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# ERGONOMIC DESIGN AND RESEARCH OF A FORCE SAVING BUCKET

Jih-Shyong Lin[1] and Sheng-Yu Tsai[1]

[1]School of Industrial Design, Tatung University, Taipei, Taiwan, ROC, jslin@ttu.edu.tw, allent404@hotmail.com

## ABSTRACT

This paper focuses on a totally new bucket design which both considers ergonomics and industrial design process. Based on mathematical and physical operation analysis, we found that if we can reduce the angle-of-arm, the user will feel more force saving. We observed that if we can change the center-of-gravity position especially when the bucket is filled up with water, we will easily reduce the angle-of-arm. It was an important concept for us to start developing new bucket design. Besides, we also had some handle form mockups which were based on comfort considerations. Afterward, we integrated all concepts into a real design prototype and finished the experiment. The anthropometry model is really helpful for problem analysis; the mathematical or physical theory being the main idea is also good for concept development. If they can be both considered in design, the concepts will be more persuasive.

Keywords: force saving, center-of-gravity position, anthropometry model.

# 1. INTRODUCTION

In the cleaning of daily life, hand carrying a heavy bucket frequently is not only the most strenuous job but also the easiest to cause the accident or injury. For instance, while mopping up the floor, you may always walk unsteadily when carrying a filled water bucket, and the water may have already spilt down to the ground. It is so apt to cause the accident of slipping therefore perhaps you must wipe the ground again. In addition, the bucket is usually taken as low-priced plastic products and always makes people feel strenuous and uncomfortable. Especially as most of the bucket handles are set up on the center line, so the distance between arm and body becomes great when you carry it with water. This causes the bucket of the same weight to consume more energy.

According to some articles, the holding posture and the weight of the holding object will have an obvious influence on the gripping force; there are also apparent relations between the weight of holding object and the height of carrying. The gripping force while holding the object is greater than the weight of the holding object (Wen-Chiang Hsu 2003). In general, the adult can bear the weight of 1 to 3kg when held by one hand (34.78%). So, when we began to study the anthropometry model, considering the following parameters were very important: holding posture, bucket weight, gripping force, and lifting height, etc.

Moreover, according to occupational pathology, the easiest injured part of the body is the waist, up to 24.24%, followed by the shoulder, shank, elbow, finger, wrist, upper and lower backs, with the lower arm is for being the fewest. Meanwhile, the fingers and palm are the aptest to get red and swollen, accounting for 7.58% (Ohtsuki 1981). In lifting movements of the bucket, strength is needed more from waists, fingers and wrists. So, the design of the new-type bucket should prevent these positions from receiving the unnecessary injury.

The supporting strength of the arch structure is the strongest (Drury 1980). This point can be applied to the handle design of the new-type bucket. When two objects slip or are prone to activity relatively, friction will be produced and hindered this relative motion or the strength slipping when it is exposed to the surface. Furthermore, the coarser to contact surface, the greater the friction is (Emanuel, Chaffee and Wing 1956). In other words, the greater friction can be held more steadily. If the regular straight pressure N is exerted on something, then the coefficient of friction M is in direct proportion to the biggest friction F. i.e. the coarser the contact surface, the greater the striction coefficient is. So, when the user constructs with the same strength, the weight that can be borne is relatively heavy. The largest striction between two objects has nothing to do with the size of the contact surface. But, if it is too big to be exposed to the straight pressure among the surfaces, it will make the object deformed, friction F will increase slightly.

So, this research will discuss the operation behavior and procedure relationship among people and bucket. Attempts will be made to change the shape of the bucket body and handle. By making people narrow the distance between arm and body very naturally during the process of carrying the bucket, so reducing the rocking of the barrel, the result will be saved effort. Looking for the proper handle material, on one hand can improve the comfortableness of holding, and can slow down the pressure while holding on the other hand.

## 2. THE EXISTING PRODUCTS ANALYSIS

This research focuses on ergonomic quantitative analysis and cooperates to general design process. So, at the beginning of the study, carry on the investigation to the existing buckets of the current market was carried out. The following is the preliminary classification (Table 1):

Table 1: Bucket products classification chart of the current market

| Type | TYPE I | TYPE II | TYPE III |
|---|---|---|---|
| Characteristics | Easy to pour water.<br>Cylindrical handle. | Design with a cover.<br>Sunken barrel and crooked lever forms a handle space to grasp. | Traditional Style.<br>The hand pressure is large while lifting it up. |
| Figure |  |  |  |

Fig. 1 shows some other general bucket pictures. By using investigation and analysis methods of the existing products, it was easy to find the following questions:

The diameter of space clenching fist naturally in human hand is about 2-3cm (Ayoub and LoPresti 1971). So, if the diameter of handle is smaller than this size, the pressure of area to the finger will increase, it is apt to cause the finger to be tired.

Figure 1: Some existing products in the market.

While lifting the bucket, the natural balance relation of the body：As Fig. 2 shows, if people lift the bucket with the right hand, the body on the left will slope naturally, it is balanced and will produce a reacting force in order to support the body.

While carrying the bucket, the lever rocking will cause strength center to move, so water may still be spattered out. So, the lever design should be considered the elastic structure to resist the rocking effect while walking.

Figure 2: The Body movements while carrying a bucket.

The followings are the causes of spattered water from the bucket:

Whether the bucket will touch the body?

The center-of-gravity position influences the body sloping angle while carrying the bucket.

The distance between the handle and barrel causes it to swing naturally.

The cylindrical handle causes slipping.

Whether the lever is fixed on the bucket? (The fixed one is more difficult to rock)

The comfort degree of the handle will influence the degree of tiredness of the wrist.

Consider the elastic structure of the lever.

Such as Fig. 3, the movements of lifting and carrying the bucket are analyzed as follows:

Waist and shoulder are apt to cause bearing.

If the bucket is overweight, it will cause the shoulder to slope, the left hand will be lifted naturally, and the waist muscle will be affected. As time passes, it will cause the injury to the waist.

When carrying the bucket and walking, the barrel always touches the knee and makes water spatter out.

Such as Fig. 4, when you plan to lift the bucket, you must bend over. And just at this moment, the strength that your waist bears is the greatest. In addition, the movements of pouring water have the following two situations:

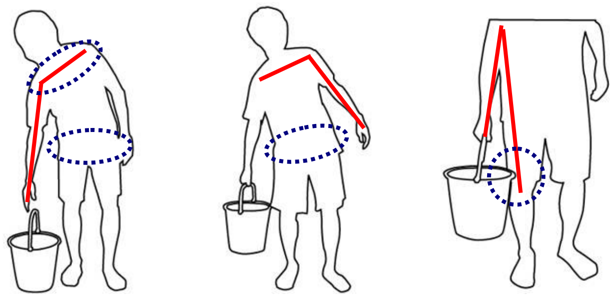


Figure 3: The Movements of lifting and carrying a bucket.

The right hand catches the edge of the bucket naturally： At this moment, the distance between the shoulder and shank is too short, and will make the muscle of the shoulder and shank tighten. The body also slopes relatively.

The right hand catches the bottom of the bucket：The distance between the hand and shoulder is relatively large; at this moment, one is apt to exert oneself naturally, and can slow down the shank discomfort.

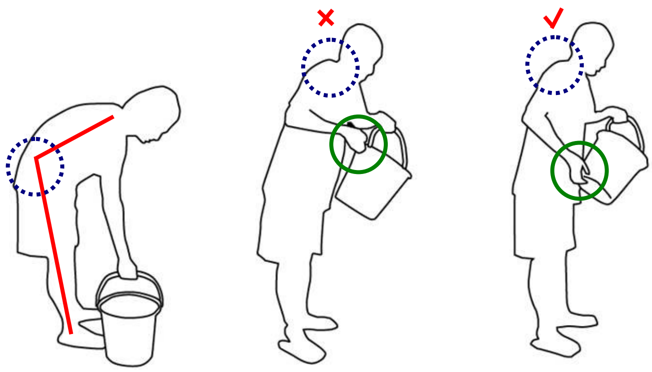


Figure 4:  Movements of life bucket and pouring water.

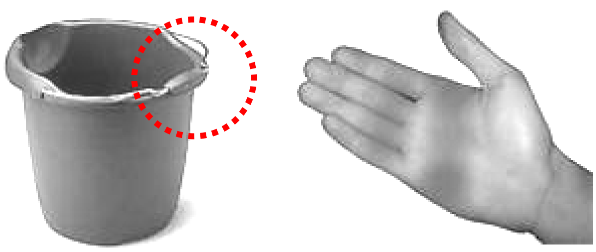


Figure 5:  The handle is designed badly and causes the palm redness.

The fingers and palm are the aptest to get red and swollen. By analyzing the bucket handle on the current market, we have the following discovery：Such as Fig. 5, most existing bucket put plastic handle into metal lever. After filling water, the bucket becomes heavy, and will cause the arch metal lever to become crookedl. The plastic handle is unable to disperse the pressure evenly, so that produce pulling force among the palm, and makes the fingers and palm red and swollen.

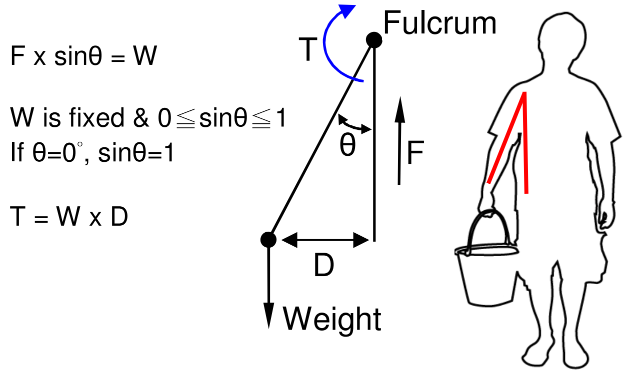


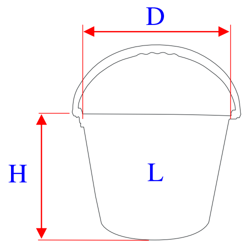

Figure 6: The strength analyzing while carrying a bucket.

Such as Fig. 6, the strength analyzing： the smaller $\theta$, sin $\theta$ is close to 1. So, the smaller the angle ($\theta$) is, the smaller the strength will be. In other words, it can let us get the result saving effort. In the same bucket weight, if value T is bigger, the arm must bear more strength. Moreover, the general volume and dimensions of a bucket are analyzed as follows:

Bucket caliber (D): 27.5cm to 34cm.

Bucket height (H): 23.5cm to 31.5cm.

Bucket volume (L): 9L to 15L.




## 3. NEW BUCKET DESIGN DEVELOPMENT

### 3.1 THE HANDLE DESIGN

According to the above-mentioned design points of a handle, we found that if we make the handle extend and adopt designing symmetry, we can reduce the both ends of the pressure in the hand effectively, and can be suitable for different users with all kinds of

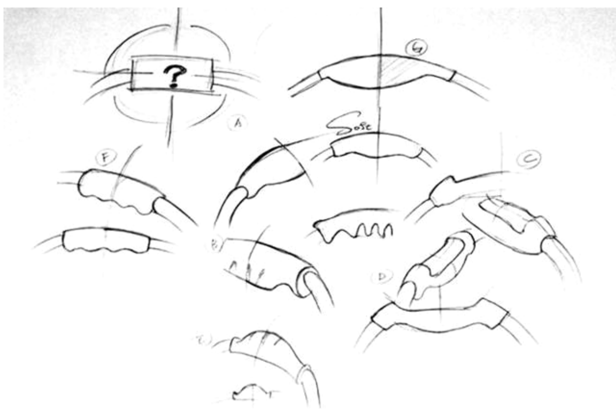


Figure 7: The quick sketch of new handle design.

palm. In addition, by combining the use of the elastomeric material, it can improve the holding comfortableness effectively. So, based on these principles, we started with a quick sketch map, and shown as in Fig. 7. After several feasible ideas were chosen and the 3D form-mockups were made, we can understand the real holding sense. Finally, the further design modification was done as shown in Table 2.

Table 2: New handle design concept mockups.

| No. | A | B | C | D | E |
|---|---|---|---|---|---|
| Mockup | Expect to be able to reduce the palm pressure. | It's conceptual for concentrating the grip. | Add the groove, and shorten the handle. | Add the groove, and elongate the handle. | Design unilaterally and curvedly. |
| |  |  |  |  |  |
| Holding In hand |  |  |  |  |  |

## 3.2 THE BUCKET BODY DESIGN

According to Fig. 6, suppose bucket caliber is 31cm, and had a sketch through mathematical way, such as Fig. 8. Then, using the 3D software to build the model and calculating automatically to define the lever position. After that, make a real sample was made in order to test and verify the concept.

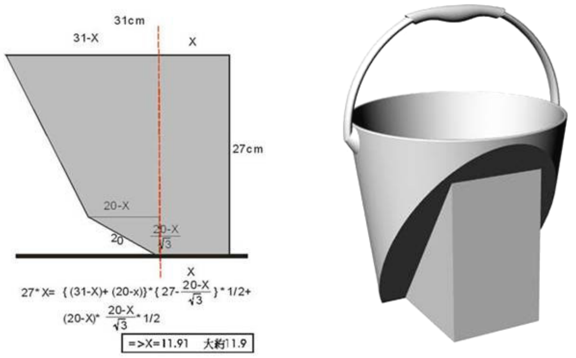



Figure 8: Bucket body studied in computer.

# 4. ERGONOMIC METHOD

## 4.1 EXPERIMENT PLAN

While lifting the bucket, the hand always keeps in touch with the handle directly. And, the fingers and palm are the aptest to get red and swollen position. So, we checked on all dimensions of the hand, it being the first important measure point of the experiment. Secondly, it is less touched directly between knees and the bucket. Except that someone has irregular and exaggerated excessive behavior to cause the bucket to strike the knee. Another factor is that the user's arm strength is unable to carry the overweight bucket filled with water. This makes users support the bucket with their body, and then causes the open angle among arm and body to be diminished and knocked the knee. Therefore, if one can reduce the open angle among arm and body, it will get the result of saved effort. And then it can be found from Fig. 6: When the bucket is regular in weight, couple strength depends on the center of clenching fist to the distance of the body center (D). In other words, if we can narrow the center-of-gravity position of the bucket to the distance of the body center line, effect can be saved effort.

Finally, by contrasting and analyzing dynamic and static state of using, we can find that other recessive factors as follows: While carrying the bucket and pouring water, it makes the body feel uncomfortable so that other muscles are affected mutually. Bend over to lift and pour water will cause waist and shank to feel uncomfortable. After improving the height of the bucket and comfortable degree of the handle, it can reduce the strength that the human muscle will be dragged and reduce therefore the body parts that cause aches.

## 4.2 THE DEFINITION OF BODY DIMENSIONS

According to the above planning, the following parameters can be defined:

Carrying Force (T) = (D) x (W)

D=the distance between the center of clenched fist and the body center line.

W = the weight of bucket filled with water.

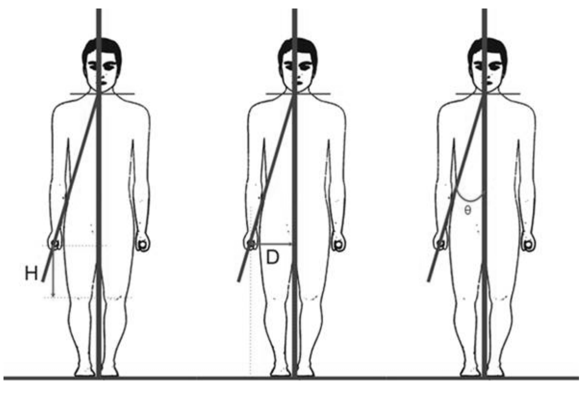


Figure 9: The definition of body dimensions.

Handle Height (H) = When carrying the bucket, the distance between the center of clenched fist to the ground.

D = the displacement of center-of-gravity position between new and old bucket.

$\theta$ = the open angle among arm and body.

$\triangle$W = the weight of spilled water. I.e. the water difference before and after carrying.

By carrying the buckets of three kinds of different height, walking ten meters, and going upstairs and downstairs, in order to know the most proper height of carrying water while walking.

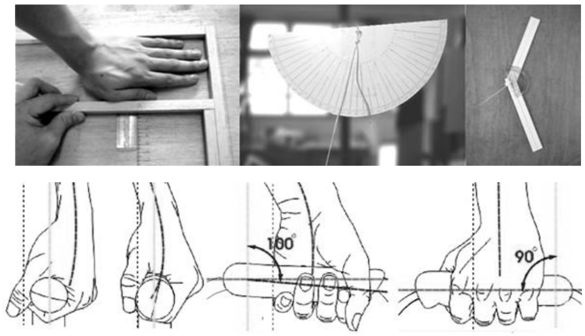


Figure 11: To show cylindrical oil soil measuring.

## 4.3 MEASURING TOOLS AND INSTRUMENTS

Before the beginning of the experiment, we must prepare the following measuring tools and instruments:

Electronic platform scale: used to measure the weight of the bucket, water, and spilled water.

Measuring tape and D.I.Y. tools: used to measure the above-mentioned parameters like D, $\triangle$D, H, $\theta$, the height of shoulder, and the width of palm.

Digital Camera: used to shoot the record, and measure the distances of real step that is noted by the eighth step while carrying the water and walking.

Buckets: including new and general types.

Cylindrical oil soil: 4cm (caliber) x 11cm (length). Used to determine the most

Table 3: User Questionnaire Form.

| | | | | | |
|---|---|---|---|---|---|
| **User Information** | | | | | |
| Name | | Age. | | sex | |
| Place | | Date. | | note | |
| **Static Dimensions (Unit: CM)** | | | | | |
| Height | □155↓ □155-165□165-175□175-185□185↑ | | | | |
| Shoulder Height | | Palm length | | Palm Width | |
| Comfort satisfaction of handles (enlarge by every 3mm,total:3) | | | | | |
| Handle No. (smaller number, smaller size，picked 15 in 1) | | | | | |
| A | □A1 □A2 □A3 | D | □D1 □D2 □D3 | | |
| B | □B1 □B2 □B3 | E | □E1 □E2 □E3 | | |
| C | □C1 □C2 □C3 | Picked reasons: | | | |
| **Dynamic Dimensions (Unit: CM)** | | | | | |
| Stand, body bend over angle: | | | | | |
| Stand, distance between bucket and rim of knee: | | | | | |
| Stand & pour water, the angle of arm: | | | | | |
| Height of Handle: | | | | | |
| **Holding center to body center line (D)** | | | | | |
| Old Type： | CM | New Type: | CM | | |
| **Holding center to rim of knee (H)** | | | | | |
| Old Type： | CM | New Type: | CM | | |
| **The angle between holding center and fulcrum ($\theta$)** | | | | | |
| Old Type： | CM | New Type: | CM | | |
| **Couple Strength (T = D x W)** | | | | | |
| Old Type： | CM x KG | New Type: | CM x KG | | |

comfortable width after clenching fist, such as Fig. 11.

Questionnaire form: Including the basic user information, static and dynamic dimensions of the persons who are examined, detailed like Table. 3.

## 4.4 EXPERIMENT PROCESS

This experiment was divided into three stages:

**Stage I: Confirmed the handle shape and size.**

According to the five different models listed in Table.2, we made totally 15 sets of form-mockup where the sectional diameter is 28mm and enlarged by every 3mm length. Then, we chose five male participants and five female participants to join the experiment at random. By grasping testing, we made tester lift the bucket that has already been fitted with these five kinds of different handles. And then, we measured the distance between center of clenched fist and the rim of knee (H). Finally, the comfort satisfaction of these 15 samples was counted, in order to confirm the handle selected in this research.

**Stage II: Confirmed the handle position and finished all of ergonomic items.**

By the following steps, all the ergonomic items were finished:

Step1. Let participant lift the new-type bucket until it was balanced, then noted down the handle position.

Step2. Let participant lift the old-type bucket, then measured the distance ($D_{old}$) between the center of clenched fist and body center line. And, under the inactive state, noted down the open angle of arm ($\theta_{old}$).

Step3. Let participant lift the new-type bucket, then measured the distance ($D_{new}$) between the center of clenched fist and body center line. And, under the inactive state, noted down the open angle of arm ($\theta_{new}$).

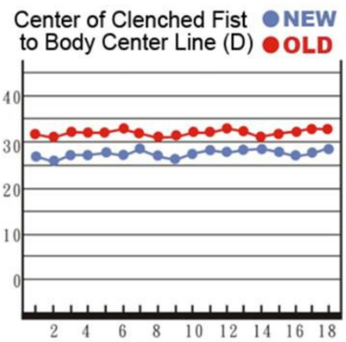
Step4. In the new and old bucket, poured into 8 liters of water into each and made it become regular testing value. Let the tester carry and walk about 10th steps distance, and stick 1M measuring tape on the ground from place on 7th-9th steps. Then, shoot by fixed camera in order to calculate the interval of paces.

Step5. Measure the weight of spilled water of the new or old bucket separately.

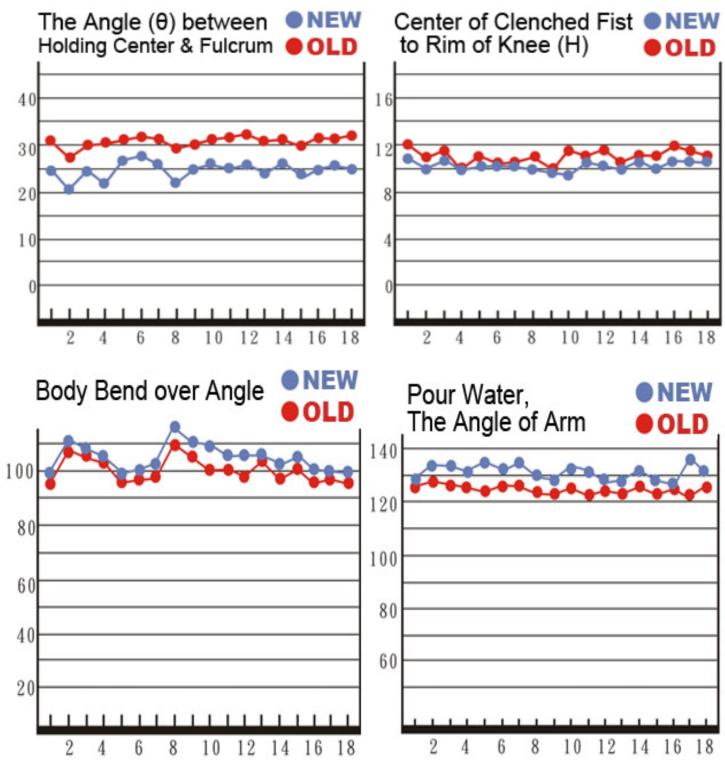
**Stage III: Calculated the couple strength and came out the result.**

## 4.5 EXPERIMENTAL RESULT

The age sample, is distributed from 20 to 50 years old, all of healthy build, with an interval of 10 years, and every group includes 6 people with 9 male and 9 female altogether, and amounted to 18 participants.




Comparing the experiment to the new-type and old bucket, the result is shown in Fig.12. In addition, each important dimension that the new-type designed bucket is proposed as follows:




Handle height: 18 cm.

Bucket caliber: 32cm.

Bottom diameter of a bucket: 24cm.

Bucket height: 30 cm.

Handle center: Move 2cm from center to the body side.

## 5. CONCLUSIONS

Finally, we have the following conclusions:

1. A center-of-gravity position change when the bucket is filled up with water is force saving when carrying a bucket.

2. The handle that is made of TPE (Thermoplastic Polyurethane Elastomer/ TPE) with a streamline shape is felt to be more comfortable than the usual one.

3. Considering elasticity of bucket lever design is obviously a help to improve water-spilling issue.

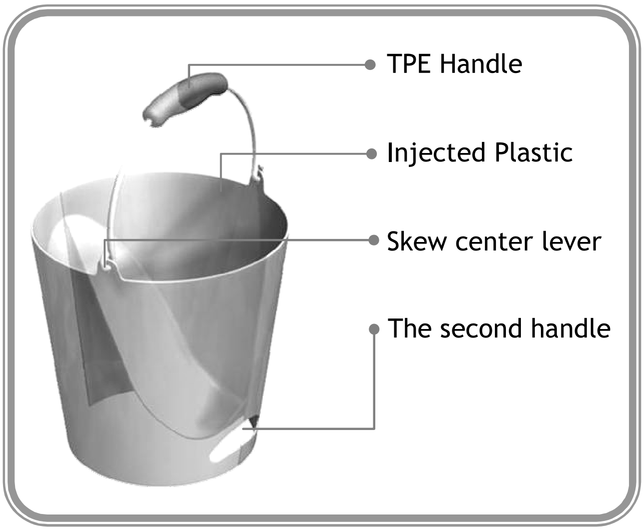



Figure 13: Final modification of new-type bucket.

4. Having a second handle design at the bottom of the bucket is also more comfortable for use when you topple and spill the water.

5. The capacity of bucket is better designed not more than 15L.

As Fig. 13 shown, it was according to this data and a consideration of mass production, then redesigned and rebuilt in the 3D-model in computer. Using this kind of ergonomic quantitative analysis model is really helpful for problem analysis. Using mathematical or physical theories to be the main idea is also good for concept development and design evaluation. If they can be both considered in product design, the concepts will be more persuadsive.

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