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The Best Strategy in Rain

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ABSTRACT

The aim of this paper is to consider the best strategy of motion, in the rain. In this paper, not only we considered the motion of object with standing vertically on the ground, but also we measured the motion of object, with angle too. Here we will show, whether the optimal speed-angle exists in any angle or in any speed, or not. If it is exists, then we can find the optimal speed or the optimal angle. We also find out the crucial factor for the optimal speed. A very clear solution of this problem is the result of using six variables in rectangle and ellipsoidal model. Moreover, here an interesting result, in comparison between motion of object in the same time and same distance, will appear. The motion of object considered in two and three dimensional coordinate system for rectangle and ellipsoid models. The discussed model also is applicable for other fields.

Key words: Rain, Optimal speed, Run, Walk. Rectangular, Ellipse
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INTRODUCTION

Till now there have been many articles about this problem. They approached by various methods to solve this problem. But some methods that previous authors used are difficult to understand and between those articles there were disagreements. Let us look at those papers. A long time ago some authors considered that it rains vertically and another author considered the angle and the speed of the rain. Their conclusion is that when it rains from behind, the best strategy is to move as the same speed of the rain. And other scientists ran in the rain and measured the amount of rain on their clothes. And they said that if they run, they will get less wet, approximately 40%, than if they walked, claiming that the best strategy is running. An author (Bailey, 2002) took into consideration that the rain falls from the side by using rectangular parallelepiped model and he said that the optimal speed has relevance to the body size. The fatty body should move as fast as possible and the slim body should move as the horizontal speed. Lately an author (Ehrmann & Blachowicz, 2011) took into consideration the cylinder body, and said that the top speed of running is not the best option. And another author (Hailman & Torrents, 2009) used the ellipse body, saying that the optimal speed of the ellipse body is not the horizontal speed of the rain like the rectangle model. Those authors used the models that move standing vertically to the ground, and the latest author (Bocci, 2012) used the slanted plane and vertical cylinder model. He said that the optimal speed can exist when it rains from ahead. The size of the raindrop can influence the optimal speed. And in the minimum value the optimal speed is the same irrespective to the body type. But the dispute about this problem has not ended yet. The conclusions above still have controversial things even though most of them are correct. The reason why this argument still goes on, I think it is because up to now there has not been the definite equation that will explain all the conclusions at the same time. Till now the focus of the dispute is “should we run or walk in the rain” and wanted to find the formula that would explain the relative value. But now we need the equation that can be applied not only “in the rain” but that can be applied in another field too. The target of this article is not only to find the equation that will show the solution “should we walk or run in the rain”, but also find the exact amount of the rain or the amount of the particle in another field. If we find the equation, I am carefully sure that there would be no longer in existence of the debate of this problem. At least we can reach the final conclusion of this problem. And by analysing those equations, we can check the new information that the previous authors didn’t find. We will use two kinds of models: rectangle and ellipse (this article will show the equation of the cylinder model too). And we will compare the two-dimensional models and three-dimensional models (when it rains from the side). Some authors have a doubt that, how it would be if we move in the same time instead of in the same distance? If the best strategy would be the same that of, when we have move in the same time?

Here we consider two cases, when the object is moves; its angle will change, so we can check the optimal speed in any angle. This paper will present some methods to find the equation but all of them are made by the same line. We will use the new method that is clear and simpler.

TERMS AND ASSUMPTIONS

Before resolving the questions, let us define some terms and make assumptions.

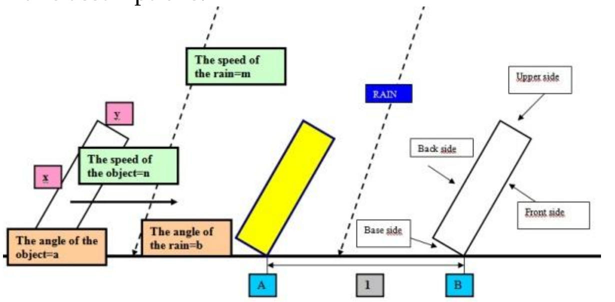


Figure.1 Terms

Here we supposed, Qd is the relative amount of rain that will hit the object when it moves in the unit of distance. Qt1 is relative amount of rain that will hit the object when it moves in the unit time. Qt2 is defined as the relative amount of rain that will hit the object when it moves in the time $(1/m)$. Qt2 is for comparing to the value of Qd. Also x, is the height of the object, y is the width of the object, a is the angle of the object to the ground (+, to the direction of the movement of the object) b is defined as angle of the rain to the ground (+, to the direction of the movement of the object) n is the speed of the object and m is the speed of the rain. This is important to mention that the terms, cross wind, head wind and tail wind, will not be used. If we use these terms, then it makes the problem more complicate. The movement of some object will not be affected by the wind. Also assumed, that the speed of the rain and the speed of the object cannot be zero at the same time, because at least one of them should move to make a problem.

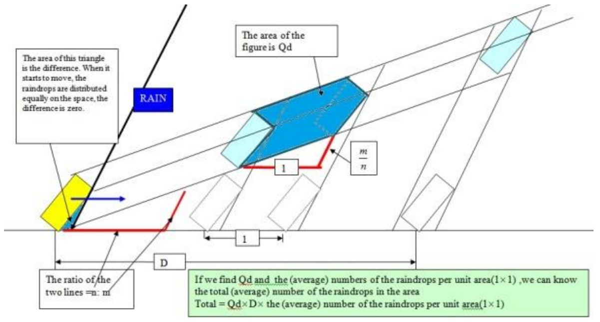


Figure.2 Assumption and the main idea.

We do not need to suppose that the rain is regularly in the space, but we have to suppose that the direction of the raindrops is the same and they are enough to be distributed equally in the space.

RELATIVE AMOUNT OF RAIN

We consider the rain region (the raindrops in the region which hit the object) as Q. We will find the area of the rain region when it moves in straight and in unit distance AB. only consider the value Q here. By knowing Q and some other values such as, average number of the raindrops in unit area and volume of the raindrop, the distance or the time of motion and so on, we are able to calculate the total raindrops or the total amount of the rain that will wet the object. The total (average) amount of rain, which will wet the object, is supposed be as Qd multiplied with distance and number of the rain in unit area multiplied by the volume of each raindrop. On some occasions, the result can be very different according to how we think about it. In an extreme case, when it rains directly from behind ($b = 180$).

Case 1: The existence of the object influences the rain before the object starts to move, that is the raindrops are not enough to be distributed equally in the space when it starts to move. There are no raindrops in front of it, so when it moves faster than rain, it will not get wet.

Case 2: The existence of the object does not influence the rain before the object starts to move, that is the raindrops are enough to be distributed equally in the space when it starts to move. There are raindrops in front of it, so when it moves faster than the rain, then it will get wet.

The difference of these two cases (influence or not) are big, if rains from behind but the object moves fast enough to get wet the front side of the object. But the other case (the angle of the rain is not big or the object moves slowly compare to the rain), even if the existence of the object affects the rain before it starts to move, the difference is zero or the difference is very small enough to ignore it, especially it moves enough distance. But to make it clear, we should suppose that the existence of the object before it starts to move does not affect the rain. In other words the raindrops are enough to be distributed equally on the space when it starts to move. In the Fig (2), the two parallel lines in the sky are made by the ratio of the speed of the rain and the object. When the object moves the distance 1, the ratio will be $1:(m/n)$. This ratio is very important in this article. Because by using this ratio, we will solve the problem.

THE DIRECTION OF RAIN AND THE WETTING PARTS OF THE OBJECT

First let us think that it rains from ahead. The location of the object in the sky is determined by the ratio of the speed of the rain and the object. When the object moves slowly compared with the rain, for example the speed of the object is 120m/s and the speed of the rain is 13.451×10^{21} m/s, and then (m/n) will be nearly infinite and it will get wet infinitely. On the contrary to this, the object moves very fast compared with the rain, for example the speed of the object is 0.00000342 m/s and the speed of the rain is 485.2123×10^{-23} m/s, therefore (m/n) will be nearly zero and only the raindrops that are in front of the object will wet the object.

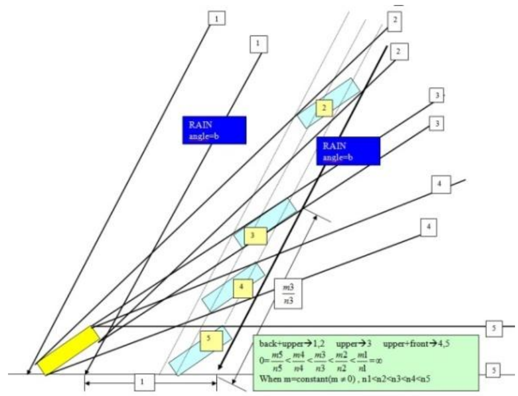


Figure.3 When it rains from ahead

Assume the speed of the rain is constant (m $\neq$ 0), as the speed of the object increases, the (m/n) will be gradually smaller. And the wetting part of the object will change depending on its speed. As the speed of the object increases, the wetting part will change like follows:

1. The object moves leaning forward his body:
(back +upper) →(upper)→upper+front

2. The object moves laying back his body:
(upper+front)→(front)→front+base

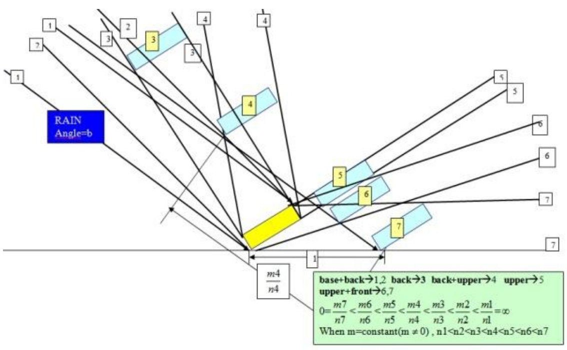


Figure.4 When it rains from behind

When it rains from behind, we can consider it as the same way when it rains from ahead. But the changing of the wetting parts is a little more complicated. As the speed of the object increases, the wetting part will change as follows:

1. The object moves leaning forward his body:
(base+back)→(back)→back+upper→upper→upper+front

2. The object moves laying back his body:
(back+upper)→(upper)→upper+front→front→front+base

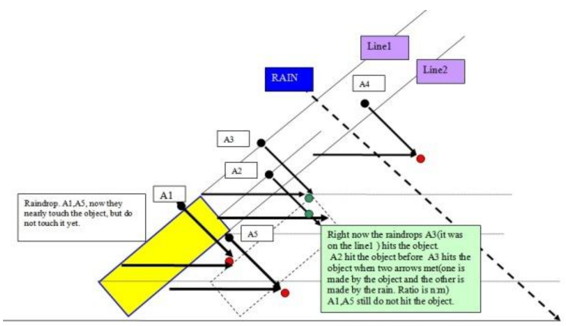


Figure.5 The movement of the rain and the object. When the rain hits only upper side

And some people may ask how the object gets wet only upper side when it rains from behind. The wetting part will be determined by the ratio between the speed of the rain and the object. The Fig (5), shows that it gets wet only upper side.

THE METHOD TO FIND Qd

Now let us find the Qd. The way to find Qd is various. When I made this article, I thought many ways and I found that the easiest method is to use vector (at least to me).

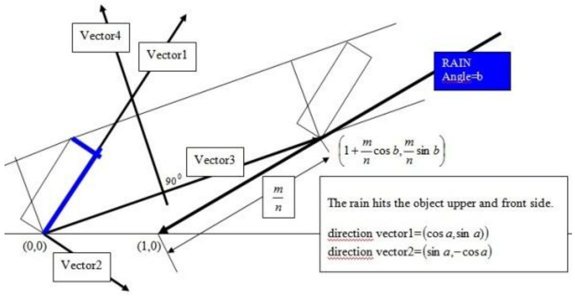


Figure.6 The method to find Qd

First find the length of the object that is projected to the vector4 and then multiply it by the distance of the two figures. That is Qd. Another method is to use the length of base of the parallelogram, $Qd = R\,sin\,b$. For the first time when I made this article, I used this method. This approach is a little hard to find the equation but it's easier to understand the principal.

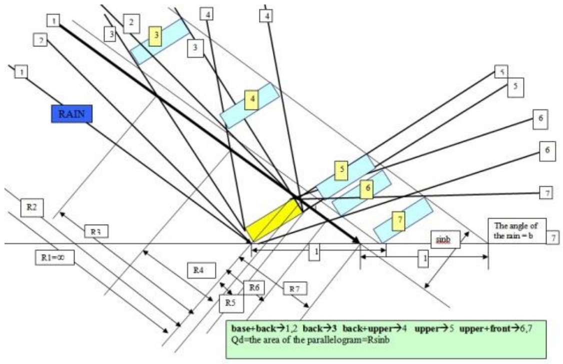


Figure.7 Another method to find, $Qd = Rsinb$ (R=the length of base of the parallelogram)

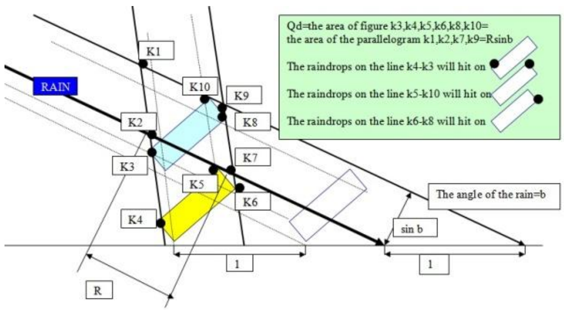


Figure.8 $Qd = Rsinb$

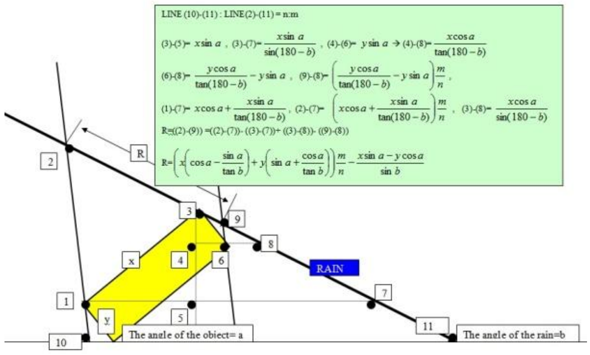


Figure.9 The way to find R

By any method, we can find Qd as follow.
$0 \le a \le 360$, $0 \le b \le 360$, $0 \le n, m$,
$0 < x, y$, m and n cannot be 0 at the same time

$$Qd = \left|\sin a + \frac{m}{n}\sin(a-b)\right| x + \left|\cos a + \frac{m}{n}\cos(a-b)\right| y \quad (1)$$

This equation can be divided into four by the wetting part of the object.

1. Upper and (or) front

$$Qd = \frac{m}{n}[x\sin(a-b) + y\cos(a-b)] + (x\sin a + y\cos a) \quad (2)$$

2. Upper and (or) base

$$Qd = \frac{m}{n}[x\sin(a-b) - y\cos(a-b)] + (x\sin a - y\cos a) \quad (3)$$

3. Back and (or) upper

$$Qd = \frac{m}{n}[-x\sin(a-b) + y\cos(a-b)] - (x\sin a - y\cos a) \quad (4)$$

4. Back and (or) base

$$Qd = \frac{m}{n}[-x\sin(a-b) - y\cos(a-b)] - (x\sin a + y\cos a) \quad (5)$$

Remember that Qd is the relative amount of rain that will hit the object when it moves unit distance 1. When the object moves in the time 1 with the speed n, it will move distance n.

Qt1= $Qd \times n$ (When the object moves in the unit time)

$$Qt1 = |n\sin a + m\sin(a-b)|x + |n\cos a + m\cos(a-b)|y \quad (6)$$

$Qt2 = \frac{Qt1}{m}$ (when it moves in the time 1/m)

$$Qt2 = \left|\left(\frac{n}{m}\right)\sin a + \sin(a-b)\right| x + \left|\left(\frac{n}{m}\right)\cos a + \cos(a-b)\right| y \quad (7)$$

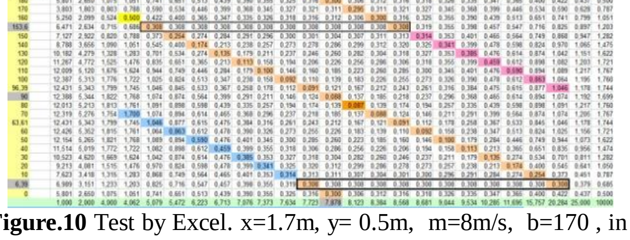


Figure.10 Test by Excel. x=1.7m, y= 0.5m, m=8m/s, b=170 , in the same distance 1

Figure.11 Test by Excel. x=1.7m, y= 0.5m, m=8m/s, b=170 , in the same time 1/8 second

ANALYSIS OF THE EQUATIONS

Now let us analyse the equations. Fig (10) and Fig (11), show the most important things about the equations and the figures below are made by assuming that the speed of the rain is not zero and the height is longer than the width and also the object changes its angle until $a = 90$.

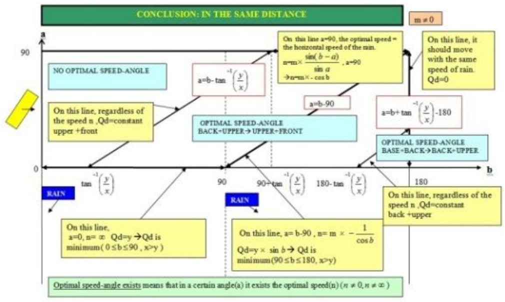


Figure.12 The conclusion: When the object has to move in the same distance

In the Fig (10), we can observe how the body size determines if it exists the optimal speed-angle or not. As the object is thinner, the optimal speed-angle region is gradually bigger. In the region 'no optimal speed-angle', it should move as fast as possible to get less wet. But when the speed of the object reaches a certain value, however it moves fast the difference is not so big. When it rains from ahead, the optimal speed-angle exists when the object gets wet only upper side. In a given condition (the angle and the speed of the rain), the best strategy (the least value of Q) is to run as fast as possible like the speed of light (to be exact, move very faster than the speed of the rain. For example, when the speed of the rain is 6.786×10^{-21}m/s, it does not need to move with the speed of light).When it rains from behind and the object moves standing vertically to the ground, the optimal speed is the horizontal speed of the rain. When the optimal speed-angle exists, the optimal speed is $n = -m\frac{\sin(a-b)}{\sin a}$ (upper side) or $n = -m\frac{\cos(a-b)}{\cos a}$ (back side).

When the raindrops hit the object only the back side, the optimal speed-angle can exist if the object is very thin and the angle of the rain is very big. And we can know that the existence of the optimal speed-angle is affected by the body size (the ratio of the height and the width). But the value of the optimal speed or the optimal angle itself has nothing to do with the body size. (An author claimed that the drop size influences the optimal speed. That is true, because he supposed that originally the raindrop falls vertically with its own speed and the wind (head, tail and cross) influences the direction of raindrop. The effect of the wind to the drop is determined by the drop size. But such approach makes this problem more complicate one. When we do the real test (a man runs in the rain),it is more easy and simple to measure only the angle and the speed of the rain than we measure the drop size and then calculate the effect of the wind to the speed of the rain. The advantage of the approach on this article is that we just need to consider the angle and the speed of rain). In the given condition (the angle and the speed of the rain), the minimum value of Qd is $y\,sin\,b$, when $(b-a)=90$, $n=-(1/cos\,b)$ (It's very good idea to check it by drawing on the paper). When $a=b-tan^{-1}(y/x)$ or $a=b+tan^{-1}(y/x)-180$, it exists the range of n (the speed of the object), in that range, Qd is constant.

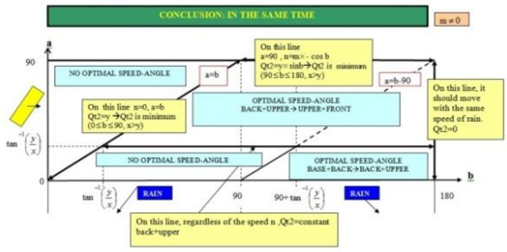


Figure.13 The conclusion: When the object has to move in the same time

Now let us think the object has to move in the same time. When it rains from ahead, the existence of the optimal speed is determined by the body size (the ratio between the height and the width). When $tan^{-1}(y/x)\leq a\leq b$, the optimal speed-angle exists. When the object is in the optimal speed-angle region, the optimal speed is $n=-m(\sin(a-b))/(sin a)$ (upper side). Now, we consider the rains come from behind. In this case, the optimal speed-angle region can be divided into two cases.

1. When $tan^{-1}(y/x)\leq a$. In this case the optimal speed angle exists when the rain hits the object only upper side.The optimal speed is $n=-m(\sin(a-b)/\sin a)$

2. When $0\leq a\leq tan^{-1}(y/x)$, $a\leq b-90$. In this case the optimal speed-angle exists when the rain hits the object only back side. The optimal speed is $n=-m(\cos(a-b)/\cos a)$. When the object is thin, it will get more possibility of having the optimal speed-angle. When $a=90$ and $n=-m\ cos\,b$, it has minimum value $Qt2=y\,sin\,b$. In Fig (8), we see that, the values of optimal speed-angle are distributed symmetrically from the minimum point. And it also exists the range of the speed n, in that range, Q is constant when it satisfies $a=tan^{-1}(y/x)$ and $tan^{-1}(y/x)\leq b\leq 180$. Now let us think another type of model.

TWO-DIMENSIONAL ELLIPSE MODEL

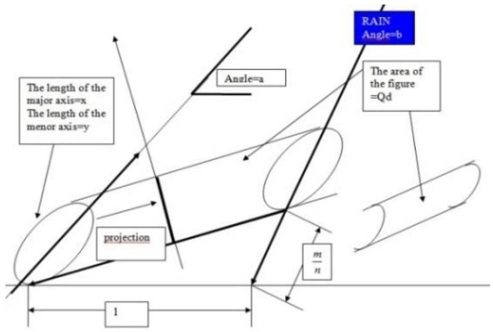


Figure.14 Ellipse model

The equation can be found on the same principal of the rectangle model.

$$Qd=\sqrt{\left(sin\,a+\frac{m}{n}sin(a-b)\right)^2x^2+\left(cos\,a+\frac{m}{n}cos(a-b)\right)^2y^2} \quad (8)$$

$$Qt1=\sqrt{(n\,sin\,a+m\,sin(a-b))^2x^2+(n\,cos\,a+m\,cos(a-b))^2y^2} \quad (9)$$

$$Qt2=\sqrt{\left(\frac{n}{m}\,sin\,a+sin(a-b)\right)^2x^2+\left(\frac{n}{m}cos\,a+cos(a-b)\right)^2y^2} \quad (10)$$

We don't need to divide these equations like a rectangle model. We will only analyse when it rains from behind. Let me leave another more detail analysis for you.

Ellipse model b=120, x=1.7m y=0.5m m=8m/s In the same distance , The horizontal speed of the rain=4

180	11,8731	5,9102	3,9295	2,9445	2,6724	2,4860	2,3577	2,3401	1,9797	1,9701	1,6962	1,6717	1,4933	1,4146	1,3378	1,2154	1,1945	1,1170	1,0366	1,0006	0,9699	0,9140	0,8666	0,8261	0,7913	0,6710
170	10,9132	5,5612	3,7855	2,9036	2,6603	2,4936	2,3789	2,3632	2,0412	2,0326	1,7879	1,7660	1,6066	1,5362	1,4674	1,3576	1,3388	1,2690	1,1962	1,1635	1,1355	1,0842	1,0405	1,0028	0,9700	0,8527
160	9,6776	5,0650	3,5387	2,7827	2,5745	2,4321	2,3342	2,3207	2,0462	2,0388	1,8306	1,8120	1,6764	1,6166	1,5581	1,4648	1,4488	1,3894	1,3274	1,2995	1,2756	1,2317	1,1941	1,1616	1,1333	1,0306
150	8,2286	4,4441	3,1991	2,5865	2,4186	2,3039	2,2252	2,2144	1,9945	1,9886	1,8225	1,8077	1,7000	1,6525	1,6063	1,5324	1,5198	1,4729	1,4240	1,4020	1,3831	1,3485	1,3189	1,2933	1,2708	1,1894
140	6,6627	3,7316	2,7827	2,3233	2,1988	2,1142	2,0564	2,0484	1,8881	1,8838	1,7640	1,7533	1,6764	1,6427	1,6099	1,5579	1,5490	1,5162	1,4820	1,4667	1,4536	1,4296	1,4091	1,3914	1,3759	1,3199
130	5,1491	2,9803	2,3129	2,0056	1,9251	1,8713	1,8349	1,8299	1,7313	1,7287	1,6573	1,6511	1,6066	1,5874	1,5690	1,5401	1,5353	1,5174	1,4991	1,4910	1,4841	1,4715	1,4609	1,4518	1,4440	1,4161
120	4,0286	2,2869	1,8279	1,6523	1,6124	1,5875	1,5716	1,5696	1,5310	1,5301	1,5069	1,5051	1,4933	1,4889	1,4850	1,4799	1,4791	1,4766	1,4746	1,4739	1,4734	1,4727	1,4723	1,4722	1,4723	1,4739
110	3,8449	1,8462	1,4003	1,2948	1,2843	1,2822	1,2831	1,2834	1,2975	1,2981	1,3196	1,3220	1,3413	1,3511	1,3615	1,3794	1,3827	1,3954	1,4095	1,4161	1,4220	1,4330	1,4429	1,4518	1,4598	1,4910
100	4,7273	1,9073	1,1726	0,9944	0,9847	0,9893	0,9977	0,9992	1,0468	1,0485	1,1055	1,1114	1,1579	1,1805	1,2037	1,2431	1,2501	1,2770	1,3063	1,3199	1,3318	1,3542	1,3739	1,3914	1,4070	1,4667
90	6,1652	2,4269	1,2863	0,8660	0,8015	0,7775	0,7718	0,7717	0,8071	0,8090	0,8807	0,8887	0,9539	0,9863	1,0199	1,0772	1,0875	1,1267	1,1695	1,1894	1,2067	1,2392	1,2679	1,2933	1,3159	1,4020
80	7,7383	3,1454	1,6629	0,9944	0,8408	0,7527	0,7036	0,6977	0,6367	0,6358	0,6753	0,6823	0,7475	0,7836	0,8225	0,8914	0,9039	0,9523	1,0057	1,0306	1,0524	1,0934	1,1295	1,1616	1,1903	1,2995
70	9,2371	3,8943	2,1386	1,2948	1,0751	0,9325	0,8402	0,8280	0,6195	0,6154	0,5493	0,5488	0,5741	0,6005	0,6341	0,7015	0,7144	0,7660	0,8248	0,8527	0,8774	0,9241	0,9657	1,0028	1,0360	1,1635
60	10,5485	4,5902	2,6194	1,6523	1,3909	1,2152	1,0967	1,0806	0,7700	0,7623	0,5756	0,5627	0,5000	0,4929	0,4998	0,5378	0,5473	0,5896	0,6438	0,6710	0,6955	0,7433	0,7868	0,8261	0,8618	1,0006
50	11,6012	5,1860	3,0581	2,0056	1,7174	1,5215	1,3877	1,3694	1,0030	0,9934	0,7356	0,7142	0,5741	0,5248	0,4878	0,4588	0,4582	0,4674	0,4959	0,5144	0,5328	0,5721	0,6107	0,6474	0,6816	0,8207
40	12,3478	5,6513	3,4273	2,3233	2,0195	1,8120	1,6696	1,6501	1,2544	1,2439	0,9618	0,9264	0,7475	0,6738	0,6067	0,5153	0,5024	0,4633	0,4415	0,4391	0,4409	0,4535	0,4736	0,4972	0,5221	0,6406
30	12,7574	5,9657	3,7087	2,5865	2,2769	2,0651	1,9196	1,8996	1,4923	1,4814	1,1756	1,1485	0,9539	0,8701	0,7903	0,6690	0,6494	0,5803	0,5175	0,4934	0,4754	0,4497	0,4367	0,4330	0,4359	0,4934
20	12,8139	6,1165	3,8903	2,7827	2,4768	2,2673	2,1232	2,1034	1,6992	1,6883	1,3825	1,3553	1,1579	1,0716	0,9881	0,8572	0,8352	0,7550	0,6750	0,6406	0,6122	0,5634	0,5257	0,4972	0,4761	0,4391
10	12,5153	6,0977	3,9649	2,9036	2,6105	2,4096	2,2713	2,2523	1,8642	1,8537	1,5690	1,5327	1,3413	1,2571	1,1752	1,0451	1,0231	0,9415	0,8578	0,8207	0,7893	0,7330	0,6863	0,6474	0,6149	0,5144
0	11,8731	5,9102	3,9295	2,9445	2,6724	2,4860	2,3577	2,3401	1,9797	1,9701	1,6962	1,6717	1,4933	1,4146	1,3378	1,2154	1,1945	1,1170	1,0366	1,0006	0,9699	0,9140	0,8666	0,8261	0,7913	0,6710
0	1,000	2,000	3,000	4,000	4,408	4,740	5,000	5,038	5,970	6,000	7,000	7,107	8,000	8,475	9,000	10,000	10,195	11,000	12,000	12,517	13,000	14,000	15,000	16,000	17,000	22,168

Figure.15 Major axis x=1.7m, Minor axis y=0.5m, m=8m/s, b=120, in the same distance 1

Let us look at the Fig (15). We can check that the optimal speed is different from the rectangle model. When a=90, it should move more fast than the horizontal speed of the rain. That is because the optimal speed is influenced by the size of the body. When the ellipse model is more similar to the round, the difference between the optimal speed and the horizontal speed of the rain is bigger. But when the length of the minor axis is the same of the width of rectangle model, they will have the same minimum value (when the direction of the rain is the same). In minimum value, the ellipse and the rectangle model have the same optimal speed. The optimal speed, by differentiating

$$\text{Qd},n=-m\frac{x^2\sin^2(a-b)+y^2\cos^2(a-b)}{x^2\sin(a-b)\sin a+y^2\cos(a-b)\cos a} \quad (11)$$

The minimum value exists in the one of the optimal speed-angle. After we substitute the optimal speed to Qd and by using the arithmetic geometric mean, we can find the minimum value and the optimal speed. When $(b-a)=90$ and $n=-\frac{\text{m}}{cos\,b}$, $Qd=y\,sin\,b$ (It rains from behind), Qd is minimum. The minimum value is only determined by the angle of the rain and the width (the width is shorter than the height), regardless of the body type.

Ellipse model b=120, x=1.7m y=0.5m m=8m/s In the same time , The horizontal speed of the rain=4

180	1,493	1,489	1,484	1,479	1,478	1,474	1,474	1,472	1,474	1,474	1,478	1,479	1,484	1,489	1,493	1,505	1,519	1,531	1,536	1,555	1,569	1,576	1,587	1,599	1,612	1,625	1,652
170	1,341	1,351	1,364	1,383	1,390	1,416	1,420	1,452	1,487	1,491	1,524	1,535	1,564	1,587	1,607	1,651	1,697	1,730	1,745	1,794	1,830	1,845	1,871	1,897	1,925	1,951	2,006
160	1,158	1,181	1,210	1,250	1,266	1,320	1,327	1,391	1,459	1,467	1,529	1,549	1,602	1,643	1,676	1,753	1,831	1,887	1,910	1,991	2,048	2,073	2,113	2,155	2,199	2,239	2,323
150	0,954	0,986	1,029	1,087	1,111	1,189	1,200	1,293	1,391	1,402	1,491	1,520	1,595	1,653	1,700	1,808	1,916	1,993	2,025	2,136	2,214	2,248	2,303	2,360	2,419	2,473	2,587
140	0,748	0,784	0,833	0,904	0,933	1,031	1,044	1,162	1,285	1,299	1,413	1,449	1,543	1,617	1,676	1,812	1,947	2,044	2,085	2,223	2,320	2,362	2,430	2,502	2,575	2,642	2,783
130	0,574	0,601	0,644	0,714	0,745	0,853	0,867	1,003	1,147	1,163	1,297	1,339	1,450	1,536	1,607	1,766	1,925	2,038	2,086	2,249	2,363	2,412	2,492	2,575	2,660	2,739	2,904
120	0,500	0,493	0,504	0,547	0,572	0,671	0,685	0,826	0,982	1,001	1,148	1,195	1,319	1,415	1,493	1,672	1,850	1,977	2,030	2,212	2,339	2,394	2,484	2,577	2,672	2,761	2,944
110	0,574	0,525	0,481	0,458	0,462	0,514	0,525	0,647	0,802	0,821	0,974	1,023	1,155	1,257	1,341	1,533	1,724	1,861	1,919	2,114	2,252	2,311	2,407	2,508	2,610	2,706	2,904
100	0,748	0,674	0,591	0,502	0,477	0,439	0,440	0,497	0,624	0,641	0,786	0,835	0,967	1,072	1,158	1,355	1,554	1,696	1,756	1,959	2,103	2,164	2,265	2,370	2,477	2,576	2,783
90	0,954	0,870	0,771	0,649	0,607	0,493	0,482	0,433	0,482	0,493	0,607	0,649	0,771	0,870	0,954	1,148	1,347	1,489	1,549	1,754	1,899	1,961	2,063	2,169	2,277	2,377	2,587
80	1,158	1,072	0,967	0,835	0,786	0,641	0,624	0,497	0,440	0,439	0,477	0,502	0,591	0,674	0,748	0,926	1,114	1,251	1,309	1,509	1,649	1,710	1,809	1,913	2,019	2,118	2,323
70	1,341	1,257	1,156	1,023	0,974	0,821	0,802	0,647	0,525	0,514	0,462	0,458	0,481	0,525	0,574	0,714	0,877	1,000	1,053	1,237	1,369	1,426	1,519	1,617	1,717	1,811	2,006
60	1,493	1,415	1,319	1,195	1,148	1,001	0,982	0,826	0,685	0,671	0,572	0,547	0,504	0,493	0,500	0,563	0,672	0,768	0,811	0,966	1,080	1,130	1,213	1,301	1,391	1,475	1,652
50	1,607	1,536	1,450	1,339	1,297	1,163	1,147	1,003	0,867	0,853	0,745	0,714	0,644	0,601	0,574	0,549	0,574	0,618	0,643	0,744	0,828	0,866	0,931	1,001	1,075	1,145	1,295
40	1,676	1,617	1,543	1,449	1,413	1,299	1,285	1,162	1,044	1,031	0,933	0,904	0,833	0,784	0,748	0,682	0,644	0,636	0,637	0,662	0,698	0,716	0,752	0,794	0,841	0,888	0,994
30	1,700	1,653	1,595	1,520	1,491	1,402	1,391	1,293	1,200	1,189	1,111	1,087	1,029	0,986	0,954	0,889	0,836	0,808	0,798	0,776	0,772	0,772	0,777	0,787	0,801	0,819	0,866
20	1,676	1,643	1,602	1,549	1,529	1,467	1,459	1,391	1,327	1,320	1,266	1,250	1,210	1,181	1,158	1,111	1,071	1,047	1,038	1,012	0,999	0,995	0,989	0,986	0,985	0,986	0,994
10	1,607	1,587	1,564	1,535	1,524	1,491	1,487	1,452	1,420	1,416	1,390	1,383	1,364	1,351	1,341	1,322	1,306	1,298	1,296	1,287	1,283	1,283	1,282	1,283	1,284	1,287	1,295
0	1,493	1,489	1,484	1,479	1,478	1,474	1,474	1,472	1,474	1,474	1,478	1,479	1,484	1,489	1,493	1,505	1,519	1,531	1,536	1,555	1,569	1,576	1,587	1,599	1,612	1,625	1,652
	0,000	0,448	1,000	1,723	2,000	2,887	3,000	4,000	5,000	5,113	6,000	6,277	7,000	7,552	8,000	9,006	10,000	10,703	11,000	12,000	12,700	13,000	13,490	14,000	14,519	15,000	16,000

Figure.16 Major axis $x=1.7$m, Minor axis $y=0.5$m, $m=8m$/s, $b=120$, in the same time 1/8 second

And now let us think that the ellipse model has to move in the same time. Like the rectangle model, it has the minimum value when it moves standing vertically to the ground. And from the minimum value, the optimal speed-angle is distributed symmetrically making S form. Optimal speed,

$$n = -m\frac{x^2 \sin a \sin(a-b)+y^2 \cos a \cos(a-b)}{x^2 \sin^2 a+y^2 \cos^2 a} \tag{12}$$

The minimum of Qd, when $a = 90$ and $n = -m \cos b$, $Qd = y \sin b$ (it rains from behind)

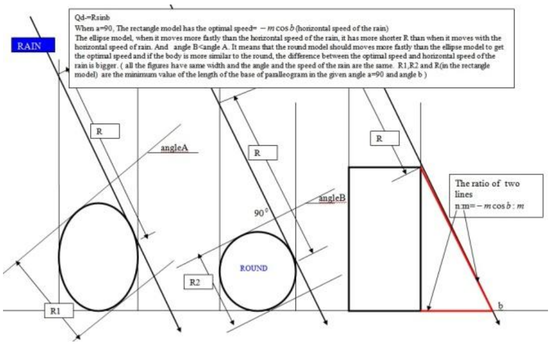


Figure.17 Understanding intuitively by the Fig (1)

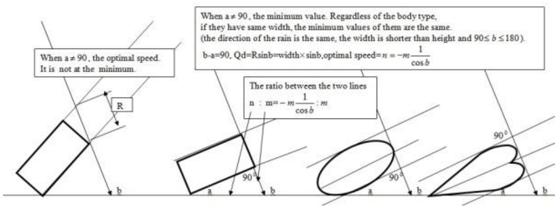


Figure.18 Understanding intuitively by the Fig (2)

THREE-DIMENSIONAL MODELS (IT RAINS FROM THE SIDE)

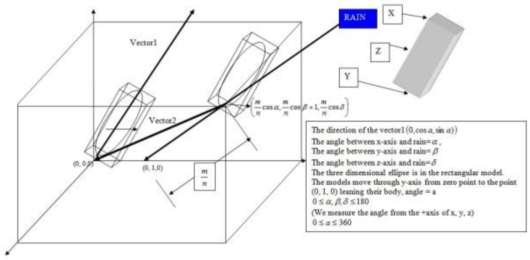


Figure 19 When it rains from side way (1)

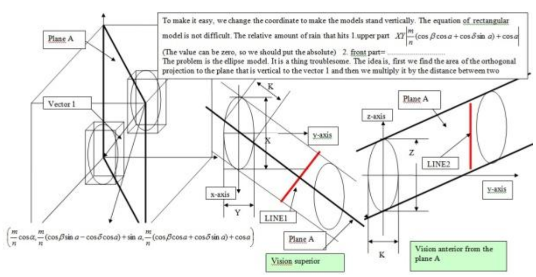


Figure.20 When it rains from side way (2)

THREE-DIMENSIONAL RECTANGLE MODEL

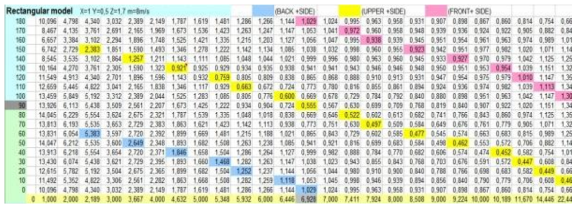
The equation of the three-dimensional rectangle model

$$Qd = XY\left|\frac{m}{n}(\cos\beta\cos a + \cos\delta\sin a) + \cos a\right| + YZ\left|\frac{m}{n}\cos\alpha\right| + ZX\left|\frac{m}{n}(\cos\beta\sin a - \cos\delta\cos a) + \sin a\right| \tag{13}$$

$$Qt1 = XY|m(\cos\beta\cos a + \cos\delta\sin a) + n\cos a| + YZ|m\cos\alpha| + ZX|m(\cos\beta\sin a - \cos\delta\cos a) + n\sin a| \tag{14}$$

$$Qt2 = XY\left|(\cos\beta\cos a + \cos\delta\sin a) + \frac{n}{m}\cos a\right| + YZ|\cos\alpha| + ZX\left|(\cos\beta\sin a - \cos\delta\cos a) + \frac{n}{m}\sin a\right| \tag{15}$$

Those equations also can be divided into four by the wetting parts.



Rectangular model		X=1 Y=0,5 Z=1,7 m=8m/s											(BACK +SIDE)				(UPPER +SIDE)				(FRONT+ SIDE)					
180		10,096	4,798	4,340	3,032	2,389	2,149	1,787	1,619	1,481	1,286	1,266	1,144	1,029	1,024	0,995	0,963	0,958	0,931	0,907	0,898	0,867	0,860	0,814	0,754	0,66
170		8,467	4,135	3,761	2,691	2,165	1,969	1,673	1,536	1,423	1,263	1,247	1,147	1,063	1,041	0,972	0,960	0,958	0,948	0,939	0,936	0,924	0,922	0,905	0,882	0,84
160		6,657	3,384	3,102	2,294	1,896	1,748	1,525	1,421	1,336	1,215	1,203	1,127	1,056	1,047	0,995	0,938	0,939	0,945	0,951	0,954	0,961	0,963	0,974	0,989	1,01
150		6,742	2,729	2,383	1,851	1,590	1,493	1,346	1,278	1,222	1,142	1,134	1,085	1,038	1,032	0,998	0,960	0,955	0,923	0,942	0,951	0,977	0,982	1,020	1,071	1,14
140		8,545	3,535	3,102	1,864	1,257	1,211	1,143	1,111	1,085	1,048	1,044	1,021	0,999	0,996	0,980	0,963	0,960	0,945	0,933	0,927	0,970	0,979	1,042	1,125	1,25
130		10,164	4,270	3,761	2,305	1,590	1,323	0,921	0,925	0,929	0,934	0,935	0,938	0,941	0,941	0,943	0,946	0,946	0,948	0,950	0,951	0,953	0,954	1,039	1,151	1,32
120		11,549	4,913	4,340	2,701	1,896	1,596	1,143	0,932	0,759	0,805	0,809	0,838	0,865	0,868	0,888	0,910	0,913	0,931	0,947	0,954	0,975	0,979	1,010	1,147	1,35
110		12,659	5,445	4,822	3,041	2,165	1,838	1,346	1,117	0,929	0,663	0,672	0,724	0,773	0,780	0,816	0,855	0,861	0,894	0,924	0,936	0,974	0,982	1,039	1,113	1,34
100		13,459	5,849	5,192	3,312	2,389	2,044	1,525	1,283	1,085	0,805	0,776	0,600	0,669	0,678	0,729	0,784	0,792	0,840	0,880	0,898	0,951	0,963	1,042	1,147	1,30
90		13,926	6,113	5,438	3,509	2,561	2,207	1,673	1,425	1,222	0,934	0,904	0,724	0,565	0,567	0,630	0,699	0,709	0,768	0,819	0,840	0,907	0,922	1,020	1,151	1,34
80		14,045	6,229	5,554	3,624	2,675	2,321	1,787	1,539	1,336	1,048	1,018	0,838	0,669	0,646	0,522	0,602	0,613	0,682	0,741	0,766	0,843	0,860	0,974	1,125	1,35
70		13,813	6,193	5,535	3,653	2,729	2,383	1,863	1,621	1,423	1,142	1,113	0,938	0,773	0,751	0,630	0,497	0,509	0,584	0,649	0,676	0,761	0,779	0,905	1,071	1,32
60		13,831	6,054	5,383	3,597	2,720	2,392	1,899	1,669	1,481	1,215	1,188	1,021	0,865	0,843	0,729	0,602	0,585	0,477	0,545	0,574	0,663	0,683	0,815	0,989	1,25
50		14,047	6,212	5,535	3,600	2,649	2,348	1,893	1,682	1,508	1,263	1,238	1,085	0,941	0,921	0,816	0,699	0,683	0,584	0,498	0,462	0,553	0,572	0,706	0,882	1,14
40		13,913	6,218	5,554	3,654	2,720	2,371	1,846	1,658	1,504	1,286	1,264	1,127	0,999	0,982	0,888	0,784	0,770	0,682	0,606	0,574	0,474	0,452	0,582	0,754	1,01
30		13,430	6,074	5,438	3,621	2,729	2,395	1,893	1,660	1,468	1,282	1,263	1,147	1,038	1,023	0,943	0,855	0,843	0,768	0,703	0,676	0,591	0,572	0,447	0,608	0,84
20		12,615	5,782	5,192	3,504	2,675	2,365	1,899	1,682	1,504	1,252	1,237	1,144	1,056	1,044	0,980	0,910	0,900	0,840	0,788	0,766	0,698	0,683	0,582	0,449	0,66
10		11,492	5,352	4,822	3,306	2,561	2,282	1,863	1,668	1,508	1,282	1,259	1,118	1,063	1,045	0,998	0,946	0,939	0,894	0,856	0,840	0,790	0,779	0,706	0,608	0,46
0		10,096	4,798	4,340	3,032	2,389	2,149	1,787	1,619	1,481	1,286	1,266	1,144	1,029	1,024	0,995	0,963	0,958	0,931	0,907	0,898	0,867	0,860	0,814	0,754	0,66
	0	1,000	2,000	2,189	3,000	3,667	4,000	4,632	5,000	5,348	5,932	6,000	6,446	6,928	7,000	7,411	7,924	8,000	8,508	9,000	9,224	10,000	10,189	11,670	14,446	22,44

Figure.21 α=68.61, $\beta = 150$, $\delta = 70$, $X = 1$,$Y = 0,5$,$Z = 1.7$,m=8m/s, in the same distance 1

Now the object has to move in the same distance. When $a = 90$, the optimal speed is the horizontal speed of the rain, to the direction of the movement of the object. But from the minimum values, the values of the optimal speed are not symmetrically distributed. That is because of the effect of the raindrops that hit the side part of the object. In other words, the speed of the object affects the amount of rain that will wet the side part of body. It also have the range of the speed of object, in that range Qd is constant regardless the speed of object. When it rains sideway, the rectangle model also shows that the existence of the optimal speed-angle will be influenced by the size (ratio) of the body, but the optimal speed or optimal angle has nothing to do with the body size. Even though it is not marked the range of n that makes the value constant, it can exist. In the minimum value $a \cong 30$, optimal speed $n \cong 11.670$.

Rectangular model	X=1 Y=0,5 Z=1,7 m=8m/s												(BACK +SIDE)				(UPPER +SIDE)				(FRONT+ SIDE)						
180	1,324	1,262	1,199	1,188	1,137	1,095	1,074	1,036	1,012	0,990	0,954	0,949	0,922	0,891	0,896	0,922	0,954	0,958	0,990	1,021	1,035	1,083	1,095	1,188	1,361	1,861	2
170	1,083	1,058	1,034	1,029	1,009	0,993	0,984	0,969	0,960	0,951	0,937	0,935	0,924	0,912	0,911	0,900	0,951	0,958	1,008	1,057	1,079	1,155	1,174	1,320	1,593	2,381	3
160	0,818	0,832	0,846	0,849	0,860	0,869	0,874	0,883	0,888	0,893	0,901	0,902	0,908	0,915	0,916	0,922	0,929	0,939	1,005	1,070	1,100	1,202	1,226	1,421	1,786	2,837	3
150	1,003	0,843	0,682	0,652	0,694	0,729	0,746	0,779	0,799	0,817	0,847	0,851	0,874	0,899	0,903	0,924	0,951	0,955	0,981	1,060	1,096	1,221	1,251	1,489	1,934	3,217	4
140	1,253	1,068	0,884	0,849	0,699	0,576	0,606	0,662	0,694	0,725	0,777	0,783	0,823	0,865	0,872	0,908	0,954	0,960	1,005	1,049	1,069	1,212	1,247	1,520	2,032	3,508	4
130	1,473	1,270	1,067	1,029	0,865	0,729	0,662	0,533	0,578	0,621	0,693	0,701	0,756	0,815	0,824	0,874	0,937	0,946	1,008	1,069	1,096	1,191	1,215	1,515	2,078	3,702	5
120	1,659	1,444	1,228	1,188	1,013	0,869	0,798	0,662	0,582	0,507	0,597	0,607	0,675	0,749	0,760	0,823	0,901	0,913	0,990	1,065	1,100	1,218	1,247	1,473	2,071	3,793	5
110	1,803	1,582	1,361	1,319	1,140	0,993	0,919	0,779	0,698	0,621	0,492	0,504	0,584	0,670	0,682	0,756	0,847	0,861	0,951	1,039	1,079	1,217	1,251	1,515	2,010	3,778	5
100	1,903	1,682	1,462	1,421	1,242	1,095	1,022	0,883	0,802	0,725	0,597	0,582	0,484	0,579	0,594	0,675	0,777	0,792	0,893	0,990	1,035	1,189	1,226	1,520	2,071	3,658	5
90	1,953	1,741	1,528	1,488	1,316	1,174	1,103	0,969	0,891	0,817	0,693	0,678	0,584	0,481	0,496	0,584	0,693	0,709	0,817	0,921	0,969	1,134	1,174	1,489	2,078	3,778	5
80	1,954	1,756	1,557	1,520	1,359	1,226	1,160	1,036	0,962	0,893	0,777	0,764	0,675	0,579	0,565	0,484	0,597	0,613	0,725	0,834	0,883	1,054	1,095	1,421	2,032	3,793	5
70	1,905	1,727	1,548	1,516	1,370	1,251	1,192	1,079	1,013	0,951	0,847	0,835	0,756	0,670	0,657	0,584	0,492	0,509	0,621	0,730	0,779	0,951	0,993	1,320	1,934	3,702	5
60	1,944	1,729	1,514	1,473	1,349	1,247	1,196	1,100	1,043	0,990	0,901	0,891	0,823	0,749	0,738	0,675	0,597	0,585	0,507	0,613	0,662	0,829	0,869	1,188	1,786	3,508	5
50	1,959	1,756	1,553	1,515	1,350	1,215	1,174	1,096	1,051	1,008	0,937	0,929	0,874	0,815	0,806	0,756	0,693	0,683	0,621	0,561	0,533	0,691	0,729	1,030	1,593	3,217	4
40	1,924	1,739	1,555	1,520	1,370	1,247	1,186	1,069	1,036	1,005	0,954	0,948	0,908	0,865	0,859	0,823	0,777	0,770	0,725	0,682	0,662	0,593	0,576	0,849	1,361	2,837	4
30	1,839	1,679	1,518	1,488	1,358	1,251	1,198	1,096	1,037	0,981	0,951	0,947	0,924	0,899	0,895	0,874	0,847	0,843	0,817	0,791	0,779	0,739	0,729	0,652	1,098	2,381	3
20	1,708	1,577	1,446	1,421	1,314	1,226	1,183	1,100	1,051	1,005	0,929	0,928	0,922	0,915	0,914	0,908	0,901	0,900	0,893	0,886	0,883	0,872	0,869	0,849	0,810	1,861	2
10	1,535	1,437	1,338	1,319	1,240	1,174	1,141	1,079	1,043	1,008	0,951	0,944	0,900	0,912	0,914	0,924	0,937	0,939	0,951	0,963	0,969	0,988	0,993	1,029	1,098	1,295	2
0	1,324	1,262	1,199	1,188	1,137	1,095	1,074	1,036	1,012	0,990	0,954	0,949	0,922	0,891	0,896	0,922	0,954	0,958	0,990	1,021	1,035	1,083	1,095	1,188	1,361	1,861	2
	0	1,000	2,000	2,189	3,000	3,667	4,000	4,632	5,000	5,348	5,932	6,000	6,446	6,928	7,000	7,411	7,924	8,000	8,508	9,000	9,224	10,000	10,189	11,670	14,446	22,446	30

Figure.22 $\alpha = \mathbf{68.61}$**,** β =150**,** $\delta = 70$, $X = 1$, $Y = 0.5$, $Z = 1.7$, $m = 8m/s$, in the same time, 1/8 seconds

Now the object has to move in the same time. When $a = 90$, it has a minimum value. The values in the optimal speed-angle are distributed symmetrically from the minimum value. That is because the speed of the object has nothing to do with the amount of rain that will hit the side part of object when it moves in the same time. The equation of the cylinder model can be made by the same principal (X is diameter and Z is height).

$$Qd = \frac{1}{4}\pi X^2 \left| \left(\frac{m}{n}\right)(\cos\beta \cos a + \cos\delta \sin a) + \cos a \right| + \mathrm{ZX}\sqrt{((m/n)\cos\alpha)^2 + ((m/n)(\cos\beta \sin a - \cos\delta \cos a) + \sin a)^2} \tag{16}$$

THREE-DIMENSIONAL ELLIPSE MODEL

In other to find the equation of the ellipse model, first we should find the orthogonal projection to the plane that is vertical to the vector 1. The orthogonal project to the plane that is vertical vector1 is ellipse. Line 1 and line 2, are the axes of the ellipse. So, the projected area $= \frac{1}{4}\pi \times (Line1) \times (Line2)$

$Qd = \frac{1}{4}\pi \times (Line1) \times (Line2)$ ×the distance between two figures. The length of Line1 is $\sqrt{X^2\cos^2\theta_1 + Y^2 \sin^2\theta_1}$. Where θ_1, is the angle between plane A and y-axis. The figure that is cut three-dimensional ellipse by the Plane A is two-dimensional ellipse. K is the length of one of the axes of the ellipse.

$$K = \frac{X^2Y^2(1+\tan^2\theta_1)}{X^2+Y^2\tan^2\theta_1} \tag{17}$$

The length Line2 $= \sqrt{Z^2\cos^2\theta_2 + K^2\sin^2\theta_2}$ and θ_2 is the angle between XY plane and vector1. The distance between two figures is

$$\sqrt{\left(\frac{m}{n}\cos\alpha\right)^2 + \left(\frac{m}{n}\cos\beta + 1\right)^2 + \left(\frac{m}{n}\cos\delta\right)^2} \tag{18}$$

Then we can find the equation of the three-dimensional ellipse model.

$$Qd = \frac{1}{4}\pi\sqrt{X^2Y^2\left(\frac{m}{n}(\cos\beta\cos a + \cos\delta\sin a) + \cos a\right)^2 + Y^2Z^2\left(\frac{m}{n}\cos\alpha\right)^2 + Z^2X^2\left(\frac{m}{n}(\cos\beta\sin a - \cos\delta\cos a) + \sin a\right)^2} \tag{19}$$

$$Qt1 = \frac{1}{4}\pi\sqrt{X^2Y^2(m(\cos\beta\cos a + \cos\delta\sin a) + n\cos a)^2 + Y^2Z^2(m\cos\alpha)^2 + Z^2X^2(m(\cos\beta\sin a - \cos\delta\cos a) + n\sin a)^2} \tag{20}$$

$$Qt2 = \frac{1}{4}\pi\sqrt{X^2Y^2\left((\cos\beta\cos a + \cos\delta\sin a) + \frac{n}{m}\cos a\right)^2 + Y^2Z^2\left(\frac{n}{m}\cos\alpha\right)^2 + Z^2X^2\left((\cos\beta\sin a - \cos\delta\cos a) + \frac{n}{m}\sin a\right)^2} \tag{21}$$

The optimal speed of Qd

$$n = -m\frac{X^2Y^2(\cos\beta\cos a + \cos\delta\sin a)^2 + Y^2Z^2(\cos\alpha)^2 + Z^2X^2(\cos\beta\sin a - \cos\delta\cos a)^2}{X^2Y^2\cos a(\cos\beta\cos a + \cos\delta\sin a) + Z^2X^2\sin a(\cos\beta\sin a - \cos\delta\cos a)} \tag{22}$$

The optimal speed of Qd2

$$n = -m\frac{X^2Y^2\cos a(\cos\beta\cos a + \cos\delta\sin a) + Z^2X^2\sin a(\cos\beta\sin a - \cos\delta\cos a)}{X^2Y^2\cos^2 a + Z^2X^2\sin^2 a} \tag{23}$$

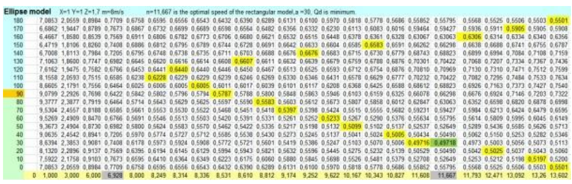


Figure.23 $\alpha = 68.61$, $\beta = 150$, $\delta = 70$, X=1, Y=1, Z=1.7, m=8m/s, in the same distance 1

Note: When $a = 30$, $n = 11.608$, Qd is not the minimum value of three-dimensional ellipse model. It has minimum value in the angle between $30 < a < 35$. It has different from the three-dimensional rectangular model even though the angle and speed of the rain is the same. And the two-dimensional model has the same speed-angle in the minimum regardless of the body type as long as the angle and speed of the rain is same.

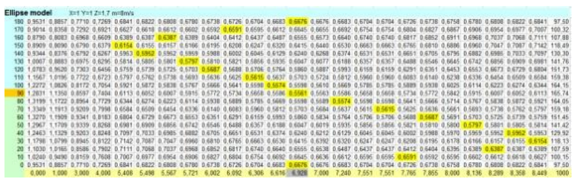


Figure.24 $\alpha = 68.61$, $\beta = 150$, $\delta = 70$, $X = 1$, $Y = 1$, $Z = 1.7$, $m = 8m/s$, in the same time 1/8second

Now it has to move in the same time. For $A = 90$, it has minimum value, and in the minimum value, the optimal speed is the horizontal speed of the rain. From the minimum value, the values of the optimal speed-angles are distributed symmetrically shaping S.

RESULT

In this work the equations between two-dimensional models and three-dimensional models are made with a rule. Moreover, the equation between the rectangle and ellipsoid model and their optimal speed also can be made by the rule. By rectangle model, we can find the range of the body's speed that makes the value of Qd constant. The equation of the rectangle model, are divided into four by the wetting part. The optimal speed of the rectangle model does not only exist when the rain hits only the shorter part of the body. The optimal speed of the ellipse model is different from the rectangle model. It's because of body size affects the optimal speed. The values in the optimal speed of two-dimensional rectangle are distributed symmetrically from the minimum value. But the values in the optimal speed of the three-dimensional model (when it rains from the side) are not distributed from the minimum value. It's because the amount of the rain that hits side part of the body affects the value. The latest article said that the optimal speed in the minimum value is the same regardless of the body type, but that is not true. It can be only true in two-dimensional model (when it rains to the same direction of the path). When it moves in the same time, it should have another strategy. The ellipse and rectangle model have the minimum value when it moves standing vertically with the same horizontal speed of the rain. And the values in the optimal speed of the ellipse and rectangle model are distributed symmetrically from the minimum value.

DISCUSSION

The best strategy in the rain, considered here. It is interesting to compare the different results between the rectangle and ellipsoidal models, between two and three-dimensional models; between same time and same distance. It is also interesting to check how the optimal speed-angle changes when the object changes his angle. Experiment and theoretical results may are different. By consider more variables such as, aerodynamic effect, the movement of the legs and the arms, the object can be more similar to the human body. If there is a big difference between the real and the theory, I think it's mainly because of the movement of the legs and the arms. When we run faster and wider then legs and arms move faster. It's a good idea to make an object which has jointed something similar to a pendulum.

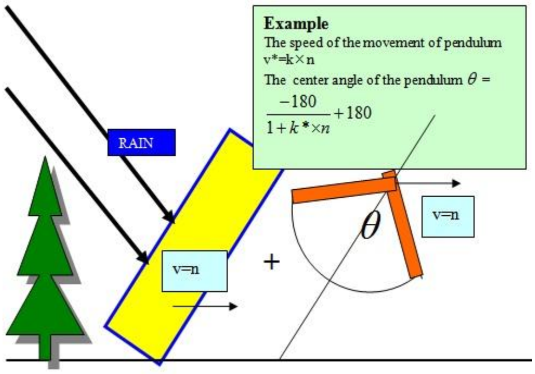


Figure.25 The ideal model

This problem is not only for the best strategy in the rain. The object can be in the flow of particle or another field and by using the equations on this article, we can establish various strategy and we can calculate the number of the particles when the object moves in a certain distance or in a certain time.

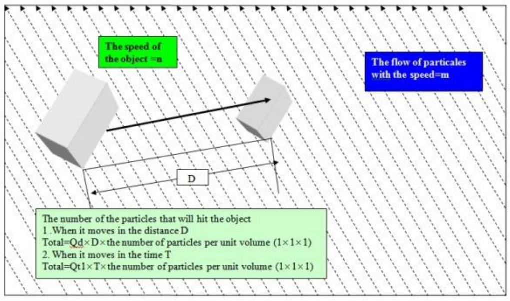


Figure.26 Apply to the another field

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