A New Approach to Human Powered Flight and Beyond

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1 Introduction

Most recent development of Wing flying suit[11] and Parabounce's indoor floating balloon bicycle[10] offers some of the pre-requisite of a commercial-viable human powered flight at low speed and low altitude. In this paper, both new designs for human powered flight, its supporting infrastructure changes and accommodations, as well as the most significant economic of scale, making the project affordable to most consumers in developed countries will be discussed. Further research suggestions and directions are provided at the end of the research survey.

Prior to the 20th century, self-autonomous flying, regardless of forms and shape, has failed miserably for humans. Though some rare records of person tattered in feathers had flown shown up in human mythology, none of such models are experimentally replicable. In 1903, Wright Brothers demonstrated that Flying machine powered by 12 horsepower engine made of aluminum was capable of taking off and maintained into flight by horizontal stabilizers, rudders, and wing flaps, setting the standard of engine powered flight for humans. More recently, sport extremists pursued the perfection of wing suit filled with air was able to lift themselves through a free fall descend by utilizing the Bernoulli Principle of difference of the gradient curvature of wing shape.

However, both of types of flights have its own disadvantages render them unable to truly achieve bird and insect-like flight behavior for human. First of all, machine based design principle requires powered engine running at high speed fueled by petroleum or equivalent high energy density source, which easily outperform any human by total power outputs. Even Wright Brother's original model's engine provides 12 horse power of power output, or more than 30 times of an average man. Furthermore, machines are capable of further producing power output at any constant rate as long as fuel lasts, which even trained athletes for competitive sport pales by comparison. As a result, traditional approach on human powered flight using wings as the only source of lift force based Bernoulli Principle are necessary but insufficient condition for lifting up or lifting upward for consistent long periods of time. Indeed, world records such as

Albatross design are set but rarely repeated constantly and practically repeatedly by any future followers.

On the other hand, hot air balloons uses the principle of buoyancy, which simply states that the total volume of displaced fluid or substances by another matter of lower density renders a lift force. Furthermore, hot air balloon is one of many possible devices to create buoyancy in earth's atmosphere. The alternatives are hydrogen and helium. Buoyancy is very easy to be explained at molecular level, because lighter elements such as hydrogen and helium, although its volume are smaller in proportion to their atomic mass, its outer electron shells diameters are nearly similar in size to heavier atom Oxygen's shell given by their experimentally derived Van der Waals radius. As a result, a hydrogen atom has less density than an Oxygen atom. Furthermore, both hydrogen and heavier atoms in gas state moves in the air about same speed at same temperature; therefore, a body of hydrogen or helium's density in a closed lightweight container are not squeezed by the surrounding heavier elements and are not forced into increased density. Under the influence of gravitational field, hydrogen, helium, and oxygen fall toward earth by the same acceleration g. However, by Newton's second law, $F = M \cdot a$. Force equals mass times acceleration, we know that downward force acting differently for lighter mass than heavier mass, as a result, heavier elements falls faster than helium and hydrogen.

As a result, it creates an "illusion" that hydrogen floats, but in fact, hydrogen also was attracted by the gravity of earth. If the earth's atmosphere is filled with hydrogen, self-closed container of hydrogen will not float at all. As a result, hydrogen and helium creates a natural lift force in static environment independent of Bernoulli principle which requires differential moving air speed. In some aspect, Bernoulli principle is also a variant of Buoyancy because lift force are created with the downside of slower air flow over the top side greater airflow and lower density. Yet the critical difference remains that Bernoulli applies to motion and speed in same fluid. Buoyancy generally refers to lift force by object of different density at static speed and motion. Air balloon uses the principle of buoyancy to lift objects and humans, yet completely ignored the principle of Bernoulli. As a result, balloons useful for drifting but have a poor navigation left to right capability and as well as both descend and ascend maneuverability. The basic advantage of balloon is the ability to hover mid-air without further assistance of wind flow or turbulence. On the other hand, flight model based on Bernoulli principle such as airplane and wing suit, are great at maneuverability to quickly change directions and ascend and descend quickly. However, one must pay the price by achieving a high speed of at least 100 km per hour. Human powered flights are not capable of generating such power on their own, human powered flight are too slow at take-off speed and quickly enters a stall once speed in air reduced by frictions with air. If one look further into the animal kingdom at insects and birds, one can quickly concludes one thing, birds and butterflies tries to utilize both Principle's of Bernoulli and buoyancy. Birds feather are filled with air and their bones are hollow, each respiratory cycle air flow through their bone system before entering their respiratory tracks, as a result, birds are in general much lighter than human by the same dimensional standard, as a matter of fact, an bird at the average sized human would weight only one fifth of a human. Birds tries to reduce its body weight as much as possible to create relatively greater level of buoyancy compare to other land-based animals. At the same time, they also took off for flight and utilize Principle's of Bernoulli at above stall speed. Insects such as butterfly do not have hollow bones but have extremely lightweight body and thin membrane based wings. This reduced the need of buoyancy and by applying Principle's of Bernoulli, they are able to achieve flight in air.

It seems like buoyancy can be created by filling a medium with anything lighter than oxygen and nitrogen mixtures, but we have essentially two gases hydrogen and helium are gaseous at normal room temperature. At first glance, hydrogen seems to provide considerable advantage over helium for being the lightest atom; however, hydrogen is a highly inflammable gas under normal room temperatures. The tragedy of Hindenburg during the 1936 came immediately to mind, which is almost the equivalent of sinking of Titanic in the balloon aviation history using helium. As a result, helium has been used as a substitute for being the latest gas to achieve buoyancy. Helium is non-inflammable and non-poisonous but it does create higher pitched voice in human if inhaled. An even better approach is to add a mixture of hydrogen and helium gas in proportion to be non-inflammable. Current world record standard are 8% hydrogen and 92% helium as the threshold of inflammability. As a result, one can conclude one needs to keep hydrogen mixture into helium at or below this level of threshold.[6]

2 Assumptions for the design

One should then conclude that both Bernoulli principle and buoyancy are important attributes in achieving flights in animal kingdom, it is reasonable to conclude both principles should be applicable to humans. Since we cannot change the physiological characteristics of human in generations in come, biological human will remain heavy as they are as a terrestrial animal species, but we can compensate to significantly reduce our weight by loading ourselves with helium.

There are two approaches; one approach is to load human with spherical volume container filled with helium and attaching wings. The Helium balloon will provide enough lifting force to significantly reduce the weight of human to those comparable to birds of similar size. Then, additional wings of light weight material attached directly to human to create flapping behavior in birds using Bernoulli principle.

The other approach is to design balloons filled with helium directly in the shape of birds or butterflies and fly using such wing. The critical requirements are the wings have considerable size and volume, equivalent to the balloon volume in the first approach. One can quickly discern that the second approach is more favorable for the following reasons. First of all, by dividing the balloons into multiple wings, two or more wings, and *one creates a redundancy in the system such that safety is ensured.* If a particular wing is torn or leaked, the system

will continue to function properly and lands under emergency situation. An analogy is birds carrying feathers, a bird losing one or few feathers rarely caused it to have trouble at lifting into air, but a fully featherless nestling at incubation cannot fly by any stretch of imagination. Furthermore, redundancy lowers the economic costs of wings. Helium can be quickly restored to storage if wings are small and in event of a loss, the total loss of helium will be bearable by the owner than total loss in an air balloon design.
Finally, flexible moving wings both reduces the speed of a fall as in accidents, and also acts as a cushion upon crash landing, essentially acting as the safety belt and air balloon upon automobile accident.
Secondly, different person may weigh differently at different times and possibly even different locations such as at higher altitudes. As a result, *by using multiple wings system filled helium, a person can adapt the total amount of lift force on his or her body depends on how much power he wants to generate per second to keep himself or herself flying depending on their strength.* A person also adapts the total number of wings attached depend on their weight. Because more than two flapping wings may affect flapping movement, most of wings are attached to the back as "immovable" wings, such wings sole purpose is to create lifting force, or imitating the air filled bones sacs inside a bird. The moving wings are attached directly to arms, are generally the largest. The larger they are the more uplifting force generated from Bernoulli principle. Further details and discussions please refer to section the Wing physics. One can easily conclude based on this assumption, light weight people with strong muscular power is favored over heavyweight powerless individual in a human powered flight.
Thirdly, if wings can be filled with helium, *we do not need additional wings with fabric to create more weight to counterbalance the uplifting buoyancy.* Any material, no matter how light they are such those made with carbon fiber, do have weight, in order to create easy, and powerful human flight experience one needs to cut as much materials as possible. As a result, wings filled with helium serves as dual purpose, it increased maneuverability because less drag is created when one moves horizontally through the air and at the same time creates buoyancy reduce the weight of the carrier.
Fourthly, by *designing helium filled wings which in open positions has greater surface area than a balloon.* Even though the total volume displaced air is the same as for balloon and wings, creating same amount of force of buoyancy, the air frictional drag factor is greater for wings with greater surface area than spherical shape, which is the reason that a crumpled piece of paper falls much faster than a plain piece of paper because of air friction creating differential terminal velocity. Such results have been show numerous times since Galileo. Sphere has the smallest surface area of all surfaces that enclose a given volume.

3 Terminal Descend Velocity

The next question is that how much lift force buoyancy is needed to achieve human powered flight? One can quickly conclude that to reach total human weight is completely unnecessary. In order to answer this question, we need to basically answer the question, how can we find a range of lifting force factor on a given weight that knowing its power output and amount of lift force it can generate, can keep itself in the air when it intends and descend and lands gracefully when it wished. One can easily conclude the total weight of lift force must always be smaller than the weight of the carrier itself. If the lift force is greater than the carrier, the carrier will keep ascend until it reaches a high altitude. If the uplifting force equals to the weight of the carrier, once the carrier flaps its wing, it will rise to higher altitude and stays at the altitude. Then, we can only design lift force to be smaller than human themselves yet lifting enough human weight to make human lifting themselves through wing flapping relatively effortless. To be more specific, the falling speed of human with helium wings due to acceleration in any given time interval (most commonly used unit is 1 sec) must be less than that of the lift force generated by wing flapping in the same time interval specified (most commonly used unit of measure is 1 sec). By using the equation regarding parachute drags and buoyancy, one can quickly formulate a graph of relationship between the surface area size of opening wings and falling speed. First, to find wind resistance force, we use the following equations:

$$F_D = \frac{1}{2}\rho \cdot C_D \cdot A \cdot v^2 \tag{3.1}$$

Where
F_D is the drag force
ρ is the density of air = 1.22 $\frac{\mathrm{kg}}{\mathrm{m}^3}$
C_D is the drag coefficient
A is the area of the parachute, or in our case, opening wings
v is the velocity through the air
Meanwhile, the weight of the carrier, otherwise known as the force of gravity (F_G), is computed to be

$$F_G = mg \tag{3.2}$$

Where m is the mass of the carrier, and assumes that the weight of the wings outer shell materials are of negligible weight in an ideal situation. g is the acceleration of gravity = 9.81 $\frac{\mathrm{m}}{\mathrm{s}^2}$ we can set

$$F_D = F_G \tag{3.3}$$

We can then solve for the surface area of wings by re-arranging equation to:

$$A = \frac{2F_D}{\rho C_D v^2} \tag{3.4}$$

Since the average weight of human is 62.0 kg worldwide, this value will be used to calculate F_G. However, as a result of helium wings, the total weight of human will be much lighter, we plot the graph of possible range of percentage values of F_G and compute the surface area requirements of wings.

we can also re-arrange and solves for the terminal velocity of opening wings given surface area, but to simplify our discussion, we will simply substitute one fixed value for terminal velocity, 2.5 m/s, a value little less than the average falling speed of parachute. We choose a value less than the average falling speed of parachutes because not everyone is trained with parachutes landing techniques and lower speeds increase safety.

$$v = \sqrt{\frac{2F_G}{\rho C_D A}} \tag{3.5}$$

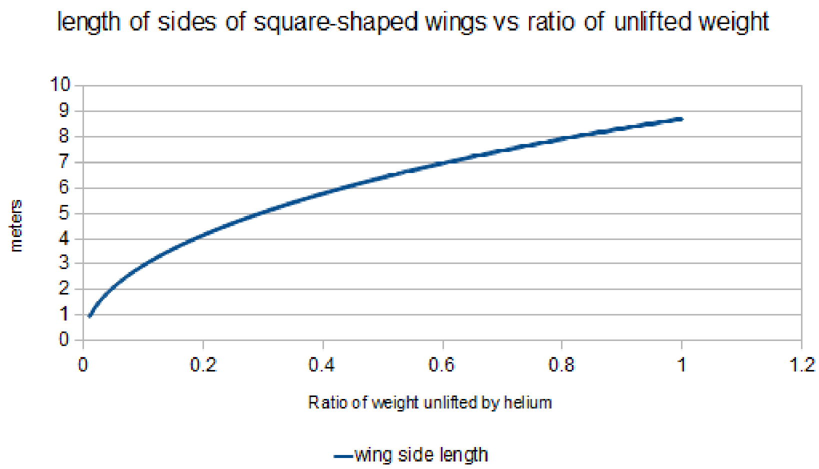

Figure 3.1: Percentage of weight unlifted by helium

From the graph above, one can tell that greater portion of the body weight is lifted by helium, the smaller the surface area of each wings are required at an opening position to reduce the speed of falling to average parachute speed of 2.5 m/s. One may conclude that if nearly all of the weight is counterbalanced by helium filled wings, one needs only 0.872 m $\cdot$ 0.872 m surface wing area on each side, which is comparable to a bird with a human body size. However, volume of wing with such size will not provide enough buoyancy to lift the weight of the human in the first place. The following equations shows the physical relationship between the volume of helium required to lift 1 kg of weight. 0.947 m^3 = 1kg [8], that is, every 0.947 cubic meters of helium provides 1 kg of buoyancy. [9]

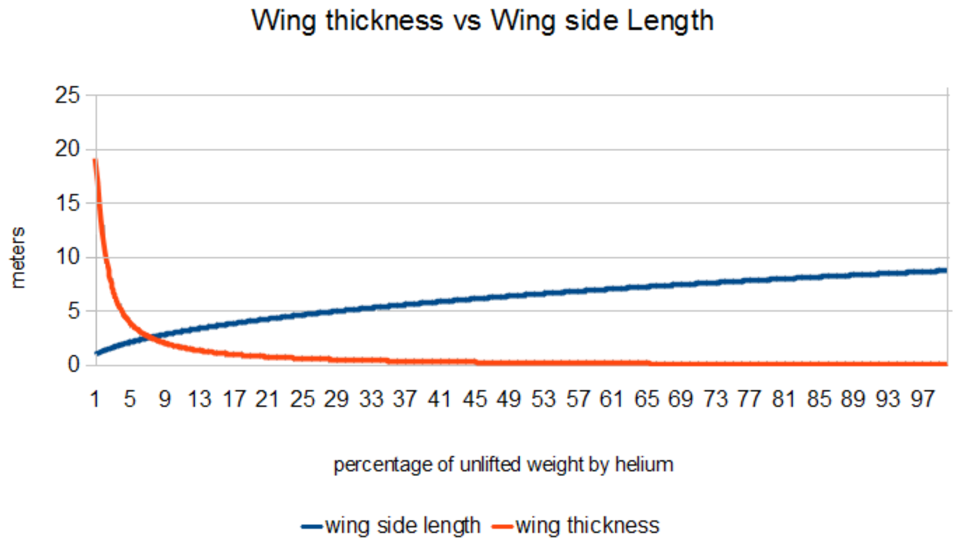

Figure 3.2: The inverse relationship between wing thickness and wing side length

The above graph shows that in order to satisfy both conditions of lifting the total weight of the object plus helium itself and supply wing surface area given by calculation is impossible, at 93% or above cases where helium lifted up the total weight, the wing thickness of a 4 wing systems (2 immovable wings and 2 movable wings) will be greater than the wing's width and length. The wing thickness ideally should approaches 25% or below compare to the wing's width and length. From calculation, the helium wings needs to replace 83% or less percentage of total weight of the system and creates wings with width and height of 3.829 meters (very small surface area) or above and wing thickness of 0.93 meters (very thick wings) at one end of range, and to replace 53% or less percentage of total weight of the system and creates wings with width and height 6.228 meters (very large surface area) and thickness of 0.2178 meters (very thin wings) at the other end of the range. Finally, the median point of the range is at replacing 72% of the total weight with both the terminal velocity calculation based wing length and width commensurate with the width and length of the 4 wing system with average wing thickness of 0.496 meters. In order to know the best among the values, one need to look further into our next issue regarding power generation at lifting the wings.

Another approach is simply take the greatest wing surface area possible by both scenarios,

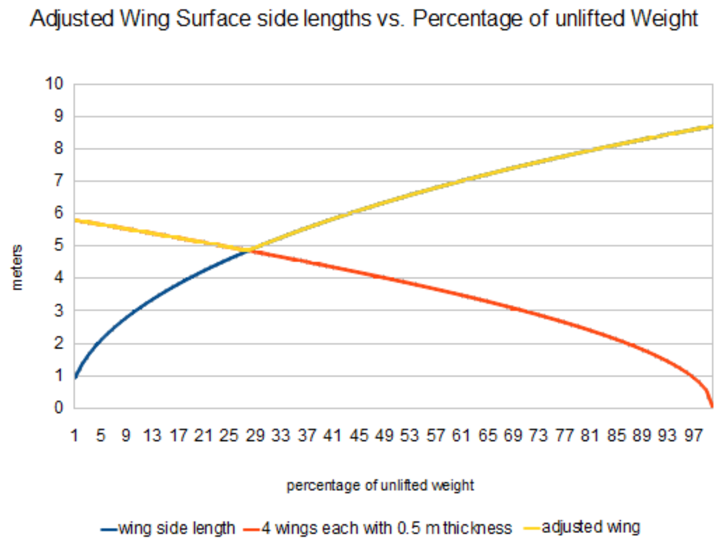

Figure 3.3: Side length vs. percentage of unlifted weight

The appropriate new wing surface area is the orange curve, where a inflection point occurs at 72% helium filled wings at lifting given weight. Under 72% of weight lifted by helium, one has to adopt the parachute terminal speed curve (the blue line) which increases as the total amount of weight supported by helium decreases, to safely slowly down the descend of the flying human when wings are fixed in open position without movement. Over 72% of weight lifted by helium, parachute terminal speed curve yields wings with increasingly small surface which unable to create large enough volume to support the weight itself, therefore, the red curve is followed, where 4 wings each with constant thickness of 0.5 meters, with 2 of them attached to the back of the flier as the immovable lift force, and another 2 of them attached as movable wings for flapping purposes. Here is the graph of final terminal velocity of adjusted flying wings:
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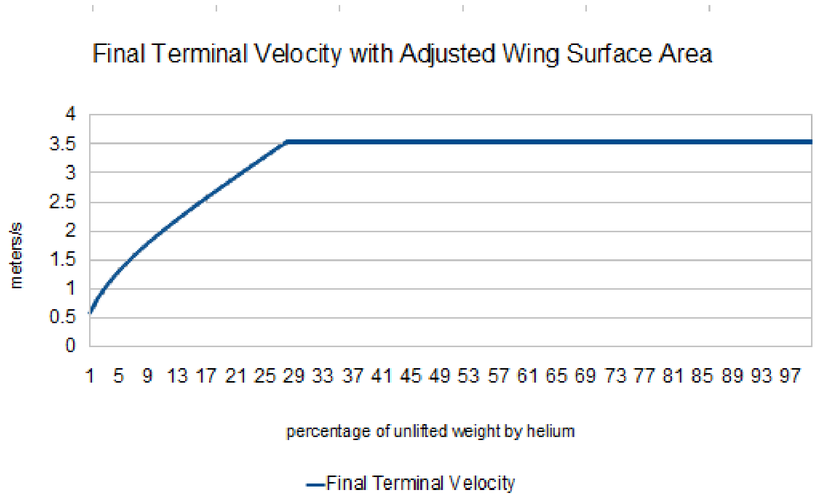

Figure 3.4: Final terminal velocity with adjusted wing surface area

Finally, children and adult share different wingspan dimension even though the relationship is held constant, lower weight carrier's relationship curve is moved downward, as is shown in the illustration below:]

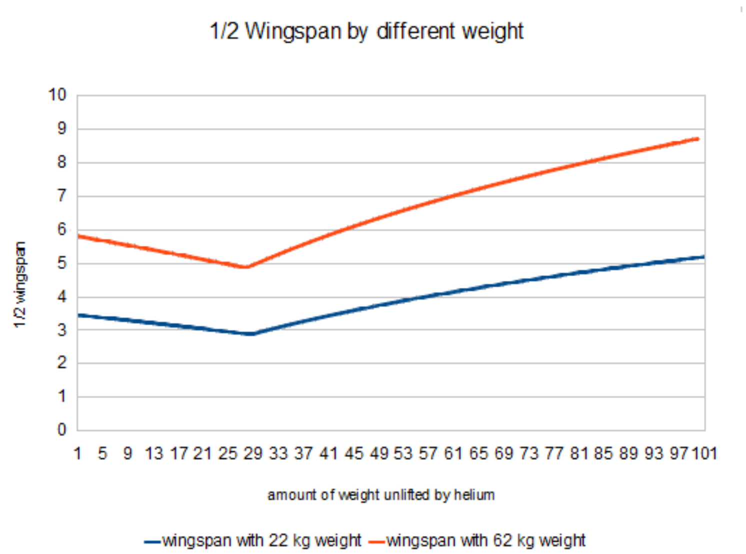

Figure 3.5: Wing span size comparison for a 22 kg lifting weight and a 62 kg lifting weight

4 Human Power Generation

To define a human powered effort, one must resort to the discussion of power output, or watt the power output per second. In 1983 Douglas Malewicki gave a landmark paper at the

International Human Powered Vehicle Association Scientific Symposium, in which he presented a graph showing the maximum duration of human effort for various steady power levels.[3]

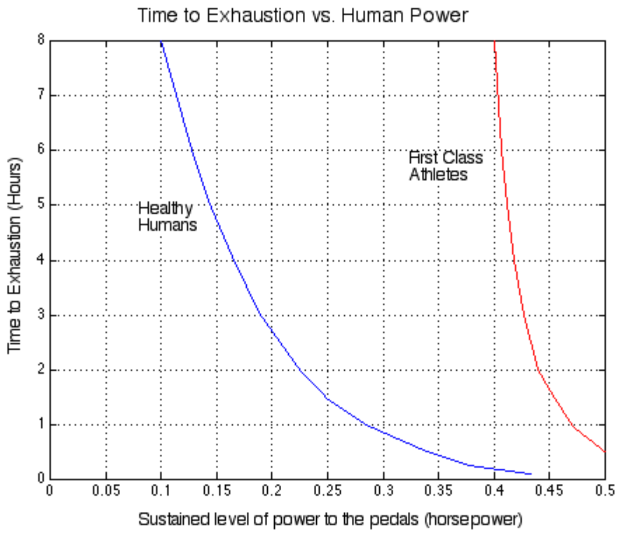

Figure 4.1: Time to exhaustion vs human power

This graph has been reproduced below for convenience. Notice from the graph that an average "healthy human" can produce a steady 0.1 horsepower for a full eight hour period, while a "first class athlete" can produce 0.4 horsepower for a similar period. Note that each data point on the curves represents an exhausted human. No more power is available without some rest and recovery.[5] The graph shows the total amount of power output by average human vs. athletes and their endurance at every level of power output, both curves are exponentially decay, yet the athletic curve moves much further to the right, One can quickly conclude that an average human to achieve sustained human flight over 30 minutes or longer should an average maintain a power output of 200 watts. Once we derived this result, we will use our equations for insect flying data to calculate the amount of lift force required and the total area and volume of helium filled wings.

5 Flapping Frequency vs. Force of Lift

The following excerpts are derived from Wikipedia which in turn cites insect flying mechanisms, by using their equation, one can derive the required flapping frequency for hovering in the air.[2] “Many insects can hover, or stay in one spot in the air, doing so by beating their wings rapidly. The ability to do so, though, is complex; requiring the use of sideways stabilization as well as the lift necessary to overcome the force of gravity. The lifting force is caused by the downward stroke of the wings. As the wings push down on the surrounding air, the result reaction force of the air on the wings force the insect up. The wings of most insects are designed so that during the upward stroke the force on the wing are small. Due to the fact that the upbeat and downbeat force the insect down and up respectively, the insect oscillates and winds up staying in the same position.[19] The distance the insect falls between wing beats depends on how rapidly its wings are beating. If the insect flaps its wings at a slow rate, the time interval during which the lifting force is zero is longer, and therefore the insect falls farther than if its wings were beating rapidly. One can calculate the wing beat frequency necessary for the insect to maintain a given stability in its amplitude. To simplify the calculations, one must assume that the lifting force is at a finite constant value while the wings are moving down and that it is zero while the wings are moving up. During the time interval t of the upward wing beat, the insect drops a distance h under the influence of gravity.[19]

$$h = \frac{g\left(\Delta t^2\right)}{2} \tag{5.1}$$

The upward stroke then restores the insect to its original position. Typically, it may be required that the vertical position of the insect change by no more than 0.1 mm (i.e., $h = 0.1$ mm). The maximum allowable time for free fall is then [19] ”

$$\Delta t = \left(\frac{2h}{g}\right)^{\frac{1}{2}} = \sqrt{\frac{2 \times 10^{-2}\ \text{cm}}{980\ \text{cm/sec}^2}} \approx 4.5 \times 10^{-3}\ \text{sec} \tag{5.2}$$

Now, making this discussion relevant to our experiment, we simply substitute h with a larger number, which is how fast ones falls with helium wings attached. Substitute h with 100 cm, the average speed of falling with opening wings, maximum allowable time for free fall is 0.4517 sec.

“Since the up movements and the down movements of the wings are about equal in duration, the period T for a complete up-and-down wing is twice r, that is,[19] ”

$$T = 2\Delta t = 9 \times 10^{-3}\ \text{sec} \tag{5.3}$$

for our wings, $2 \cdot 0.4517$=0.9035 sec.

“The frequency of the beats, f, meaning the number of wing beats per second, is represented by the equation:[19] ”

$$f = \frac{1}{T} \approx 110\,\text{sec}^{-1} \tag{5.4}$$

our wings, $1/0.9035 = 1.106$ sec^{-1}.

In the examples used the frequency used is 110 bit/s, which is the typical frequency found in insects. Although butterflies have a much slower frequency with about 10 bit/s, which means that they can’t hover. While other insect may be able to produce a frequency of 1000 bit/s. Restoring the insect to the vertical position must be during the downward stroke, the average upward force, F_{av}, must be equal to twice the weight of the insect. Note that since the upward

force on the insect body is applied only for half the time, the average upward force on the insect is simply its weight.[19] ”
Compared to insects, notice that our wings flapping frequency can maintain its flying position by maintaining 1.106 bit/s, which is about little less of 1 flap per 1 sec. Of course, we need to test a range of possible values, here is the graph of possible values given by different falling speed ranges from 0.57 m/s to 3.53 m/s.

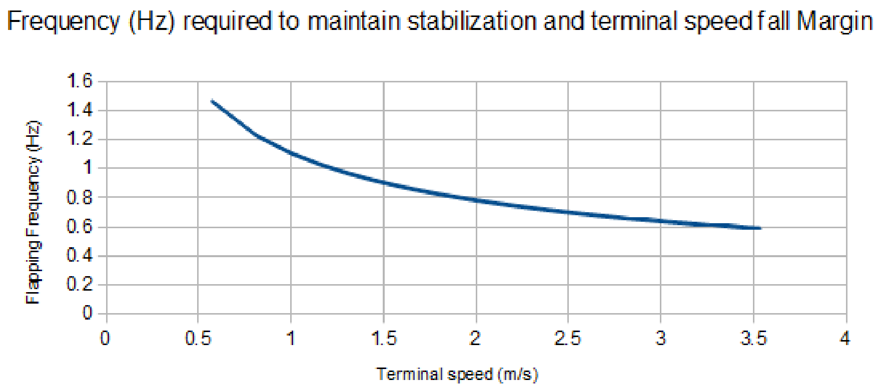

Figure 5.1: Flapping frequency requirements for vertical height stability

6 Power input

“One can now compute the power required to maintain hovering by, considering again an insect with mass m=0.1 g, average force, F_{av}, applied by the two wings during the downward stroke is two times the weight. Because the pressure applied by the wings is uniformly distributed over the total wing area, that means one can assume the force generated by each wing acts through a single point at the midsection of the wings. During the downward stroke, the center of the wings traverses a vertical distance d.[19] The total work done by the insect during each downward stroke is the product of force and distance; that is,

$$W_{ork} = F_{av} \times d = 2W_{eight} \times d \tag{6.1}$$

If the wings swing through the beat at an angle of 70°, then in the case presented for the insect with 1 cm long wings, d is 0.57 cm. Therefore, the work done during each stroke by the two wings is:”[19]

$$W_{ork} = 2 \times 0.1 \times 980 \times 0.57 = 112\,\text{erg} \tag{6.2}$$

for our wings if we choose our mid-point in our range: Work $= 2 \times 72.02\,\text{kg} \times 0.04 \times 1,000 \times 980 \times 5.8 \times 0.57 \times 100 =$ 1,866,689,260.8 erg

“After, the energy has to go somewhere; here, in the example used, the mass of the insect has to be raised 0.1 mm during each down stroke. The energy E required for this task is:”[19]

$$E = mgh = 0.1 \times 980 \times 10^{-2} = 0.98\,\text{erg} \tag{6.3}$$

substitute for our wings, we got $72.02\text{kg} \times 1,000 \times 980 \times 250\text{cm}$ = 16,973,600,000 erg
“This is a negligible fraction of the total energy expended which clearly, most of the energy is expended in other processes. A more detailed analysis of the problem shows that the work done by the wings is converted primarily into kinetic energy of the air that is accelerated by the downward stroke of the wings. The power is the amount of work done in 1 sec; in the insect used as an example, makes 110 downward strokes per second. Therefore, its power output P is, strokes per second, and that means its power output P is”:[19]

$$P = 112\,\text{erg} \times 110/\text{s} = 1.23 \times 10^4\,\text{erg/s} = 1.23 \times 10^{-3}\text{W} \tag{6.4}$$

for our case:
$1,866,689,260.8\,\text{erg} \times 1.106/\text{s} = 20.6604 \times 108\,\text{erg/s} = 206.6$ watt, from the human powered chart, one can see that to maintain mid air hovering for 5.8 meters long wings on each side with 96% of the weight lifted by helium one needs only maintain 0.7 bit/sec and expanding **206 watts**, and *it can last average man 1.2 hours.* Of course, we will set up more strident criteria by having a range of values and the graph is plotted below for each possible cases.

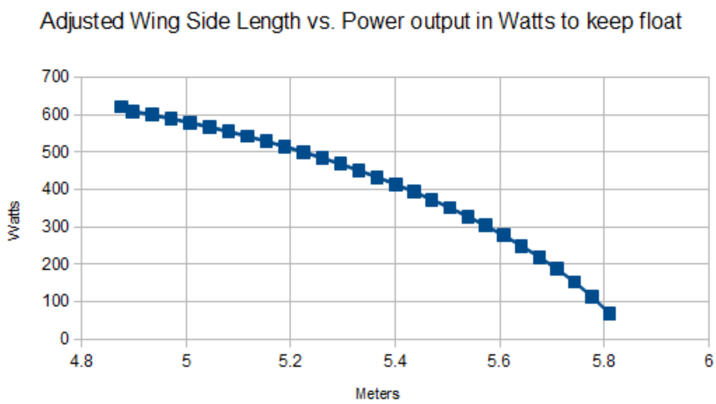

Figure 6.1: Wing size vs power output requirements to keep afloat

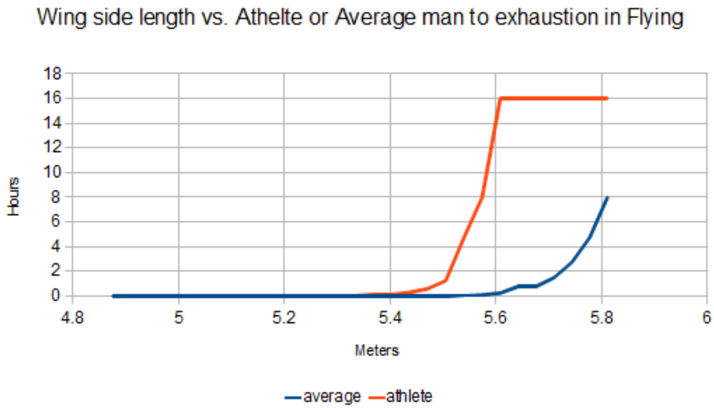

Figure 6.2: Wing side length vs athlete or avearge man endurance duration

7 Power output

"In the calculation of the power used in hovering, the examples used neglected the kinetic energy of the moving wings. The wings of insects, light as they are, have a finite mass; therefore, as they move they possess kinetic energy. Because the wings are in rotary motion, the maximum kinetic energy during each wing stroke is:[19]

$$KE = \frac{1}{2} I \omega_{max}^2 \tag{7.1}$$

Here I is the moment of inertia of the wing and ω_{max} is the maximum angular velocity during the wing stroke. To obtain the moment of inertia for the wing, we will assume that the wing can be approximated by a thin rod pivoted at one end. The moment of inertia for the wing is then:[19]

$$I = \frac{ml^3}{3} \tag{7.2}$$

Where l is the length of the wing (1 cm) and m is the mass of two wings, which may be typically 10^{-3} g. The maximum angular velocity, ω_{max}, can be calculated from the maximum linear velocity, ν_{max}, at the center of the wing:[19]

$$\omega_{max} = \frac{v_{max}}{l/2} \tag{7.3}$$

During each stroke the center of the wings moves with an average linear velocity $_{av}$ given by the distance d traversed by the center of the wing divided by the duration t of the wing stroke. From our previous example, d = 0.57 cm and t = 4.5×10^3 sec. Therefore:[19]

$$v_{av} = \frac{d}{t} = \frac{0.57}{4.5 \times 10^{-3}} = 127 \, \frac{\text{cm}}{\text{s}} \tag{7.4}$$

The velocity of the wings is zero both at the beginning and at the end of the wing stroke, meaning the maximum linear velocity is higher than the average velocity. If we assume that the velocity varies sinusoidally along the wing path, the maximum velocity is twice as high as the average velocity. Therefore, the maximum angular velocity is:[19]

$$\omega_{max} = \frac{254}{l/2} \tag{7.5}$$

And the kinetic energy therefore is:[19]

$$KE = \frac{1}{2} I \omega_{max}^2 = \left(10^{-3} \frac{l^2}{3}\right) \left(\frac{254}{l/2}\right)^2 = 43 \,\text{erg} \tag{7.6}$$

Since there are two wing strokes (the upstroke and downstroke) in each cycle of the wing movement, the kinetic energy is $2 \times 43 = 86$ erg. This is about as much energy as is consumed in hovering itself."[19]

8 Cross Verification/Validation

Finally, in order to guarantee our conclusion is sound, we will use a different set of numbers from different teams studying insect wings aerodynamics to confirm our results. A group of researchers studying on butterfly wakes utilized a model organism with the following characteristics:[4]

Characteristics of Parantica sita niphonica

Total mass	M	kg	0.238×10^{-3}
Aspect ratio	AR		4.068
Wing loading	$Mg/2S_W$	Nm^{-2}	0.988
Thorax mass	m_{Bt}	kg	0.095×10^{-3}
Thorax length	$2l_{Bt}$	m	15×10^{-3}
Thorax width	$2w_{Bt}$	m	8×10^{-3}
Abdomen mass	m_{Ba}	kg	0.105×10^{-3}
Abdomen length	$2l_{Ba}$	m	20×10^{-3}
Abdomen width	w_{Ba}	m	5×10^{-3}
Wing mass	m_W	kg	0.019×10^{-3}
Wing length	y_{tip}	m	0.049
Wing area	S_W	m^2	0.118×10^{-2}

Figure 8.1: Butterfly wakes statistics

we are interested in using research data regarding butterfly specimen Parantica sita niphonica flying model to back-extrapolate and confirm our wings equation and numerical relationship predictions are sound. First of all, we need to extract and confirm three critical calculations regarding Parantica sita niphonica: its terminal falling velocity, its upward acceleration by its wings' lift force, and lift force from air flow. From the chart above, we can compute the terminal velocity using our terminal velocity equations earlier. Our results show that Parantica sita niphonica falls at the speed of 1.7 m/s at terminal velocity. To counteract the falling speed, each second, the butterfly has to lift itself through upward force of an acceleration of 1.7 m/s. First of all, the wings' upward lift force and its acceleration on the flying body can be summed and derived for a 1 second interval. From the paper, it showed that the lift force exerted by the wings in a given flapping cycle of 0.136 sec. The total impulse during the upward force period of total 0.04 second can be calculated to be the area under the force curve, 0.00025 N.

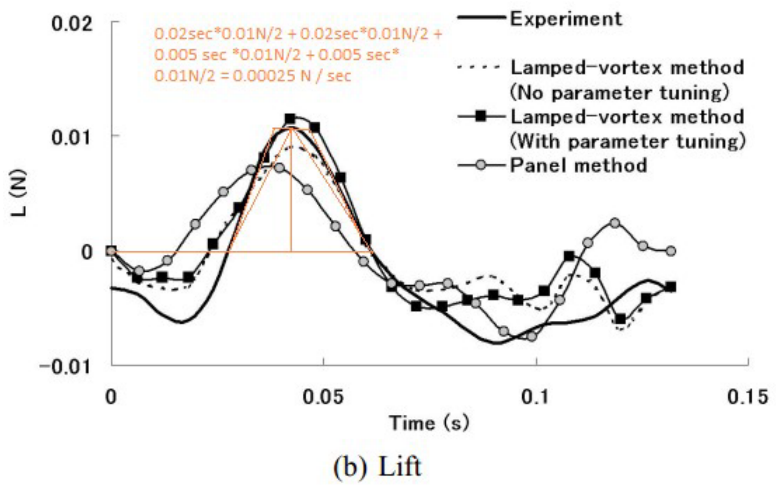

Figure 8.2: Butterfly wakes statistics

Using F=ma, 0.00025N=$0.238 \times 0.001 \times a$. We find that *upward acceleration of* $1.05\,\frac{\text{m}}{\text{s}^2}$. From the paper it states that the main flow was 1.64 m/s, the lift force can also be deduced if the drag coefficient is known. The drag coefficient for was not known directly from the research, but other butterflies with similar characteristics are known [20] and the number 0.032 for Monarchy butterfly is used. The final lift force is at $\frac{1}{2} \times 1.225 \times (1.64)^2 \times 0.118 \times 0.01 \times 0.032 = 0.000149$ N, or $0.62\,\frac{\text{m}}{\text{s}^2}$ *per second acceleration*. The total upward acceleration is 0.62 m/s^2 +1.05 m/s^2 =1.67 m/s^2 , which is acceleration to offset the terminal velocity of 1.7 m/s. The butterfly creates 7 Hz flaps so that t creates 7 times the terminal velocity of its fall speed. Butterfly utilize quick ascent to avoid capture and predator. We simply need the force generated to equal to terminal velocity for in air stabilization. Therefore, we simply need to upward force generated by Parantica sita niphonica at the frequency of 1 Hz instead of 7 Hz for our human scaled extrapolation. A critical reader may question that drag coefficient for Parantica sita niphonica could be smaller than 0.032, its Reynold number, respectively, higher. This does not undermine our assumption because the butterfly repeats 7 Hz flapping cycle. If one cycle of flapping-of-Wings is not suffice for stabilization, additional cycles are taking account for human scale extrapolation, implying greater power output at human scale under the same wingspan. Next, we need to extrapolate the butterfly data into real human sized wings comparable to our earlier data derivation. The foremost aspect of extrapolation is to maintain the terminal velocity of 1.7 m/s as the weight not lifted by helium approaches 1% to 99% of our earlier example of 70 kg. We computed the wing span requirements for terminal velocity reaching 1.7 m/s, we plotted the curve on the graph below with blue and labeled as butterfly predicted, which indicates, that in ideal case, the butterfly wing proportion stretched to human scale would match this line. One notices that this line is similar in curvature to our very first experiment with terminal velocity involving human scale, both grows as the squared of the weight of the flier. However, butterfly extrapolation does not require wing size adjustment at lower values of weight not lifted by helium because the prediction assumes butterfly or human with few kilograms of weight, but in reality, most humans weight are grouped by normal distribution, and lower weight are compensated by greater helium volume and hence greater wingspan keeping wing thickness at a constant. This is again demonstrated in the yellow curve labeled adjusted wing. Finally, we can calculate the real increases in butterfly wing span based on experimental results. We know from the equation of lift force, upward force is directly proportional to the size of the wing. As a result, we can use the relationship of lift force equation: $0.00025\ \mathrm{N} = \frac{1}{2} \times 1.225\,\frac{\mathrm{km}}{\mathrm{m}^3} \times 0.00118\,\mathrm{m}^2 \times 4.980 \times v^2$, where the drag coefficient is the monarchy butterfly drag coefficient, or the reverse Reynold number.[20] We do not know the angular velocity or its linear equivalent from the data, but we can derive by solving the equation and v=0.2635 m/s. Now, we plug in our lift force needed to generate 1 m/s^2 acceleration upward per every percentage of weight not lifted helium to solve for the $\frac{1}{2}$ wingspan of wing requirements. The red curve labeled Butterfly real Wingspan at 1 Hz is the result of our calculation. One notices that it closely matches the predicted wingspan size based on terminal velocity. Its a little lower because some lift force through main flow and Bernoulli principle provides limited lift force. However, in order for the butterfly wing to match our adjusted wing size, we find that flapping of wings frequency at 1.7 Hz, which is the terminal velocity of the wings, provides 1.7 m/s^2 upward acceleration, shares closer similarity. The yellow curve labeled Butterfly real Wingspan at 1.7 Hz is plotted on the graph closely resembles our adjusted wing curve. At frequencies higher than 1 Hz at $\frac{1}{2}$ wing span less than 5.7m is generally too demanding for human powered flight, as a result, only the blue shaded region should be the range of human powered flight, which is 15% or less of the total weight not lifted by helium, and having $\frac{1}{2}$ wing span at or greater than 5.5 m. In conclusion, *our green curve labeled adjusted wings under the blue shaded region offers much greater surface area than those of extrapolated butterfly wings for similar weight, and at lower terminal velocity, and low frequencies of flapping-of-Wings, is sufficient for human powered flight for reasonable amount of time before exhaustion.*

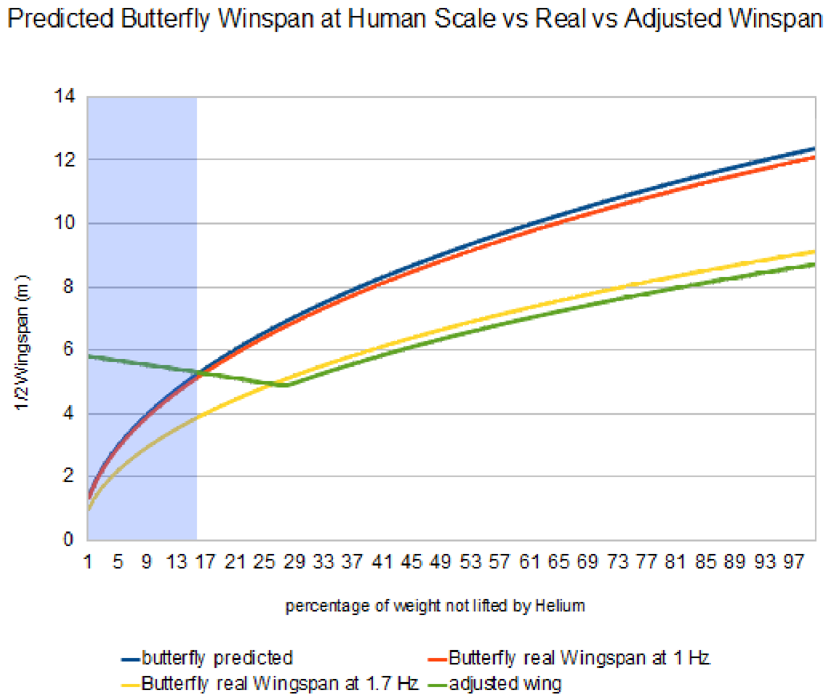

Figure 8.3: Predicted butterfly wingspan at human scale vs real vs adjusted wingspan size

9 Wing Design

Since we have concluded that wings with certain size can carry human into the air and sustain human flight for a constant number of hours, we now draw the diagram of possible configurations of our wing system. All pictures are drawn to scale and human beings are drawn at the center of each graph. Since human powered flight are low in speed, we can create different wing shapes as long as the total volume and air displacement creates the appropriate ratio of lift force and appropriate surface area to create drag coefficient upon soft landing. The weight of human is assumed to be 64 kg, the average weight of an adult human, and non-athletic form. As for an athletic child, the wings requirements will certainly be small.

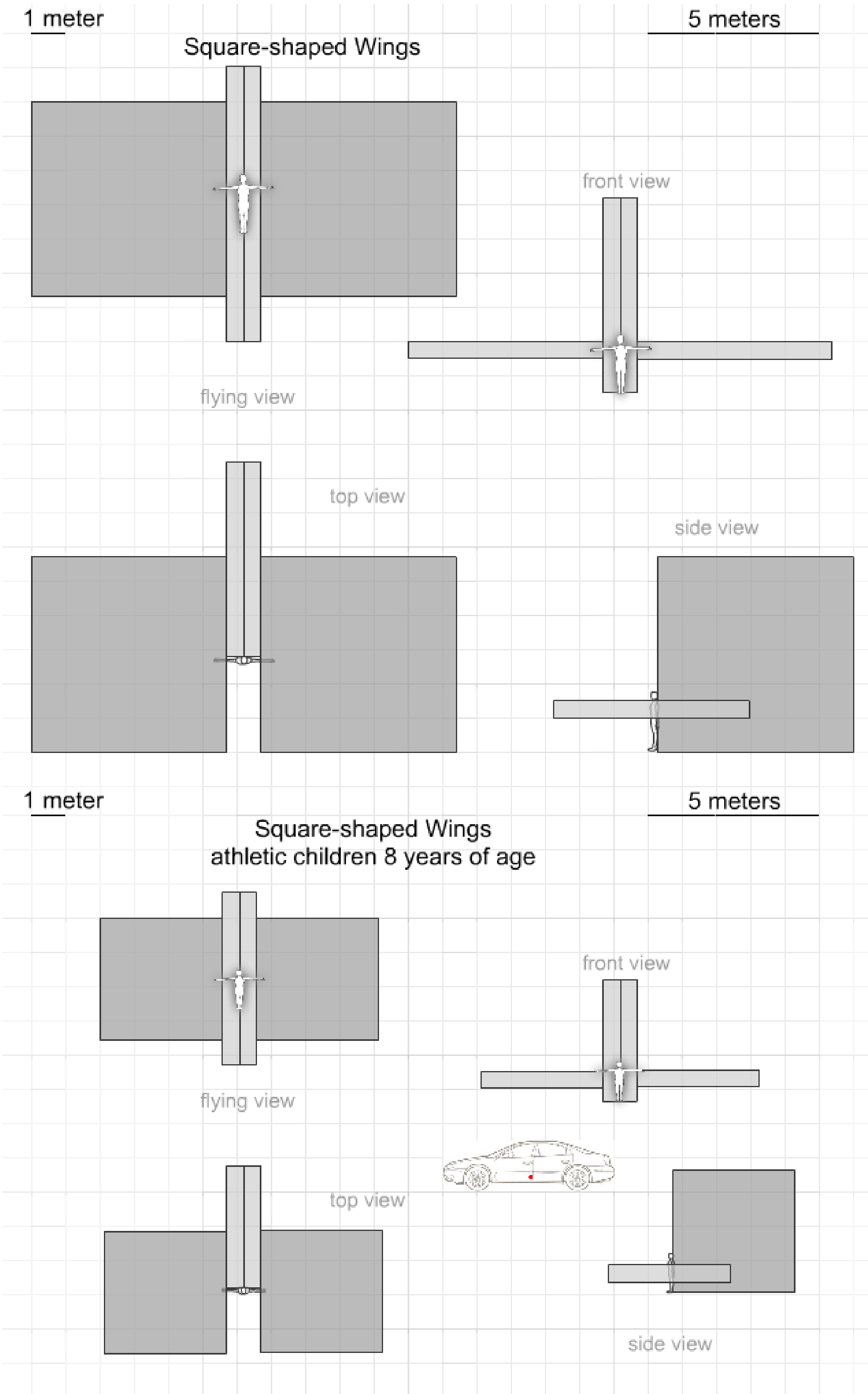

Figure 9.1: Design 1

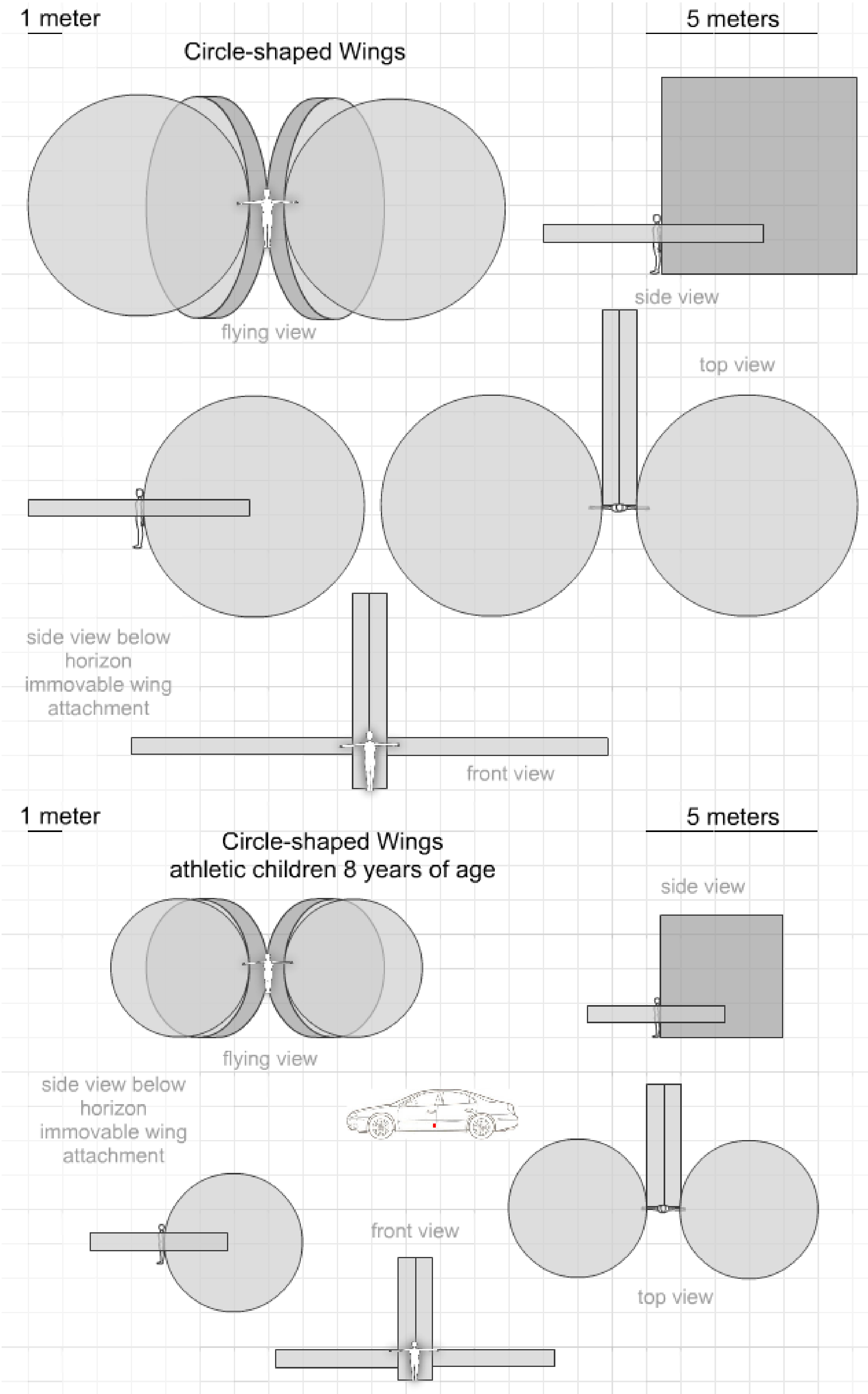

Figure 9.2: Design 2

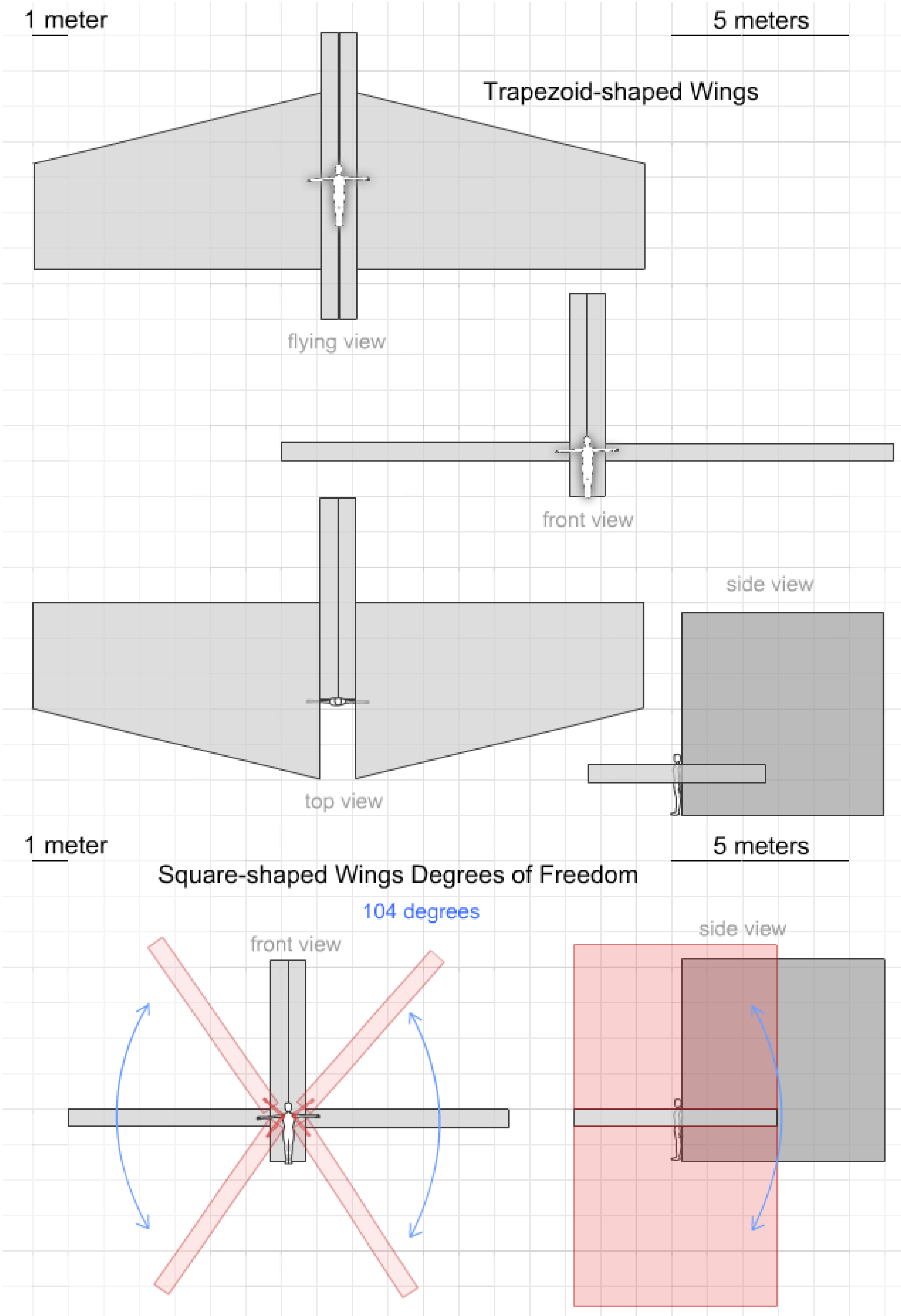

Figure 9.3: Design 3

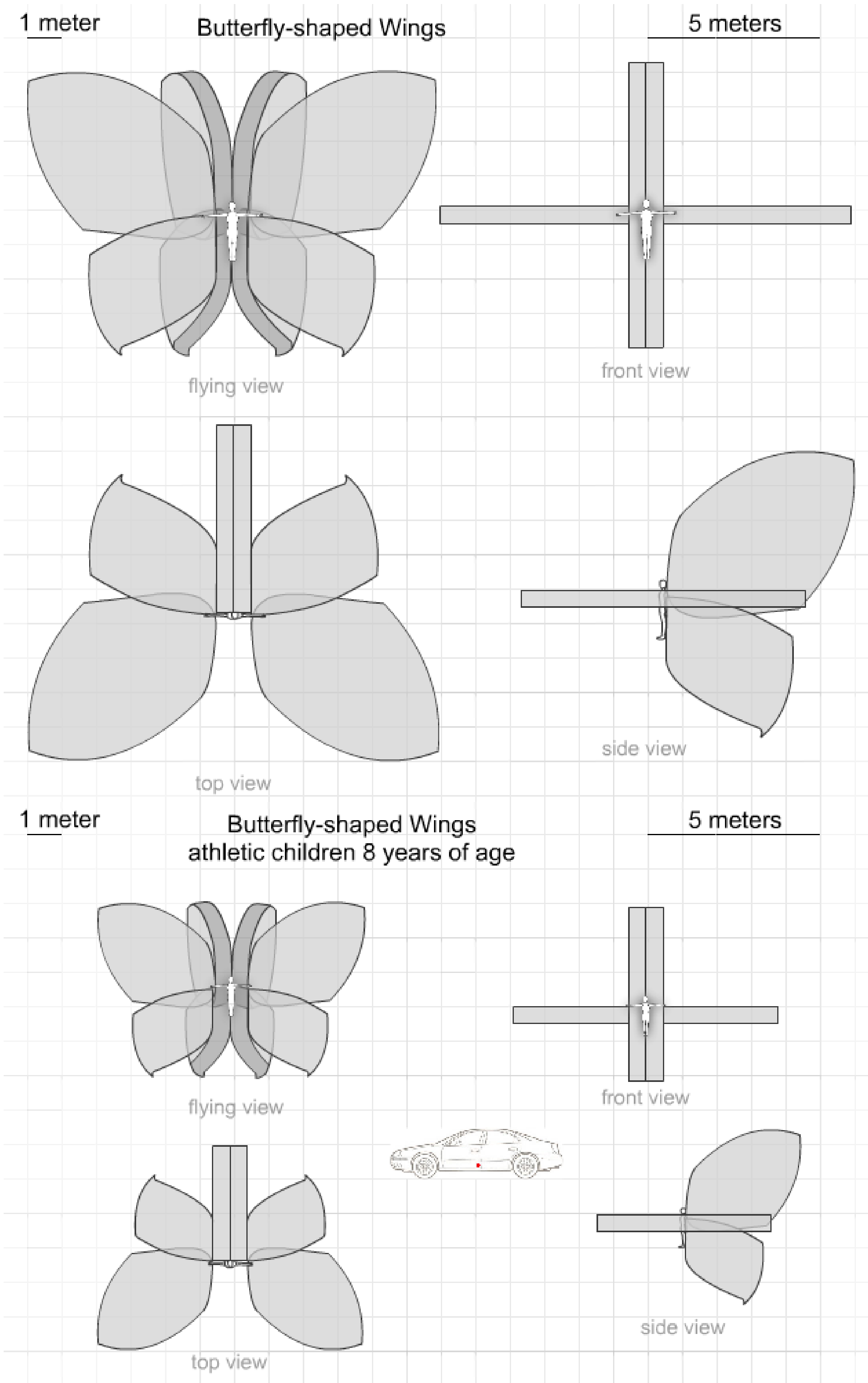

Figure 9.4: Design 4

10 Detailed Suit design - Arm Power vs. Leg Power

In order for the suit to be sturdy and steady in flight. Special design is required. The best design incorporates every piece of the suit in one piece. The user immerses himself into the suit through strong zipper control from the hip up to the neck. In order to streamline and reduce the air friction while in flight, an additional cap can also be attached as one piece to the suit to enhance steadiness during the flight. The fingers are exposed from the suit through openings. One can further wear gloves to protect one's palms. Hand openings are necessary because it provides dexterity for the user during his flight experience and can use them during emergency measures.

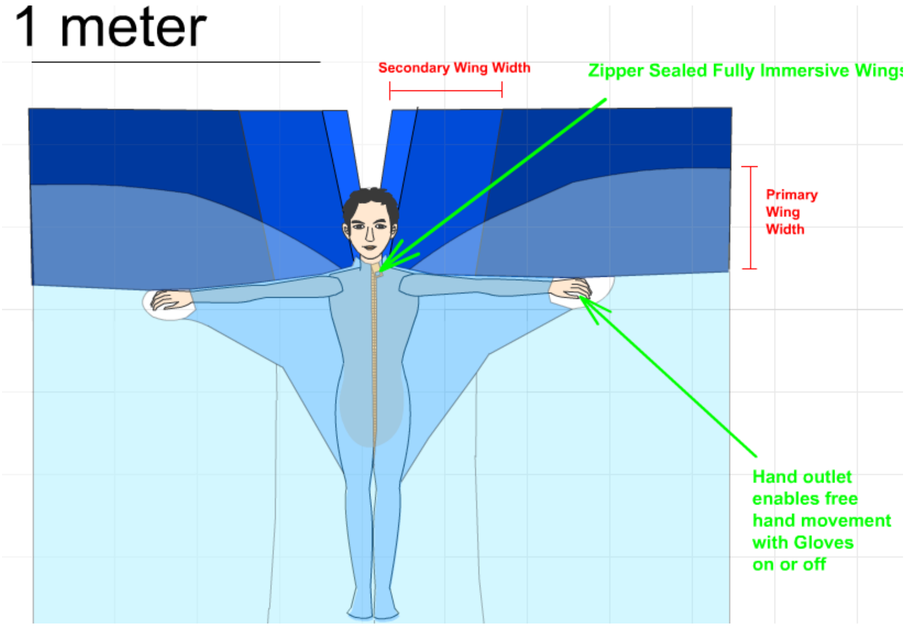

Figure 10.1: Design specification

With further development of battery technology in the near future for extremely lightweight design light weight wearable drone helmet can assert further power output for the user during flight if not eliminate human power all together.

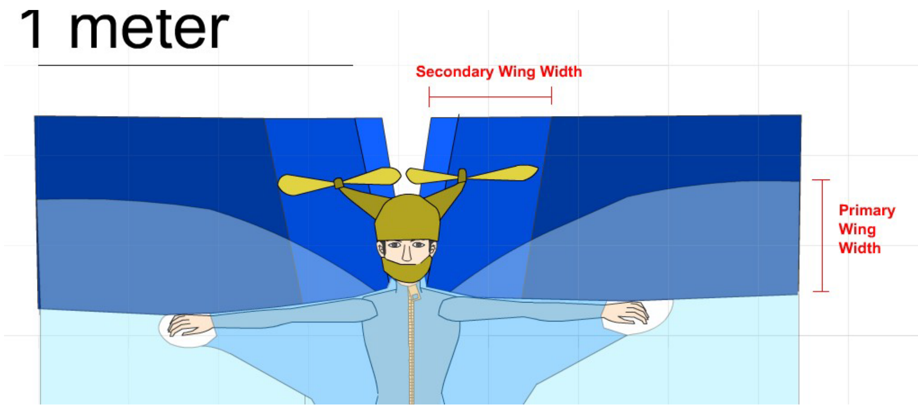

Figure 10.2: Machine aided design

Although many bird species uses their leg to assist their lift up, majority of the muscle power of birds are distributed in their wings. This is directly in contrast to human, which has a majority of the power stored in their leg and calf muscles. As a result, flapping of wings should also utilize human leg muscle power. Because human leg muscle does not directly provides up and down motion, a set of mechanical wedges and gearings are required to transform the power input. Fortunately, power efficiency using gearing for power transformation are very efficient. Bicycle, for examples, can achieve remarkable efficiency of 87-97% in Derailleurs type of gearing and 86-95% in Gear Hubs.[23] A circular motion based wheel with pedals attached to legs to enhance steadiness. The motion is transformed and delivered toward the upper edge of the movable wing, where the circular motion is faithfully copied from the leg locomotion. However, a two-staged movable arm is attached this wheel, which bends inward or stretch outward depend on its fixed position on the rotating wheel; therefore, generating a sinusoidal up and down wave-like up and down motion of wing flapping. [24][25]

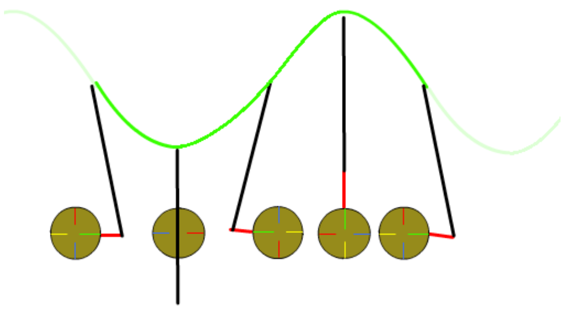

Figure 10.3: Circular movement into up and down motion

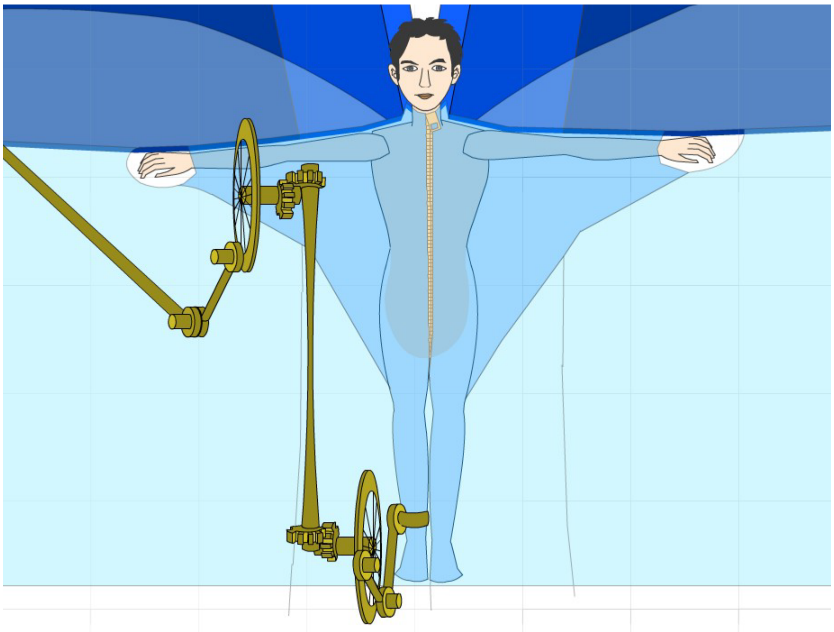

Figure 10.4: Leg powered design

Further research, however, are required to significantly reduce the weight increase posed by the the installation of gears and very light and strong synthetic materials will be required.

11 Horizontal Velocity Ranges and Horizontal Terminal Velocity

One of the important question regarding human-powered flight is the possible maximum speed achievable based on our current design. Compared to our earlier calculation, we computed the amount of power required to keep one afloat by flapping wings. Moreover, we are interested in the speed of horizontal movement. In order to calculate the maximum velocity we need to consider the exerted force, the Reynold number, and the drag within the human power output availability in persistent duration. From the table T5 (see end of the paper), one can find that as the horizontal speed increases, from 1 km per hour to 40 km per hour, the drag force increases and drag force on the mover increases as well. The amount of power required to move the mover in watts also increases as the speed increases. To derive power output, one has to consider both the force exerted and the total displacement made within 1 second. Assuming the acceleration required to achieve the constant velocity in 1 second time interval is maintained, the final displacement per second is just the acceleration in meters per second per second. Therefore, the final displacement is just:

$$d = at \tag{11.1}$$

$$d = a(1) \tag{11.2}$$

We know that the mover's body weight and helium gas has a total mass of 72 kg, so F=$m \cdot a$, and

$$P_{ower} = F \cdot d \tag{11.3}$$

$$P_{ower} = m \cdot a^2 \tag{11.4}$$

From the table, one can see that to achieve horizontal speed of 6 km/h, 200 watts of power is required, which is the power requirement for walking at 6 km/h on the ground, which is the speed to overcome some negligible air friction and ground friction. Final drag force, is the air friction generated proportional to one's current speed, as the current velocity rises, the drag force increases, and final velocity is the velocity generated by accelerating the mover mass upon given power output minus the air drag generated. One can see that the air drag force is much weaker than the ground friction. As a result, a mover, once airborne, is able to maintain a horizontal flying speed by just occasional generating horizontal acceleration using very low level of power output (much lower than walking!) One can also supply a continuous power output in horizontal movement using moderate power output such as 200 watts. After 4 seconds, a constant velocity of 2.568 m/s is achieved. No further velocity increase is possible at this level of power output because the drag force becomes greater than the force that moves the flier. The maximum velocity based on our wing design is at 2.8624 m/s, or **10.34 km/h**. One can achieve this speed in 1 second if one exerts 2,450 watts of power. Any greater velocity will generate greater drag that causes the final speed to slow down. The maximum speed is plotted in the following chart:

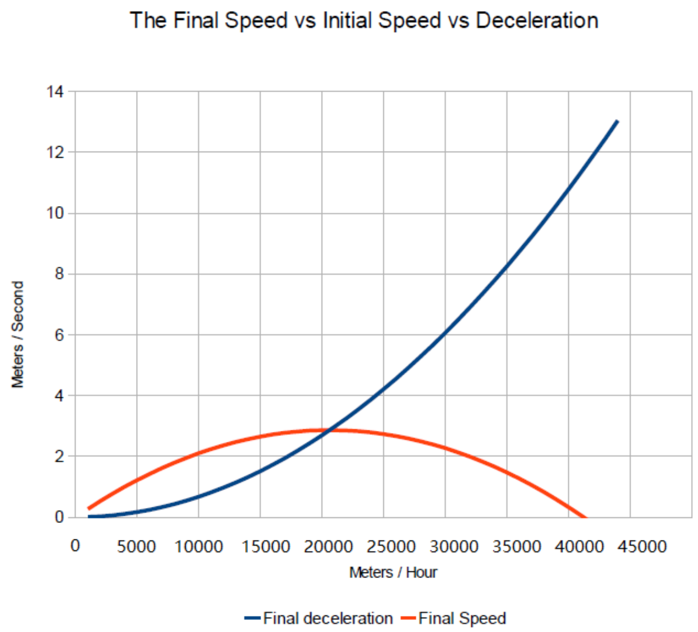

Figure 11.1: Final speed and terminal velocity

Besides generating constant power output by the user, the user can further achieves “free” power by utilizing gravity in short fall by closing the wings in to decrease vertical terminal velocity. On the other hand, one can also gain horizontal speed by following the wind patterns. The following map of United States and World indicates the average wind speed at 80 meters above the ground and their consistent flow direction. By following the wind flow, one could easily achieves the maximum horizontal speed of 10.34 km/h. Of course, one has significant difficulty reaching pre-determined destination in persistent windy zone if one against the wind flow. Based on the map below, the midwestern United States, the Patagonia of Argentina, north Europe, Scandinavia, Tibet, Machuria, and Kenya provides some of the best windy region for gliding activities. Further research will be conducted to help reducing the Reynold number of the crosssection of the wing, therefore, further increase the terminal horizontal velocity.

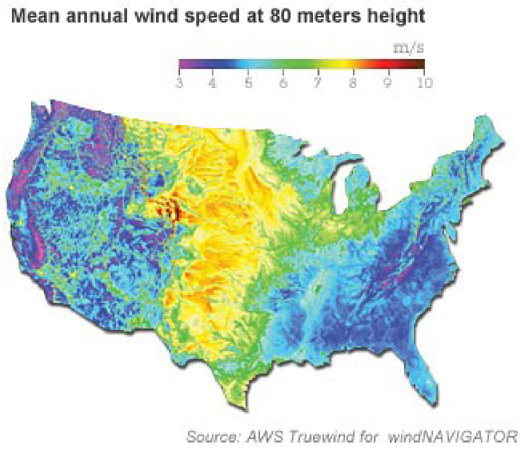

Figure 11.2: Wind map of United States

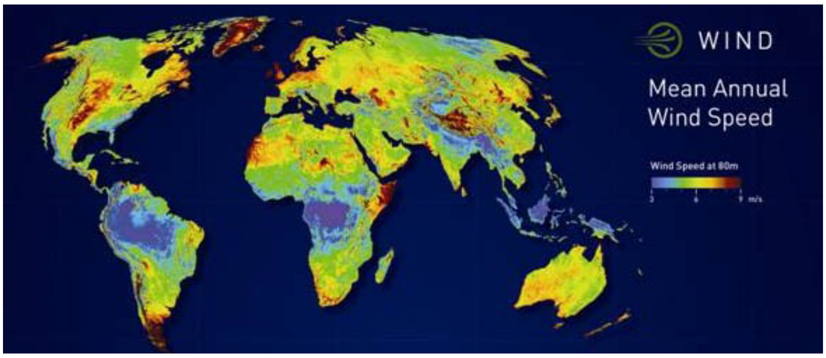

Figure 11.3: World wind map

12 Modified Version with Battery-Powered Variant

Currently, battery technology based on lithium still follows somewhat a exponential growth albeit at larger doubling period.[22] Nevertheless, drone-type helicopter with multiple blades systems are currently being tested in Germany.[21] It is predicted that in foreseeable future light weight battery weighting a few kilograms with provide the power to either directly drive the wings filled with helium with greater flapping frequency or attaching blades directly to human with safety and helium filled wings are used as an lifting force to reduce the power consumption and size of roller blades. The helium filled wings will still be essential for two reasons. First, helium helps to significantly reduce the number of rotating blades provided by electric driven battery. It provides a minimalist design approach as a solo flying apparatus. Second, Helium filled wings are essential as a component of engineering redundancy to provide the additional safety when the battery or blades system fails. It both reduces the speed of a fall as in system failure, and also acts as a cushion upon crash landing, essentially acting as the safety belt and air balloon upon automobile accident. Unlike 8~16 rotating blades design of the Germany manufacture, solo flight may require only 1~2 rotating blades with very little redundancy built into the system. On the other hand, however, the helium filled wings can certainly becomes smaller in size due to higher output power available. Depending on the level of safety and redundancy, solo flight with 1.5 meters × 1.5 meters helium filled wings are possible, essentially providing a more bird like wings size compare to human body size instead of current butterfly wing size compare to human body size. In order to provide flapping sturdiness, the wings can be compartmentalized into chambers filled with helium which are tightly bound into each other. Much of the nature provides existing examples of such approach such as the wings of cicada or dragonfly. We can also compartmentalize the wings based on branching factors similar tree leaves, where central stems branches into accessory branches, each chamber will then bounded by the edge of leaf, the leaf stem, and adjacent branches. Of course, the leaf chamber is further broken into microscopic chambers through recursive branches, for our design purpose, a limited branching factor is sufficient because the supporting casing material will provide sufficient strength to cover each compartmentalized volume.

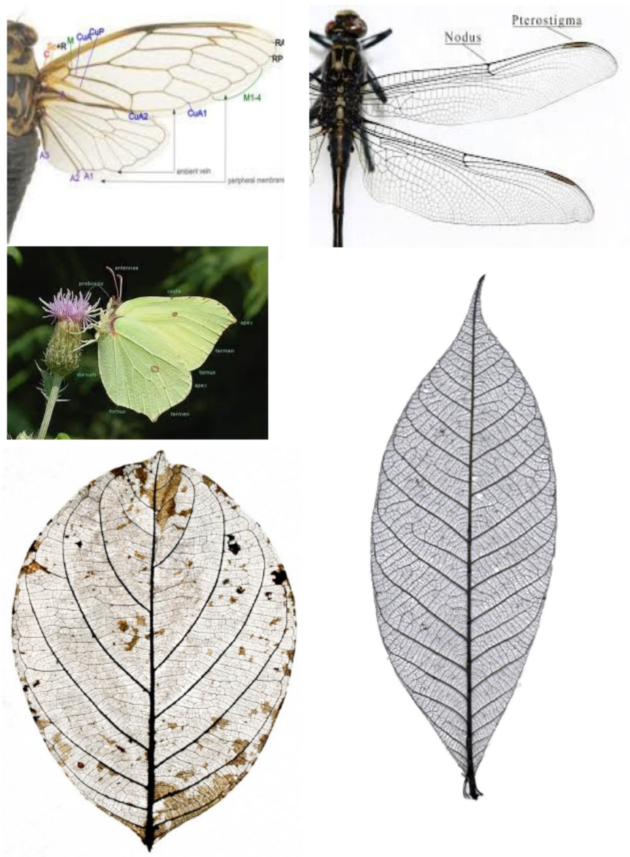

Figure 12.1: Segmented chambers increase redundancy

13 Social and Economic Impact

The advantages of human powered flights are mainly concerned in four areas. First of all, compare to bicycle, automobile, airplanes, it's the most lightweight transportation device. All other forms of transportation are heavier than air, but flying wings are actually lighter than air. Secondly, it does not require significant parking space. Automobiles and airplanes require large space for storage, but helium filled wings are minimal in space usage, because each wing can be independently attached and removed, they can be stacked vertically toward the sky. The horizontal volume occupation is very small if not much larger than a bicycle occupation. Furthermore, unused helium filled wings can be quickly restored in helium tank, which can compress helium at much higher density to avoid further space occupation. The deflated wing can then store at even smaller volumes. Thirdly, human powered flight adds a new dimension to human activities; finally human activities are no longer constrained to two dimensional landscape constrained humans for generations. Crowdriness is reduced by having people move at different altitudes across a three dimensional space. Fourthly, human powered flight takes less time to travel to any destination compare to the same speed achievable on land. One do not need to wait on traffic lights and crosses streets, taking corners of streets turning left and right. Even without traffic lights, sometimes terrains are marked by high and low points, as a result, even taking the shortest path on two dimensional terrain takes longer time than flights in three dimensional space.

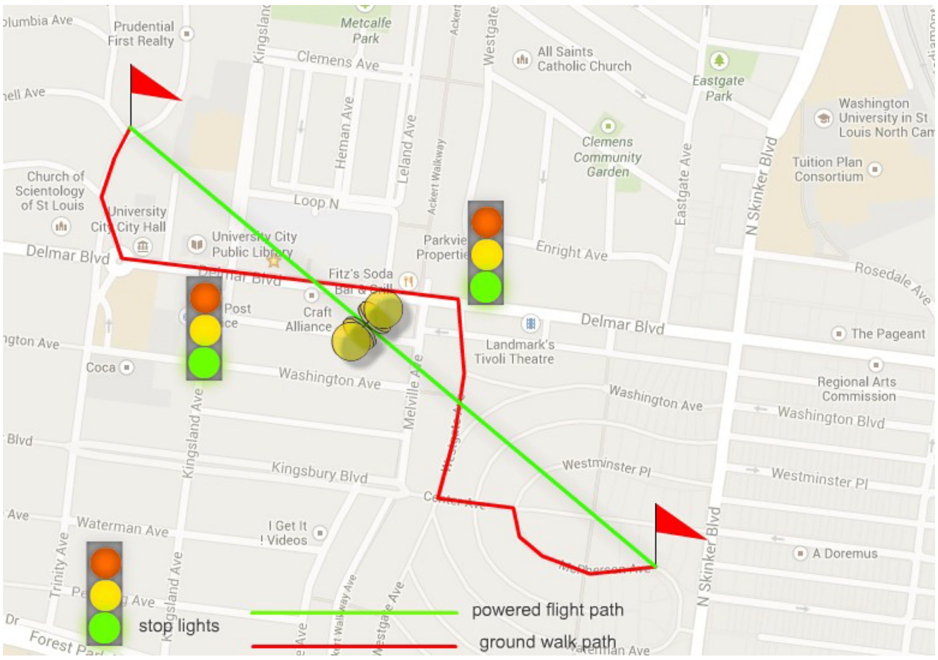

Figure 13.1: Fly path

Public infrastructure changes are surely to occur as the revolution of human powered flights set

in. First of all, since direct take off and landing on normal ground both interferes with pedestrians and poses dangers when one stuck on trees and especially electric power transformers, one should ideally took off from the top of each building and apartment. In order to facilitate take off, jumpy boards or even large spring stored with potential energy can dash user into the air. Further cushioning system can be used to aid emergency landing. New regulation will be set to mark each roof with landing instruction such as those recommended at airport runway. The recommended flying behavior shall include flying only from roof to roof only, no ground landing is recommended unless an emergency situation occurs. No landings on unauthorized property or moving vehicles such as cars and trains are allowed. Some houses have to revamp their roof to conform to new taking off and landing requirements. Each building, especially higher apartment requires larger landing area, to ensure a given number of people can take off and lands at the same time. During the night, lights should lights up the outer edges of contours of roof so one can more appropriately land. Further traffic control at given landing site may be required or certain new types of human courtesy for signaling needs to be developed.
Helium is non-renewable resource, a by-product of natural gas processing, though new method of helium synthesis is well underway, one should not overlook the preciousness of the resource. Since market price of helium ranges from $30 to $50 per 1,000 liters, a human powered flight would be too expensive for normal consumer as daily expenses, as a result, helium recycling and renting should be the central business model of human powered flight. One can look directly at our current gas station model for gas refilling. Unlike petroleum, helium, if properly sealed, will stored for long time and are not exhausted in each trip as petroleum is burned in internal engine to generate work power. Helium refurbishment, storage, and maintenance can and should be practiced as a business under current gas station paradigm, without significant change in infrastructure, or creating new simple storage facility at every apartment facility much like electricity meter room and natural gas pipes. If helium renting is subject to minimal leakage, majority of the helium in circulation can be re-harvested and the price of renting can be significantly reduced to be comparable to internet and mobile phone billing.

14 Safety

For safety concerns, the foremost concern by anyone is the flying heights. Since one takes off from roof and lands on roof, it is likely that the minimum flying height is above 5 to 7 meters, above two stories building height, the maximum limit depends on the wing material durability, but potential upper limit should be in hundreds of meters, though further research are required, However, in order to avoid interference with aviation landing of airplanes and helicopters, no flight higher than 300 meters or more should be recommended to city dwellers and essentially no flying zones around the vicinity of airport. Further breakdown of flying altitude are presented in the graph below:

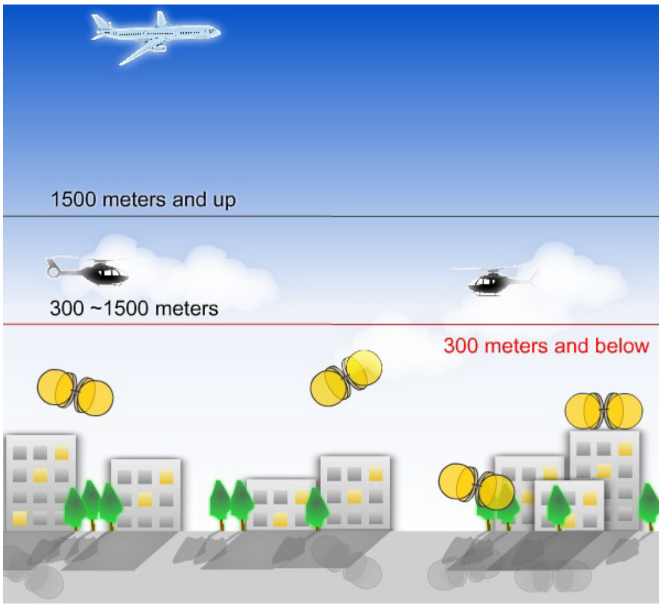

Figure 14.1: Altitude regulation

Helium poisoning are another possible concern regarding to health, yet numerous demonstration of immersion circumstances does not show any adverse effect of helium on humans, much like nitrogen gas in the atmosphere since they are inert. It does certainly change the pitch of one's voice, further evidence can be obtained from a video titled "Talking and singing inside a giant helium balloon". [1]

Safety Belts that bind the wings firmly into the solo flyer is one of the critical and essential feature of the wing design. One must look into belt which is both light weight and resistible to friction. One will not lose a wing or two upon wind or physical maneuver. Further investigation and research data will be gathered and consultation with automobile and aviation industry regarding safety belt technology and design will be conducted.

Flying at night is also a concern worth to mention. It seems that the wings should be equipped with light reflecting material or possibly even light emitting material so its presence in the air can be quickly detected by both people on the ground, others flying along, or other fast flying craft to avoid collision, miniaturized computer to probe nearby fliers will also be helpful, however, not all flier could possibly open their signal broadcast system.

Fatality and accident rates are probably the best indicator of the level of safety inherent in a form of activity, sport, or transportation. We will compute the likelihood of fatality rate per 1,000 users of our human powered flying apparatus based on our speed of flying, speed of descent, likelihood of obstacles encountering, and density of traffic flow. The chart is tabulated below: [5] [14][12]

[1]https://www.youtube.com/watch?v=UyQLCC7lrTc

Extreme Sport Name	Fatality out of 1000	Death per number of people
Skydiving	0.01	100,000
Base Jumping	0.75	1333
Hang Gliding/Paragliding	3.8	263
Summiting K2	104	9.615
ATV Riding	0.5	2,000
Scuba Diving	0.06	16,667
Snowboarding	0.05	20,000
Wingsuit flying	0.1	10,000

Table 14.1: Fatality statistics by sport

And a list of common transportation stats:[13]

Transportation type	Total Fatality	Total passengers	Death per number of people
Railroad	447	31,200,000	69,799
Bicycle	677	57,000,000	84,195
Walking	4,432	250,000,000	56,407
Bus	54	100,000,000	1,851,852
Motorcycle	4,612	6,678,958	1,448
Passenger car	11,981	150,000,000	12,520
Aviation	444	150,000,000	337,838
Recreational boating	758	250,000,000	32,982

Table 14.2: Fatality statistics by transportation type

The closest types of sport recreation in terms of similarity are skydiving and wingsuit flying, both activities taking place in the air. However, skydiving occurs at a high altitude and wingsuit flying occurs at high speed, neither of which accurately reflects the fatality rates of human powered flight. One of the best guesstimate can be done by using the speed of human powered flight comparing to wingsuit flying. On average, human powered flight sustains 5 km/h, while wingsuit on average flies at 160 km/h [6]. As a result, $\frac{160}{5} = 32$. If human reaction time remains biologically constant yet speed increases linearly, we can use the statistics derived from the injury rates vs. speed of vehicle from the department of transportation.[15] One can quickly deduce that at speed of 160 km/h has at least 35 times higher relative rate compare to at 55 km/h, more likely 225 times higher of the relative rate, we can take an average of the two values, at 130.

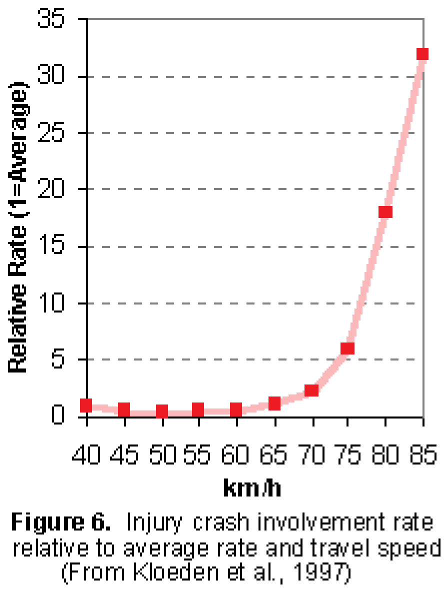

Figure 14.2: Injury crash involvement rate vs travel speed

Furthermore, we know that passengers in car in more protected compare to pedestrians when accidents occur. Our helium filled wings provides some safety cushion against accident so that fatality rates falls more likely between pedestrians and vehicle passengers. Pedestrians accident curve vs speed is provided below:[16]

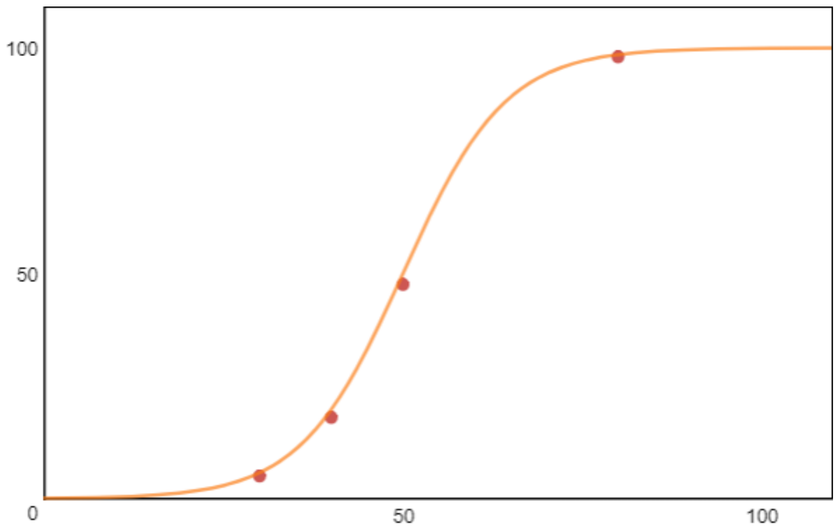

Figure 14.3: PDF of pedestrian fatal injury vs crash speed

A pedestrians hit by vehicle less than 10 km/h on average has fatality rate of less than 1%, yet hit by vehicle over 80 km/h has a fatality rate of 100%, as a result, the difference is a matter of 100 times. As a result, the fatality rate over 160 km/h is also well over 100%. Since wingsuit flying fatality ranges from 1 per 10,000 on the upper bound and 1 per 750[17] on the lower bound and injury rate of 1 per 254.[14], the human powered flying is likely to be at 1 per 1,000,000 on the upper bound and 1 per 75,000 on the lower bound, and injury rate of 1 per 25,400. The upper bound shows a fatality rate somewhat lower and safer than bicycle riding and half as safe as bus riding. The lower bound shows that a fatality rate similar to train riding and higher than pedestrian walking and twice as safe as commercial aviation and boating. Even if we take the worst case scenario of injury rate of 1 per 25,400 as our fatality rate, we are still twice as safe as passenger car driving. Though further research and data will be gathered as the product enters mainstream, human powered flight should be as safe as ground walking in busy cities if not safer.

15 Further Research

Further studies on this research eventually will focus on the following area: Beyond human powered flight, highly developed storage device with high energy density can replace human powered approach with electric powered flapping wings with higher frequencies. However, helium wings are still required as a safety measures. Low altitudes crash is not recoverable in reaction time parachute deployment. Ideally, electric powered flapping wings can power human much the same way as lightweight motorcycle or electric bicycle, providing comparable speed to fast bicycle and car driving within city, furthering increasing the utility and usefulness of human flight as an economical and practical approach to human mobility. A further investigation into Helium isotope Helium-2 is required which holds only two protons in its nucleus and no neutrons. Such atom further reduces the weight of helium and creates higher lift force on the wings. Helium-3 can also be considered, which have been documented with abundance on the moon. However, this approach requires further investigation into physics. Though our initial model will use the cheapest of the lightest metals aluminum to increase the structural integrity of the wings, eventually such design will give away to even lighter metal frame such as lithium, with atomic number 3 just barely heavier than helium itself. Finally, we may investigate further on ways to seal helium without causing leakage in greater duration than currently existed membranes.[1] Graphene has been shown to be an ideal candidate which can store helium up to months without leakage and self-repair upon leakage, yet such material are still expensive, produced in limited quantity, and economically impractical.[18]

16 Conclusion

Human powered flight combining with various design techniques and basic physical principles are definitely possible and desirable. Certainly, its success will depend on many aspects our-rethinking about our current choices in physical locomotion and recycling of existing resource helium which is rarely used today in civilian commercial market in significant proportion. Nevertheless, its adoption and commercialization will provide us with unprecedented degrees of freedom and new possibilities.

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18 Appendix - Addendum Data Tables:

T1:

Flier weight (N)	**Ratio of unlifted weight**	**Helium weight (N)**	**Total weight (N)**	**Wing surface area (m^2)**
608.22	0.01	98.3082122449	706.5282122449	0.882470835
608.22	0.02	97.3152	705.5352	1.7624610773
608.22	0.03	96.3221877551	704.5421877551	2.639970727
608.22	0.04	95.3291755102	703.5491755102	3.514999784
608.22	0.05	94.3361632653	702.5561632653	4.3875482483
608.22	0.06	93.3431510204	701.5631510204	5.2576161201
608.22	0.07	92.3501387755	700.5701387755	6.1252033991
608.22	0.08	91.3571265306	699.5771265306	6.9903100856
608.22	0.09	90.3641142857	698.5841142857	7.8529361793
608.22	0.1	89.3711020408	697.5911020408	8.7130816804
608.22	0.11	88.3780897959	696.5980897959	9.5707465889
608.22	0.12	87.385077551	695.605077551	10.4259309047

608.22	0.13	86.3920653061	694.6120653061	11.2786346279
608.22	0.14	85.3990530612	693.6190530612	12.1288577584
608.22	0.15	84.4060408163	692.6260408163	12.9766002963
608.22	0.16	83.4130285714	691.6330285714	13.8218622416
608.22	0.17	82.4200163265	690.6400163265	14.6646435941
608.22	0.18	81.4270040816	689.6470040816	15.5049443541
608.22	0.19	80.4339918367	688.6539918367	16.3427645213
608.22	0.2	79.4409795918	687.6609795918	17.178104096
608.22	0.21	78.4479673469	686.6679673469	18.010963078
608.22	0.22	77.454955102	685.674955102	18.8413414673
608.22	0.23	76.4619428571	684.6819428571	19.669239264
608.22	0.24	75.4689306122	683.6889306122	20.494656468
608.22	0.25	74.4759183673	682.6959183673	21.3175930794
608.22	0.26	73.4829061224	681.7029061224	22.1380490981
608.22	0.27	72.4898938776	680.7098938776	22.9560245242
608.22	0.28	71.4968816327	679.7168816327	23.7715193576
608.22	0.29	70.5038693878	678.7238693878	24.5845335984
608.22	0.3	69.5108571429	677.7308571429	25.3950672466
608.22	0.31	68.517844898	676.737844898	26.2031203021
608.22	0.32	67.5248326531	675.7448326531	27.0086927649
608.22	0.33	66.5318204082	674.7518204082	27.8117846351
608.22	0.34	65.5388081633	673.7588081633	28.6123959126
608.22	0.35	64.5457959184	672.7657959184	29.4105265975
608.22	0.37	63.5527836735	671.7727836735	30.2061766898
608.22	0.38	61.5667591837	669.7867591837	31.7900350963

T2:

$\frac{1}{2}$ **wingspan (m)**	**4 helium wings & 0.5m thick**	**Butterfly predict**	**Butterfly real Wingspan at 1 Hz**
0.9393991883	5.8104241926	1.334373847	1.3046330644
1.3275771455	5.7769401589	1.8857629908	1.8437327402
1.6247986727	5.7433443653	2.3079526601	2.2565125645

1.8748332683	5.7096348387	2.6631154379	2.6037594055
2.0946475237	5.675809553	2.9753515961	2.9090363837
2.2929492188	5.6418664259	3.2570301404	3.1844368221
2.4749148266	5.6078033176	3.5155040151	3.4371497811
2.6439194552	5.5736180284	3.7555674079	3.6718625945
2.8023090799	5.5393082962	3.9805526703	3.8918333418
2.9517929603	5.5048717941	4.1928877277	4.0994358343
3.0936623263	5.4703061281	4.3944067134	4.2964633259
3.2289210125	5.435608834	4.5865355291	4.4843099373
3.3583678518	5.4007773749	4.7704088804	4.6640850837
3.4826509671	5.3658091381	4.9469473964	4.8366888752
3.6023048589	5.3307014318	5.1169103109	5.0028636233
3.7177765185	5.2954514822	5.2809325547	5.1632301076
3.8294442931	5.2600564294	5.4395515527	5.3183137747
3.9376318205	5.2245133245	5.5932270178	5.4685640912
4.0426185229	5.1888191248	5.7423558563	5.6143691173
4.1446476444	5.1529706907	5.8872835858	5.7560666695
4.2439325016	5.1169647803	6.0283132125	5.8939530006
4.340661409	5.0807980459	6.1657122286	6.0282896409
4.4350016081	5.0444670283	6.2997181933	6.1593088547
4.5271024362	5.0079681521	6.4305432333	6.2872180408
4.6170979066	4.97129772	6.5583777083	6.4122033163
4.7051088296	4.9344519072	6.6833932238	6.5344324618
4.7912445694	4.8974267554	6.805745127	6.6540573621
4.875604512	4.8602181659	6.9255745909	6.7712160437
4.9582792981	4.8228218931	7.0430103667	6.8860343882
5.0393518677	4.7852335366	7.1581702666	6.998627582
5.1188983485	4.7474485341	7.2711624268	7.109101351
5.1969888171	4.7094621522	7.3820863879	7.2175530174
5.2736879539	4.6712694783	7.4910340254	7.3240724089
5.3490556094	4.6328654103	7.5980903543	7.4287426455
5.4231472963	4.5942446471	7.7033342277	7.5316408232
5.4960146188	4.5554016772	7.8068389471	7.6328386093
5.6382652559	4.4770259498	8.0088995113	7.8303956085

T3:

Butterfly real Wingspan at 1.7 Hz	Wing thick based on wingspan on terminal v	Adjusted wing	Final Terminal Velocity
0.9834041736	19.128694094	5.8104241926	0.5716067487
1.3897658438	9.4677374809	5.7769401589	0.8124879056
1.7009103434	6.2474186098	5.7433443653	1.0002065752
1.9626574983	4.6372591743	5.7096348387	1.7558094811
2.1927686787	3.671163513	5.675809553	1.3047825639
2.4003595699	3.0270997388	5.6418664259	1.4369003262
2.59084913	2.5670541858	5.6078033176	1.5603516722
2.7677705699	2.222020021	5.5736180284	1.6771272862
2.9335797594	1.9536601151	5.5393082962	1.7886093781
3.090066026	1.7389721904	5.5048717941	1.8958051131
3.2385810858	1.5633184338	5.4703061281	1.9994764081
3.3801757967	1.4169403033	5.435608834	2.1002173018
3.5156864121	1.2930818851	5.4007773749	2.198502657
3.6457914151	1.1869175268	5.3658091381	2.2947201922
3.7710503445	1.0949084162	5.3307014318	2.3891923288
3.8919311302	1.0144004444	5.2954514822	2.4821915525
4.0088298427	0.9433639987	5.2600564294	2.5739515005
4.1220852801	0.8802204914	5.2245133245	2.6646751469
4.2319899538	0.8237236691	5.1888191248	2.7545409683
4.3387985025	0.7728765291	5.1529706907	2.8437076697
4.4427342352	0.7268719738	5.1169647803	2.9323178677
4.5439942878	0.6850496508	5.0807980459	3.0205010014
4.6427537361	0.6468640515	5.0444670283	3.1083756659
4.7391689128	0.6118605855	5.0079681521	3.1960515069
4.833380109	0.5796573968	4.97129772	3.2836307772
4.925513794	0.5499313764	4.9344519072	3.371209632
5.0156844554	0.5224072835	4.8974267554	3.4588792182
5.1039961344	0.4968491972	4.875604512	3.5355339059
5.190543718	0.4730537376	4.9582792981	3.535533906
5.2754140311	0.4508446419	5.0393518677	3.5355339059

5.3586867677	0.4300683912	5.1188983485	3.5355339059
5.4404352871	0.4105906561	5.1969888171	3.5355339059
5.5207272995	0.3922933897	5.2736879539	3.5355339059
5.599625459	0.3750724332	5.3490556094	3.5355339059
5.6771878787	0.3588355313	5.4231472963	3.5355339059
5.7534685801	0.3435006796	5.4960146188	3.5355339059
5.9023827712	0.3152522684	5.6382652559	3.535533906

Terminal V (m/s)	cycle	freq	kg	adjusted wing	joules	Power (W)	ratio	horsepower	average (hr)	athlete(hr)
0.5716067487	0.68309	1.463927	72.02	5.8104241926	467519002.153	68.4413611	0.01	0.091744452	16	N/A
0.8124879056	0.8144	1.22789	71.92	5.7769401589	928343006.948	113.990343	0.02	0.152802069	8	N/A
1.0002065752	0.9036	1.106683	71.82	5.7433443653	1382467832.76	152.995348	0.03	0.205087598	4.5	N/A
1.1609387947	0.9735	1.02722	71.72	5.7096348387	1829888817.27	187.969803	0.04	0.251970245	1.75	N/A
1.3047825639	1.03205	0.968945	71.62	5.675809553	2270600800.71	220.008651	0.05	0.294917763	0.75	16
1.4369003262	1.08304	0.923325	71.52	5.6418664259	2704598107.79	249.722378	0.06	0.334748496	0.2	8
1.5603516722	1.12861	0.886047	71.41	5.6078033176	3131874529.32	277.498828	0.07	0.371982344	0.1	1
1.6771272862	1.17008	0.854644	71.31	5.5736180284	3552423302.7	303.605575	0.08	0.406977983	0.05	0.25
1.7886093781	1.20834	0.827581	71.21	5.5393082962	3966237091.43	328.23808	0.09	0.439997427	0.025	0.125
1.8958051131	1.24402	0.803843	71.11	5.5048717941	4373307963.69	351.545271	0.1	0.47124031	0.0125	0.0625
1.9994764081	1.27759	0.782726	71.01	5.4703061281	4773627370.15	373.644348	0.11	0.500863737	0.00625	0.03125
2.1002173018	1.30938	0.763723	70.91	5.435608834	5167186120.07	394.629942	0.12	0.52899456	0.003125	0.015625
2.198502657	1.33966	0.746457	70.81	5.4007773749	5553974356.9	414.580067	0.13	0.555737355	0.0015625	0.0078125
2.2947201922	1.36866	0.73064	70.71	5.3658091381	5933981532.23	433.560158	0.14	0.581179837	0.00078125	0.00390625
2.3891923288	1.39655	0.716049	70.6	5.3307014318	6307196378.33	451.625902	0.15	0.605396651	0.000390625	0.00195313
2.4821915525	1.42347	0.702507	70.5	5.2954514822	6673606879.89	468.825276	0.16	0.628452113	0.000195313	0.00097656
2.5739515005	1.44955	0.689871	70.4	5.2600564294	7033200243.21	485.200061	**0.17**	0.650402227	9.76563E-005	0.00048828
2.6646751469	1.47487	0.678025	70.3	5.2245133245	7385962865.28	500.786979	0.18	0.671296219	4.88281E-005	0.00024414
2.7545409683	1.49953	0.666873	70.2	5.1888191248	7731880299.19	515.618568	0.19	0.691177705	2.44141E-005	0.00012207
2.8437076697	1.52361	0.656335	70.1	5.1529706907	8070937220.16	529.723865	0.2	0.710085609	0.000012207	6.1035E-005
2.9323178677	1.54717	0.646342	70	5.1169647803	8403117386.82	543.128949	0.21	0.728054891	6.10352E-006	3.0518E-005
3.0205010014	1.57026	0.636837	69.9	5.0807980459	8728403603.5	555.857375	0.22	0.745117125	3.05176E-006	1.5259E-005
3.1083756659	1.59294	0.627771	69.79	5.0444670283	9046777677.49	567.930525	0.23	0.761300972	1.52588E-006	7.6294E-006
3.1960515069	1.61525	0.619101	69.69	5.0079681521	9358220375.81	579.367898	0.24	0.776632571	7.62939E-007	3.8147E-006
3.2836307772	1.63723	0.610789	69.59	4.97129772	9662711378.36	590.187345	0.25	0.791135851	3.81470E-007	1.9073E-006
3.371209632	1.65892	0.602803	69.49	4.9344519072	9960229229.18	600.405274	0.26	0.804832807	1.90735E-007	9.5367E-007
3.4588792182	1.68035	0.595114	69.39	4.8974267554	10250751284.6	610.036811	0.27	0.817743715	9.53674E-008	4.7684E-007
3.5355339059	1.69887	0.588627	69.29	4.875604512	10567602710.3	622.038147	0.28	0.833831296	4.76837E-008	2.3842E-007

Figure 18.1: T4

Speed (m/hr)	Acceleration (m/sec2)	Force (N)	Watt	Final drag (N)	Final deceleration	Final Speed
1000	0.2777777778	20	5.55555556	0.4851793981	0.0067367314	0.271041046
2000	0.5555555556	40	22.2222222	1.9407175926	0.0269469258	0.52860863
3000	0.8333333333	60	50	4.3666145833	0.0606305829	0.77270275
4000	1.1111111111	80	88.8888889	7.7628703704	0.107787703	1.003323408
5000	1.3888888889	100	138.888889	12.1294849537	0.1684182859	1.220470603
6000	1.6666666667	120	200	17.4664583333	0.2425223318	1.424144335
7000	1.9444444444	140	272.222222	23.7737905093	0.3300998405	1.614344604
8000	2.2222222222	160	355.555556	31.0514814815	0.431150812	1.79107141
9000	2.5	180	450	39.29953125	0.5456752465	1.954324754
10000	2.7777777778	200	555.555556	48.5179398148	0.6736731438	2.104104634
11000	3.0555555556	220	672.222222	58.7067071759	0.815144504	2.240411052
12000	3.3333333333	240	800	69.8658333333	0.970089327	2.363244006
13000	3.6111111111	260	938.888889	81.995318287	1.138507613	2.472603498
14000	3.8888888889	280	1088.88889	95.095162037	1.3203993618	2.568489527
15000	4.1666666667	300	1250	109.1653645833	1.5157645735	2.650902093
16000	4.4444444444	320	1422.22222	124.2059259259	1.7246032481	2.719841196
17000	4.7222222222	340	1605.55556	140.2168460648	1.9469153855	2.775306837
18000	5	360	1800	157.198125	2.1827009858	2.817299014
19000	5.2777777778	380	2005.55556	175.1497627315	2.431960049	2.845817729
20000	5.5555555556	400	2222.22222	194.0717592593	2.6946925751	2.86086298
21000	**5.8333333333**	420	2450	**213.9641145833**	**2.9708985641**	**2.862434769**
22000	6.1111111111	440	2688.88889	234.8268287037	3.2605780159	2.850533095
23000	6.3888888889	460	2938.88889	256.6599016204	3.5637309306	2.825157958
24000	6.6666666667	480	3200	279.4633333333	3.8803573082	2.786309359
25000	6.9444444444	500	3472.22222	303.2371238426	4.2104571486	2.733987296
26000	7.2222222222	520	3755.55556	327.9812731481	4.5540304519	2.66819177
27000	7.5	540	4050	353.69578125	4.9110772181	2.588922782
28000	7.7777777778	560	4355.55556	380.3806481481	5.2815974472	2.496180331
29000	8.0555555556	580	4672.22222	408.0358738426	5.6655911392	2.389964416
30000	8.3333333333	600	5000	436.6614583333	6.063058294	2.270275039
31000	8.6111111111	620	5338.88889	466.2574016204	6.4739989117	2.137112199
32000	8.8888888889	640	5688.88889	496.8237037037	6.8984129923	1.990475897
33000	9.1666666667	660	6050	528.3603645833	7.3363005357	1.830366131
34000	9.4444444444	680	6422.22222	560.8673842593	7.7876615421	1.656782902
35000	9.7222222222	700	6805.55556	594.3447627315	8.2524960113	1.469726211
36000	10	720	7200	628.7925	8.7308039433	1.269196057
37000	10.2777777778	740	7605.55556	664.2105960648	9.2225853383	1.055192439
38000	10.5555555556	760	8022.22222	700.5990509259	9.7278401961	0.827715359

Figure 18.2: T5