Flow visualization around an apple with and without bagging

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Abstract. The typhoon often causes the vast damage to drop the apple before harvest. Many apples fall from trees by the strong wind. These apples are usually bagged to protect them from insects and control sun light for the apples colouring while they are ripening on the tree. We directly measured the drag force acting on an apple with and without bagging experimentally to bare the influence of the bagging on the dropping mechanism. There are two interesting results through the experiment: the drag coefficient of a naked apple is smaller than a sphere, and the bagging is a cause of increasing drag coefficient. To know the reason of these results, we visualized flow around the apple with and without bagging by using the hydrogen bubbles method in an open water channel in this study. We found two facts as follows: the hollow on the top of an apple plays reduction of width of the wake of an apple and reason of increasing the wake width is the flow separation from peripheral edge of the bagging.

1. Introduction

News tells us that apples drop by strong wind of a typhoon every year. These apples are often bagged to protect them from insects and control sun light for the apples colouring while they are ripening on the tree. When we estimate the drag force on the apple by the wind, the drag coefficient of the apple is necessary. The drag coefficient $C_D$ of a sphere is well known as 0.47 [1], but there are no data about $C_D$ of the apple and much more several shapes of body. Therefore, we have experimentally measured $C_D$ of the apple with and without the bagging, to investigate the influence of the bagging on the drag force of the apple [2]. As a result, two interesting facts become clear through our experiments: the drag coefficient of a naked apple is smaller than a sphere, and the bagging is a cause of increasing drag coefficient. To know the reason of these results, we visualized flow around the apple with and without bagging by using the hydrogen bubbles method in an open water channel in this study. We found two facts as follows: the hollow on the top of an apple plays reduction of width of the wake of an apple and reason of increasing the wake width is the flow separation from peripheral edges of the bagging.

2. Experimental setup
Figure 1 shows an open water channel with 0.18 m width × 0.22 m height × 1.0 m length of a test section. The free stream velocity is 0.18 m/s. The apple model showing in figure 1 was modelled on an apple, Jonathan. This model was made with the silicon (Shin-Etu silicon KE-12) to realize the hollow of a real apple and unique curve of the profile of the apple. The dimension of this apple model based on the average of that of Jonathan is as follows: diameter is 76 mm, height is 75 mm. The hardness of this model is 40 durometer angstrom based on the real apple. The Reynolds number of the flow around the apple is $1.4 \times 10^4$. The blockage effect of the apple in the test section is 11%.

![Figure 1](image1.png)

**Figure 1.** Experimental set up. Apple model in the test section of an open water channel.

The apple is wrapped by the paper bagging (height: 165mm, width: 137mm) that is popularly adopted by famers in Aomori prefecture in Japan. Its surface is waterproofed. The bag has a long slid near the opening of the bag for putting in a stem. Some short slides are on the bottom part for some reasons: preventing a temperature rising in a bag, draining out rain water and allowing air to pass through easily. A wire embedded along one edge is used to close a bag by twisting. Opening a bag along perforation on the middle of the bag makes bright color of apple by exposing to sunlight before just harvest. Figure 2 shows the covered models in top, front and side views. Measured angle is defined in Figure 2(d). Measurement of the drag force acting on the covered model and visualizing the flow around an apple model is carried out with the different angle, since $C_D$ and wake depends on the geometry.

![Figure 2](image2.png)

**Figure 2.** Bagging in three different views and the directions of observing the bagging. (a)top view, (b) front view, (c) side view, (d) definition of angle to the main stream in the top view

Flow around the apple is visualized by a hydrogen bubble method to study the bagging on the drag and the influence of the hollows at top and bottom part of the apple on the drag. Hydrogen bubbles emanate from a tungsten wire connected to a positive electrode to that DC voltage applied continuously. The diameter of wire is 0.05 mm that is placed 30 mm above from the model upright in
water tank. A copper plate connected to negative electrode is placed in the downstream of water tank. A light sheet illuminates a vertical plane of the flow around the apple. The measurement of half width is carried out by interval of 10 second in every 5 times due to wavelength of vortex.

A digital camera is used for recording the flow patterns by means of hydrogen bubbles. Behaviour of hydrogen bubble was recorded as flow around the apple model 2 minutes by digital camera. The half width of the wake is measured to correlate with the magnitude of the drag from the flow patterns of the wake. The shape of the covered model has a different projected area with different angle against flow as shown in figure 2.

3. Result

The visualized flow patterns, drag coefficients, half widths are shown in table 1. For comparison, the data of a sphere with similar dimension with the apple obtained in this experiment is presented in the table. We maintain the condition of a model during the measurement of $C_D$ in Table 1 to investigate the effect of the bagging to drag force acting on an apple. Drag coefficient is calculated from the definition. The value of $C_D$ on a sphere is $C_D = 0.45$. This warrants adequacy of our experiment. The drag coefficient of the naked apple with hollows is $C_D = 0.36$. This is the minimum value in our experiment. Furthermore, this is less than the known $C_D$ of a sphere. The result of the bagging for $C_D$, when the model was set 0, 30, 60 and 90 degs, is 0.80, 0.69, 0.61, and 0.55 respectively. This means that the drag force acting on an apple becomes larger due to the bagging. Among the results of the $C_D$ acting on the bagging, the maximum value appears at 0 deg. The minimum value is at 90 deg., this is due to similar shape to a streamlined body. The $C_D$ of the bagging is about twice as larger than the naked apple. The bagging shows a possibility of the cause of dropping apple from the tree easily. This means that if we can find the low influenced shape or surface material of the bagging, the number of dropping apples due to the strong wind of typhoon may be decreased.

To understand the reason why the $C_D$ of the naked apple is smaller than the sphere, we show the flow around the apple, $C_D$ and half width of the wake as shown in Table 1. We can see that the half width of the naked apple is smaller than that of the sphere, and that of the filled hollows. The drag coefficient $C_D$ and half width of the apple filled hollows are a little bit larger that the naked one. This means that the hollow plays an important role to reduce the drag. We think that small eddy in the hollow retards the separation as similar to sucking from the surface of the airfoil.

The $C_D$ and half width of the bagging obtained in each direction show larger values than those of the naked apple. The flow along the bagging apple separates from the peripheral edge of the bagging because of singularity. Thus, the half width of the wake depends on the frontal shape of the bagging. The half width increases with increasing the angle of orientation. The minimum value appears at 90 deg. and the maximum 0 deg. This is similar to change of the $C_D$.

4. Conclusion

We visualized flow around the apple with and without bagging by using the hydrogen bubbles method in an open water channel in this study. We found two facts as follows: the hollow on the top of an apple plays reduction of width of the wake of an apple and reason of increasing the wake width is the flow separation from peripheral edges of the bagging. Thus, we need to review the shape of paper bagging to decrease the drag force for preventing the apple dropping by the strong wind.

References

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Table 1. Flow pattern around a model, $C_D$ and half width of wake

| Model         | Set-up          | Flow visualization using hydrogen bubbles | $C_D$ | Half width |
|---------------|-----------------|------------------------------------------|-------|------------|
| Sphere        | flow            |                                          | 0.45  | 1.1        |
| Apple         | a hollow        |                                          | 0.36  | 0.26       |
|               | filled          |                                          | 0.39  | 0.37       |
| Covered apple | $0^\circ$       |                                          | 0.80  | 1.7        |
|               | $30^\circ$      |                                          | 0.69  | 1.1        |
|               | $60^\circ$      |                                          | 0.61  | 0.95       |
|               | $90^\circ$      |                                          | 0.55  | 0.62       |