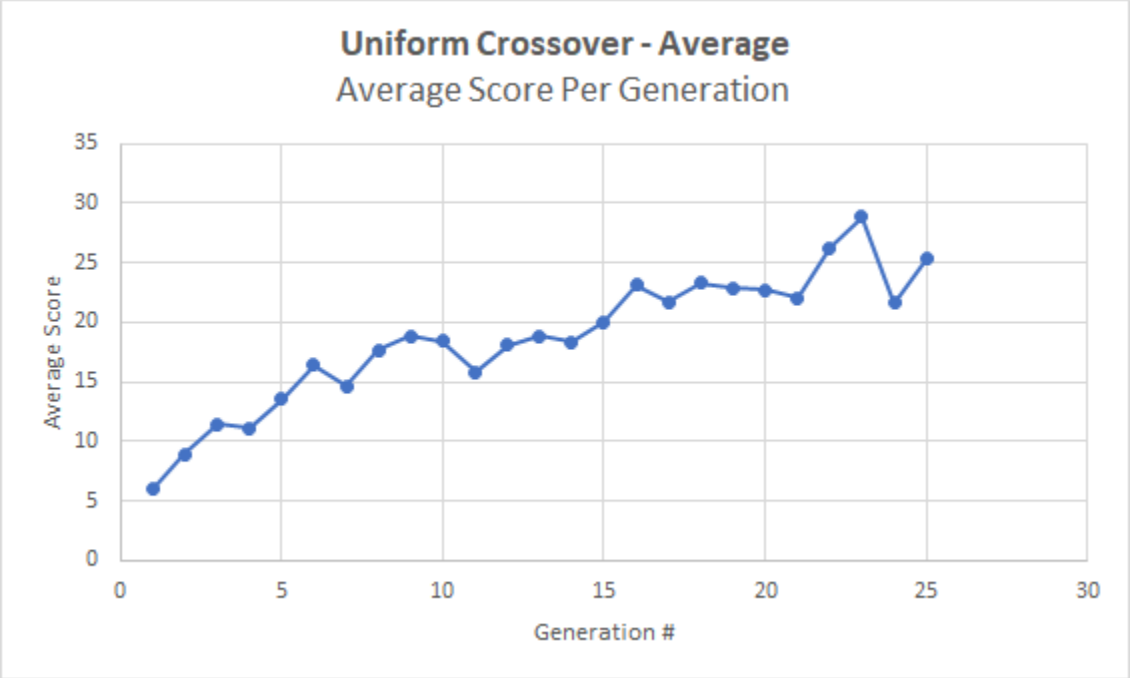
LeftWingLength	RightWing Length	LeftWing Width	BodyDiameter	RightWing Width	LeftWingThickness	RightWingThickness
2.282935	**3.598958**	**3.829222**	**3.606087**	**3.510516**	**2.643354**	**3.431449**

Uniform Crossover

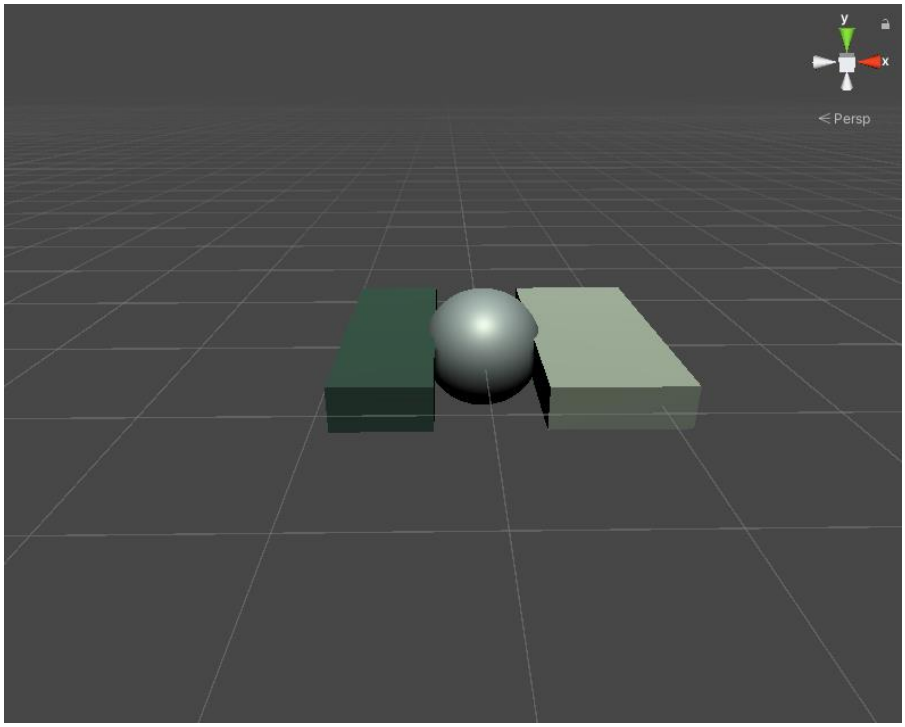
Overall average (per generation)





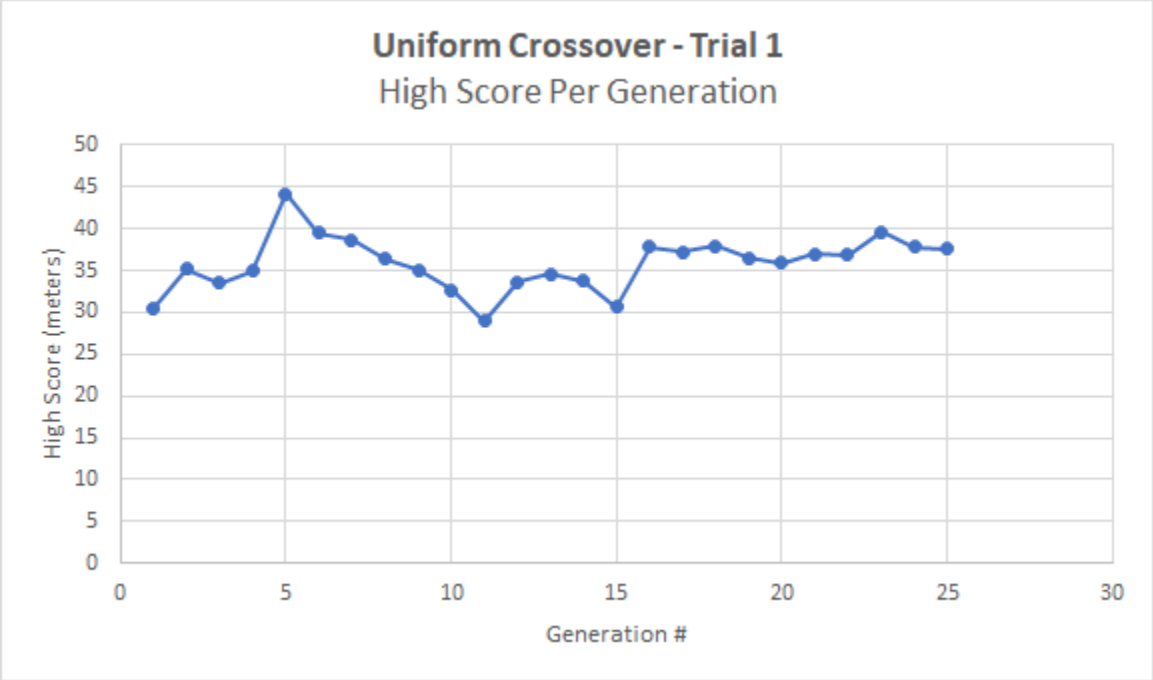


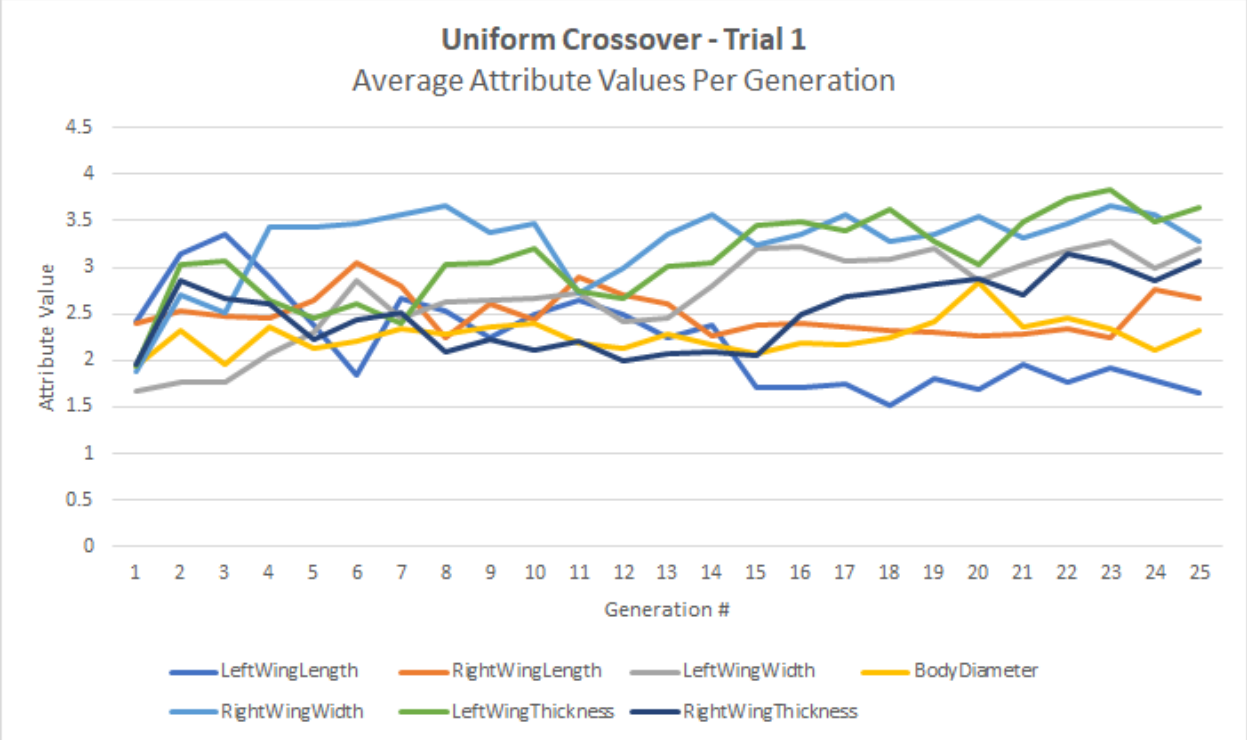
Average of all 3 trials' Highest Scores: 44.07405 meters
Trial with the Overall Highest Score: Trial 2

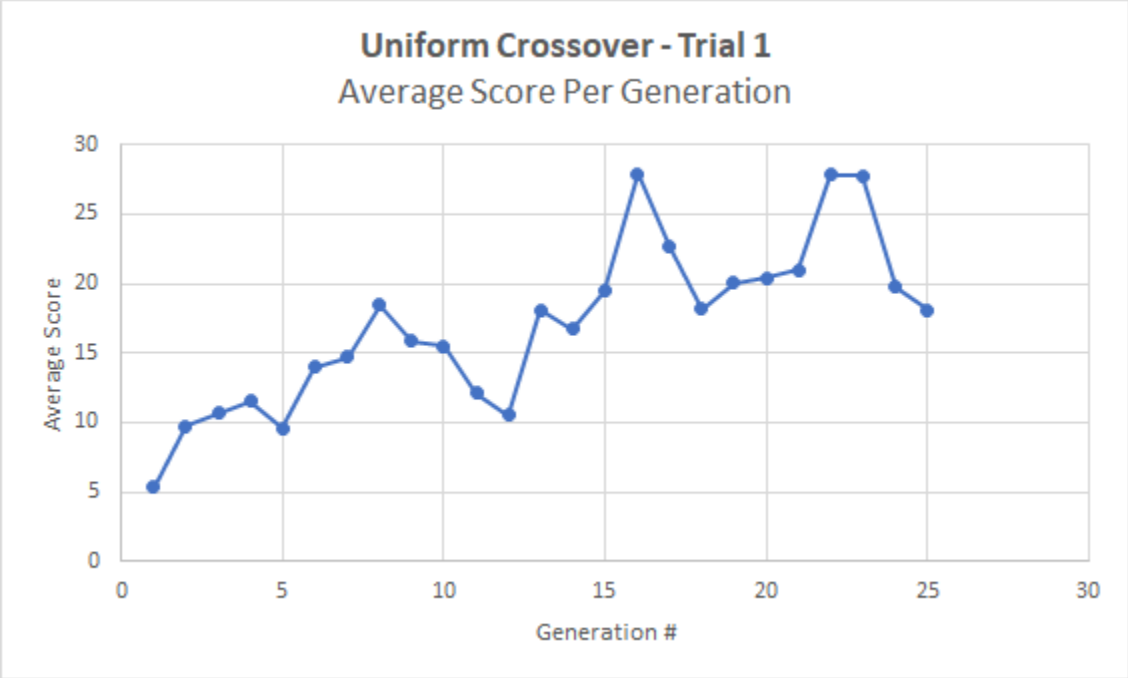


Best Flyer

Trial 1


Uniform Crossover - Trial 1
High Score Per Generation
High Score (meters)
Generation #
0
5
10
15
20
25
30
35
40
45
50


Uniform Crossover - Trial 1
Average Attribute Values Per Generation
Attribute Value
Generation #
LeftWingLength
RightWingLength
LeftWingWidth
BodyDiameter
RightWingWidth
LeftWingThickness
RightWingThickness

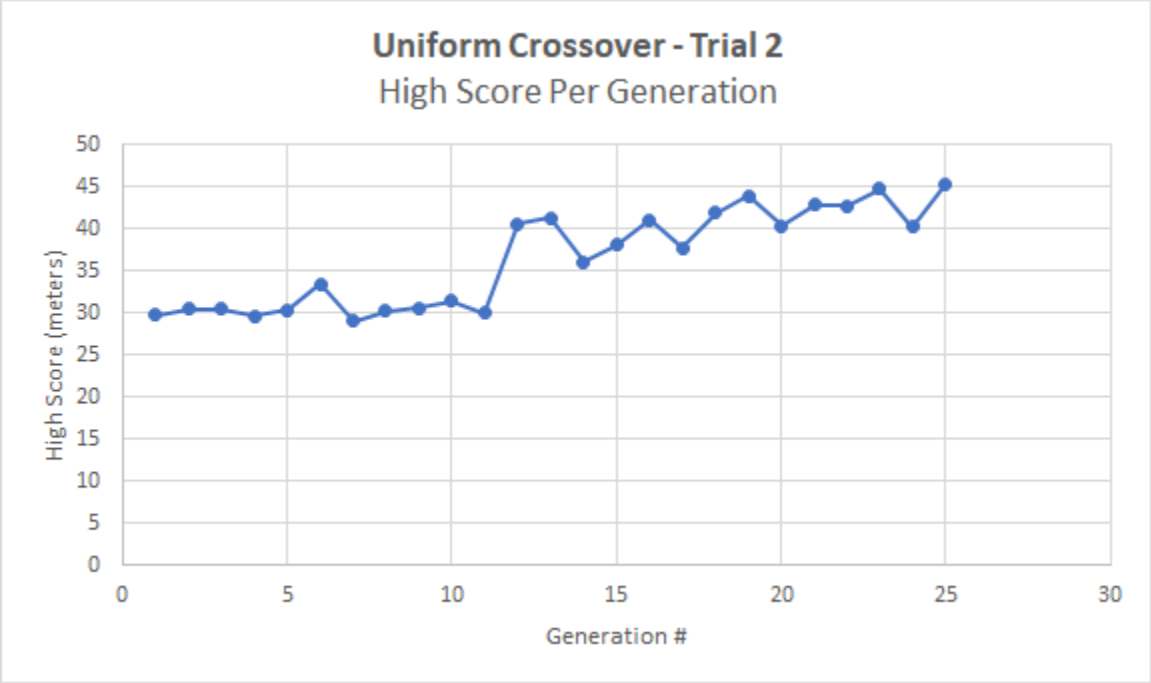


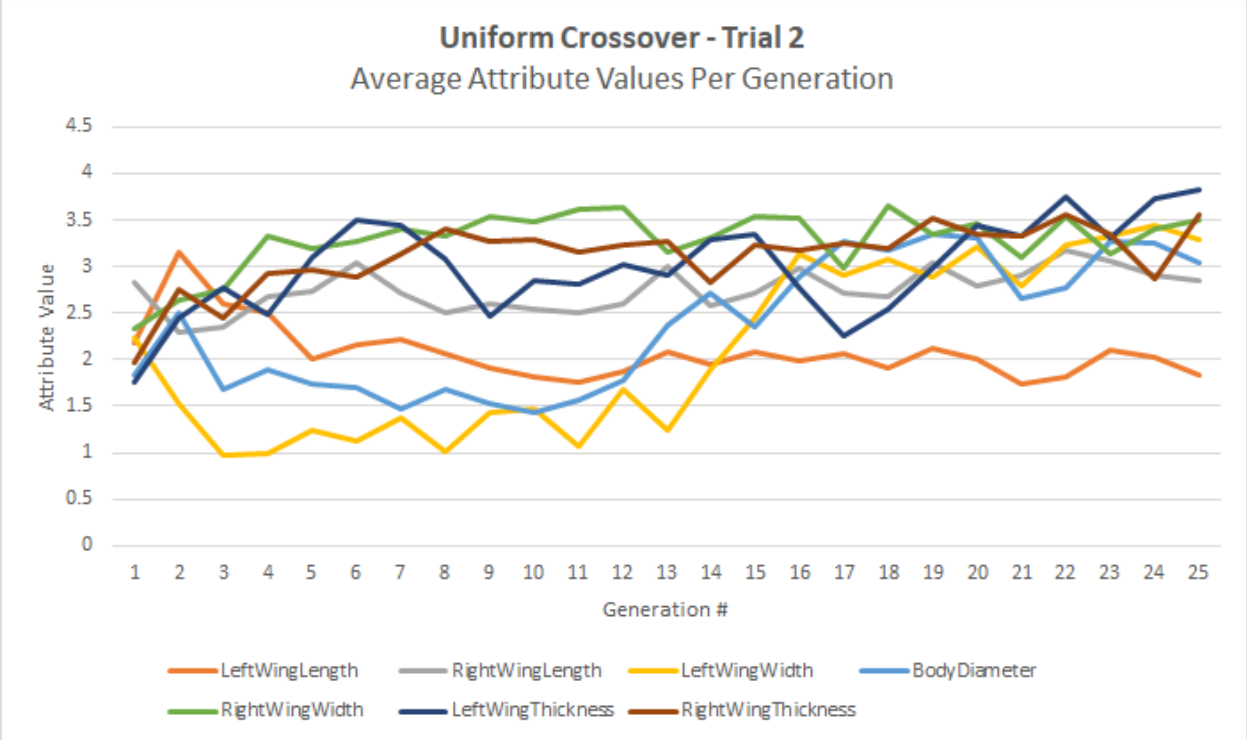
Highest Score: 44.09472 meters

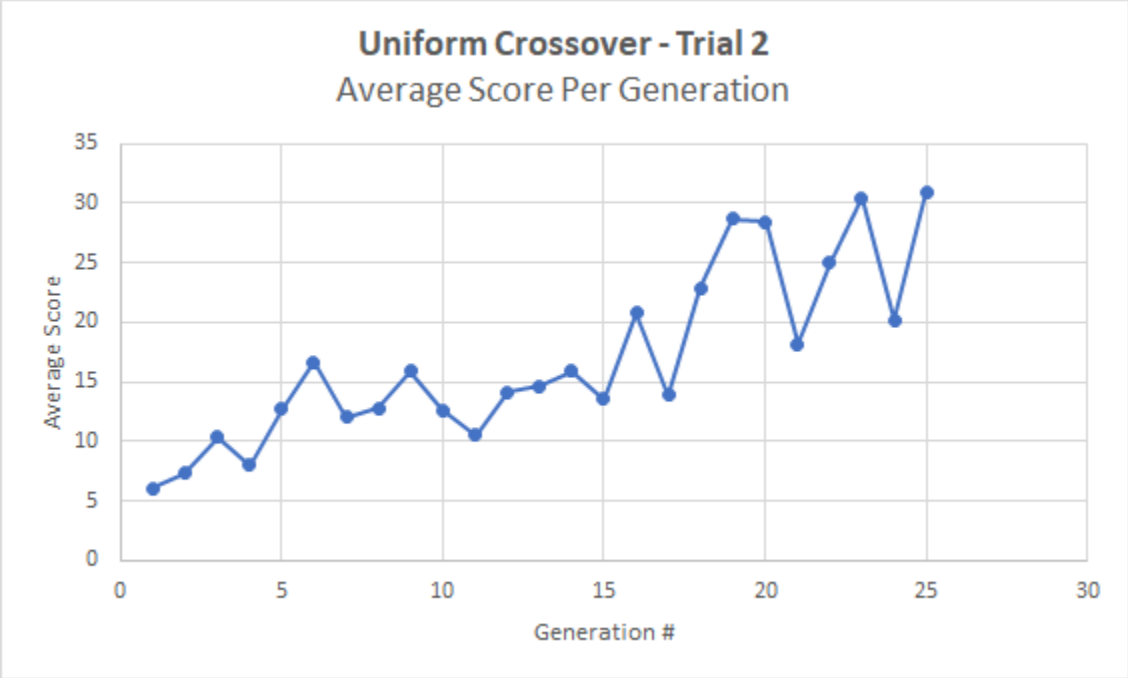
Best Flyer Chromosome (Flyer that achieved Highest Score):

LeftWingLength	RightWing Length	LeftWing Width	BodyDiameter	RightWing Width	LeftWingThickness	RightWingThickness
2.389143	**3.237123**	**3.252407**	**2.454668**	**3.681267**	**2.195402**	**2.232904**

Trial 2


Uniform Crossover - Trial 2
High Score Per Generation
High Score (meters)
Generation #
0
5
10
15
20
25
30
35
40
45
50


Uniform Crossover - Trial 2
Average Attribute Values Per Generation
Attribute Value
Generation #
LeftWingLength
RightWingLength
LeftWingWidth
BodyDiameter
RightWingWidth
LeftWingThickness
RightWingThickness

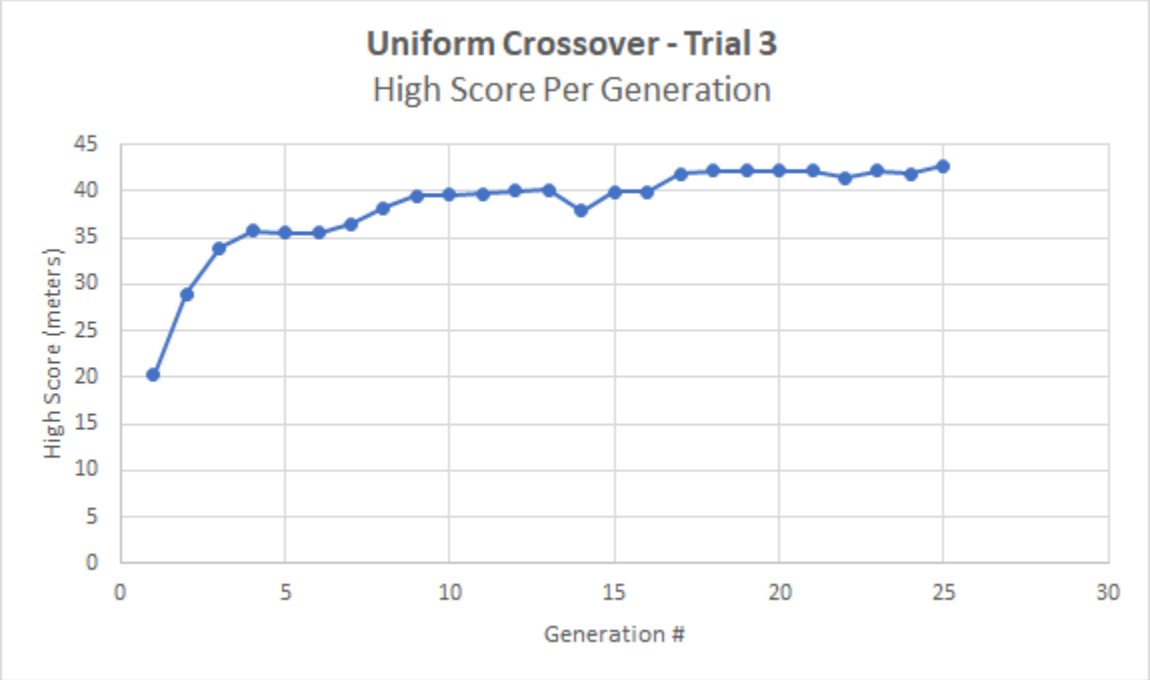


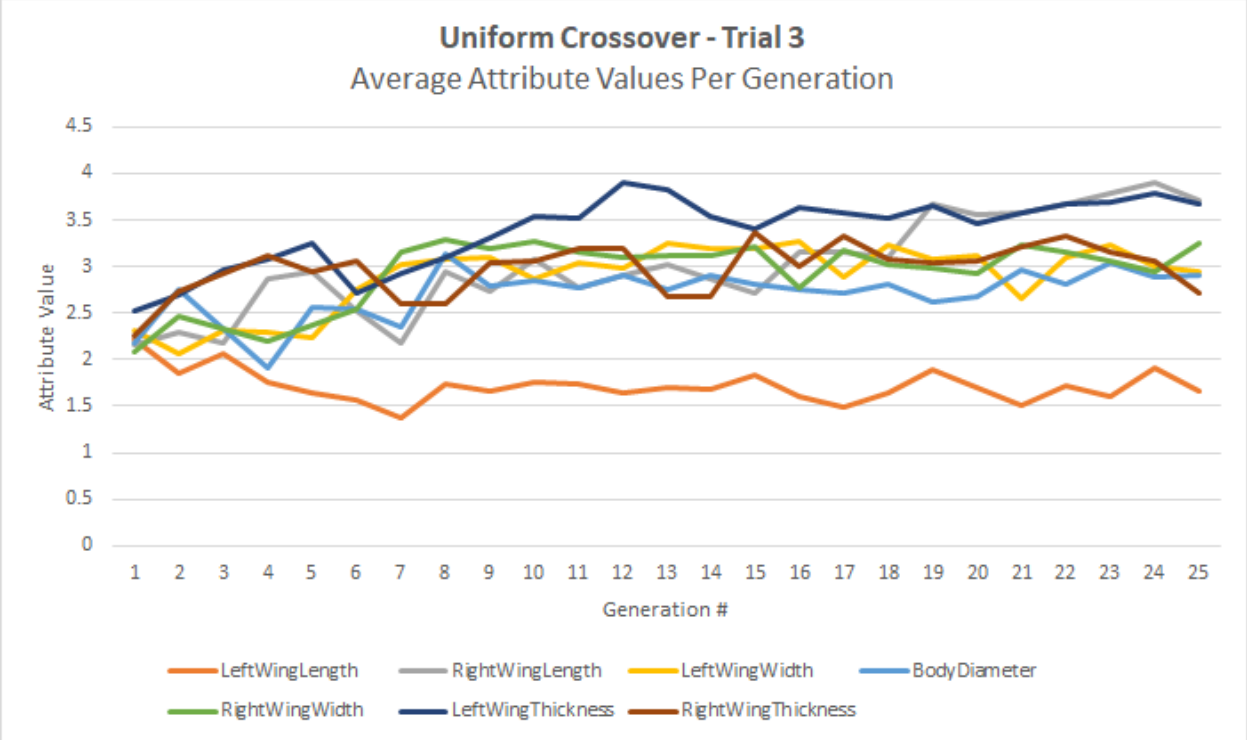
Highest Score: 45.38079 meters

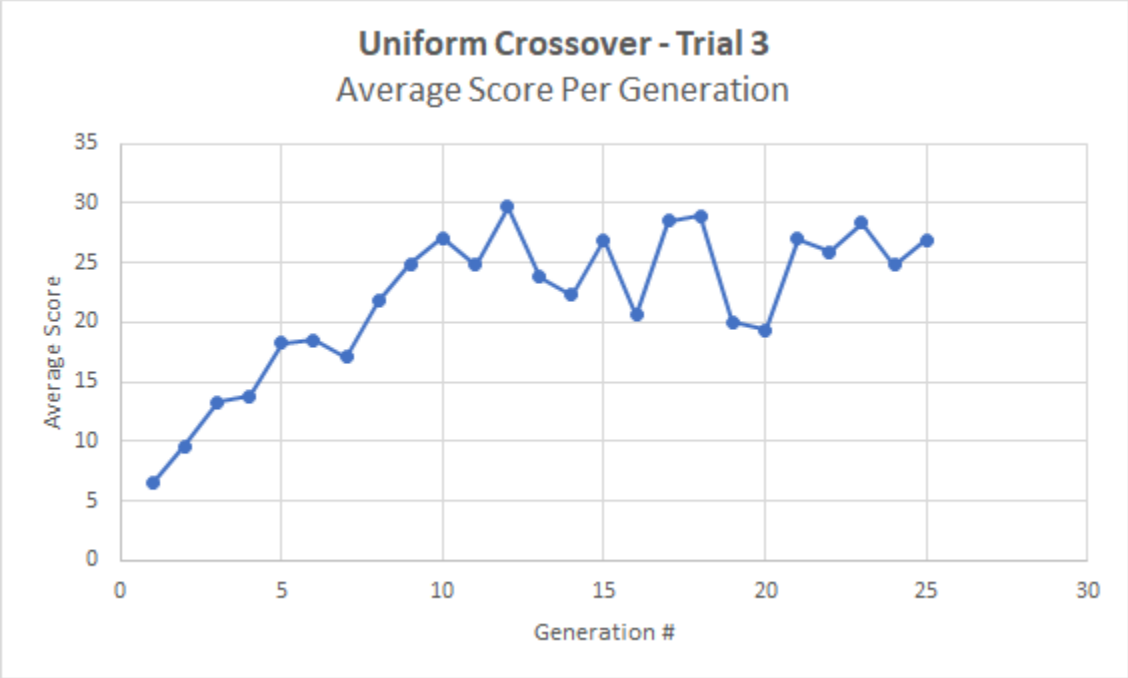
Best Flyer Chromosome (Flyer that achieved Highest Score):

LeftWingLength	RightWing Length	LeftWing Width	BodyDiameter	RightWing Width	LeftWingThickness	RightWingThickness
2.066612	**3.048501**	**3.530656**	**3.340074**	**3.545026**	**3.830632**	**3.551865**

Trial 3


Uniform Crossover - Trial 3
High Score Per Generation
High Score (meters)
Generation #
0
5
10
15
20
25
30
35
40
45


Uniform Crossover - Trial 3
Average Attribute Values Per Generation
Attribute Value
Generation #
LeftWingLength
RightWingLength
LeftWingWidth
BodyDiameter
RightWingWidth
LeftWingThickness
RightWingThickness



Highest Score: 42.74664 meters

Best Flyer Chromosome (Flyer that achieved Highest Score):

LeftWingLength	RightWing Length	LeftWing Width	BodyDiameter	RightWing Width	LeftWingThickness	RightWingThickness
1.637495	**3.931123**	**3.315953**	**2.900353**	**3.325307**	**3.811975**	**3.298044**