COEFFICIENT OF FRICTION AND LOCATION OF CENTER OF GRAVITY IN POME FRUIT

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ABSTRACT

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by David Floyd Wolf

The orientation of apples and pears is important to packers and processors since labeling and inspecting can only be performed on an oriented fruit when being done automatically.

The coefficient of friction and the location of the center of gravity are necessary for analyzing the forces which exist in mechanical orientation of apples and pears. Apparatus was assembled to measure these two parameters on several varieties of fruit from different growing areas in the United States.

The equipment for friction studies consisted of a load cell to measure the frictional force applied to the fruit by a horizontal platform which moved at a constant velocity. The location of the center of gravity was found by placing a fruit on a simply supported beam and making the necessary measurements to sum moments about the fixed end of the beam. From the moment equation, the location of the center of gravity could be determined.

Friction tests were run on four different surfaces: Teflon, Ethafoam, stainless steel, and food belt. Preliminary experiments demonstrated that the friction coefficient increased as the surface began to accumulate deposits from the cuticle layer of the fruit. Therefore, the surfaces were conditioned by running fruit across them a large number of times before final data were taken.

A very slow platform velocity was used to try to determine a static coefficient of friction. However, the results were inconclusive because the values of the static coefficient of friction which were determined by this test were less than the dynamic coefficients of friction obtained. This is contrary to most theories of friction.

The results which are presented were obtained at a platform velocity of 200 inches per minute. This gave an estimate of the values of coefficient of friction for machine design purposes. However, significant deviations from the mean values were found in the tests. Teflon gave the most consistent coefficients of friction.

The location of the center of gravity was measured along the core and correlated to the total length of the fruit as a ratio. These ratios indicated that the center of gravity is closer to the stem end in apples and closer to the calyx end in pears. Using this physical property, a mechanism was designed to orient apples stem down.

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I. INTRODUCTION

With the high cost involved with controlled atmosphere storage of apples and pears, it is of great concern to growers and packers to store only fruit which will be in good condition when placed on the market at a later date. To ensure this high quality, the fruit would have to be individually inspected both externally and internally. Both of these inspections could be made with optical methods. Birth (1960) developed a spectrophotometer which is capable of evaluating the internal condition of fruit without affecting the specimen. Techniques for external color evaluation were worked on by Desrosier et al. (1952).

Certain drawbacks evolve from these possible methods of evaluating the fruit quality. The inspection must be made rapidly to handle the vast amount of fruit grown in a season, and the fruit must be oriented in a specified position before the light transmittance technique will work. Although, it may be noted, that speed is of secondary importance since it will be needed only after the orientation problem has been solved.

Several West Coast packers and processors have also indicated that orientation of apples and pears is important. With the large amount of small quantity packaging, positioning is necessary to fill the container properly. Also, some companies wish to label "extra fancy" fruit, and this can be done correctly only on a fruit which is in an upright position.

Several machines have been developed to orient apples and pears (see the literature review, section 2.3), and positioning in water was studied by Dewey et al. (1966). However, none of these techniques are accurate enough for the internal quality evaluation by light transmittance. It is very important, therefore, to study some of the basic principles involved with the problem of orientation.

First, a close look must be taken at some of the existing methods of positioning to determine what physical properties are important. From a study of existing orienting machinery, it was noticed that the size, shape, coefficient of friction, and location of the center of gravity were some of the parameters which determined if the machine would operate. Some preliminary tests using different flow patterns in water failed to produce any results which were conclusive, but flow patterns and drag forces might be employed to orient apples and pears.

1.1. Objectives

In any kind of mechanical orientation of apples or pears, a force analysis on the fruit would be important. The body force or weight of the fruit would act through the location of the center of gravity, and an external force could be applied as a frictional force. In view of these observations, the coefficient of friction and the location of the center of gravity are the two main topics studied here.

Coefficients of friction for apples have been studied by Cooper (1962) and Matthews (1963), but there is a discrepancy among the values reported. These differences are believed to be a result of different surface conditions which according to Bickert (1964), are very important to friction testing. Therefore, a closer investigation of some of the factors involved with the coefficient of friction will also be discussed.

II. LITERATURE REVIEW

2.1. Basic Laws of Friction

The basic laws describing friction were developed by Leonardo da Vinci. These laws specify that the frictional force is proportional to the normal force and independent of the area of contact. Later, Charles A. de Coulomb added that the frictional force was independent of sliding velocity.

These laws do not hold according to Halliday et al. (1960). He stated that increasing the velocity decreases the kinetic coefficient of friction. Also, the condition of the surface, humidity, temperature, and contamination on the surface affect the coefficient of friction. With all of these variables, most laws of friction are empirical.

The work done by Burmistrova (1956) suggested that there are several factors affecting the coefficient of friction when working with agricultural products. Included are: velocity, normal pressure, moisture content, surface contact (length of contact time for static friction), surface conditions, and atmospheric conditions. He indicates that contact pressure, moisture content, and condition of the surface are the most important factors connected with friction measurements.

Buelow (1961) discussed three phases of coefficient of friction which depend on the velocity. The initial portion of the curve is called the creep portion and it peaks at the static coefficient of friction. Then as the velocity increases, the object begins to slide and the coefficient of friction decreases to the kinetic coefficient. This decreasing phase is called the stick-slip portion. In the final phase, the curve levels off at the kinetic coefficient of friction.

2.1.1. Methods of Evaluation

Several methods and types of apparatus have been used to measure the coefficient of friction. One of the simplest methods, used by Burmistrova (1956), is simply an inclined plane on which the product is placed. The degree of incline can be varied until the product slides at a constant velocity. The tangent of the angle of incline is equal to the dynamic coefficient of friction, and the tangent of the angle at which the object begins to slide is the static coefficient of friction.

Another method used by Burmistrova is a large revolving disc on which the sample is placed. The force is measured by a scale attached to the object. One disadvantage of this method is the fact that the object makes contact at different radii and thus has different velocities. This difference can be reduced by using a disc with a large radius.

Balis (1958) used a horizontal table as a surface on which to measure friction coefficients of grains. He pulled the sample across the table and measured the force required to hold the container of grain. In his procedure, the grain container contacts the surface. This effect can be eliminated by subtracting the friction force of the empty container.

Buelow (1961) measured the coefficients of friction for grains by using a horizontal platform which moved at a constant velocity. He placed the grain on this platform and restrained the sample with a container which did not make contact with the surface. The force from friction was measured by a strain gage arrangement.

The deflection of an object on an oscillating platform was related to the coefficient of friction by Henderson (1966). From a force analysis on the product, the coefficient of friction is:

$$\mu = \frac{16\ d}{T^2\ g}$$

where d = displacement

T = time

g = gravitational constant.

The main drawback of this method is the inability to measure the deflection accurately.

2.1.2. Previous Work Done on Fruit and Vegetables

Both Cooper (1962) and Matthews (1963) have measured the coefficient of friction of apples by using the inclined plane method. They kept the apples from rolling by wiring them together in groups of three or four. The following are some of the results that were reported.

TABLE 1.

Apple Coefficients of Friction from Cooper and Matthews

	STATIC		DYNAMIC	
Variety and Surface	Cooper	Matthews	Cooper	Matthews
McIntosh				
Wood	.36	.33	.29	.32
Metal	.38	.38	.28	.39
Ethafoam	.38	.48	.33	.52
Delicious				
Wood	.37	.35	.33	.29
Metal	.40	.34	.31	.33
Ethafoam	.40	.45	.29	.45

Other surfaces used by the two investigators were canvas and plastic foam. Melba, Golden Delicious, Staymen, Rome Beauty, and Jonathan apples were also tested.

Mohsenin (1965) performed a test to determine the frictional force between two potatoes rubbing together. The frictional force was measured by holding one potato and pulling the other across it. He also measured the area of contact between the potatoes by applying a thin layer of Prussian Blue to the contact area. Then, a print was made on a paper while loading the potato with a specified normal force.

2.2. Center of Gravity

Shames (1958) defined the center of gravity of a mass as the point in the body at which the weight is concentrated or the point acted on by gravity. The location of the center of gravity is unaffected by the orientation of the body.

Halliday et al. (1960) defined the center of gravity by dividing a body into particles. Each particle, i, has a weight defined as $m_i g_i$. The moment of this point about the center of gravity is given as $m_i g_i x_i$ where x_i is the distance to the center of gravity. The summation of the moments of all the points about the center of gravity, $\Sigma\ m_i g_i x_i$, must equal zero.

A method for obtaining the location of the center of gravity was also suggested by Halliday. By suspending a body on a string, it can be determined that the center of gravity lies on a line beneath the string. After marking this line, the body is rotated and hung at another point and again a line is marked on the body in line with the string. Where the first and second lines cross is the location of the center of gravity.

Barger et al. (1952) suggested several ways of determining the location of the center of gravity of tractors. The first was a suspension method quite similar to the method used by Halliday.

Secondly, a way to find the center of gravity of a crawler type tractor is to drive it over a block until the back of the machine tips up off the ground. At this instant, the center of gravity is directly above the edge of the block.

A method which seems quite applicable to apples and pears was also presented by Barger. Here the tractor is placed on a horizontal plane with the front wheels on a scale. By knowing the total weight of the tractor, the reaction at the weighed end, and the length between the points of contact of the wheels, a summation of moments about the fixed end gives the location of the center of gravity.

2.3. Existing Orienting Machinery

Several machines have been developed to orient apples and pears. Of greatest interest to this study are the characteristics of the fruit which are used for orientation.

Keesling (1965) patented a machine to orient apples by a set of feelers. The feelers rotate the apple in a cup until the indentation at the stem and calyx end is held by the sensors. This machine oriented the apple in either the stem up or stem down position. The properties of the apples which are most important to Keesling's machine are the size, shape, and friction coefficient.

The pear has a unique shape and mass distribution which lend to orientation. Coons (1950) invented a mechanism to orient pears by rolling them down an inclined trough. Because of the center of mass being closer to the bulb end, the pear will stop rolling when the stem end is toward the bottom of the trough. The frictional force also plays an important part in this machine.

A machine designed by Chamberlin (1965) orients pears by pushing them through a narrow walled section which converges at the bottom. The pear is supported by the walls and hangs stem down. A collector gathers the pears and holds them in this stem down position.

Gardiner (1964) invented a machine to orient pears by shuffling them along an incline. The pears topple end over end until their heavy ends are toward the top of the incline and are thus oriented.

Thompson (1952) devised a machine that would orient pears by passing them along rollers which had convoluted threads. The pears line up along the threads with their stem ends in the direction of travel.

III. APPARATUS AND PROCEDURE

3.1. Friction

The equipment used for friction testing is shown in Figure 1. The horizontal platform is supported by six casters which run on angle iron tracks. These angles are supported by a pipe and angle iron framework. A piece of six-inch channel iron is attached beneath the platform to provide rigidity. The platform is driven by a ball bearing screw assembly which is driven by an electric motor through a series of pulleys. The desired speed of the platform is obtained through a selection of pulley sizes. Each revolution of the screw displaces the table one inch. For the slow speed, used in the preliminary tests, a speed reducer is used between the motor and screw.

Figure 2 is the holder for the fruit and is constructed of a quarter inch stove bolt welded to a three-eights inch nut which provides for height adjustment for different sized fruit. With this apparatus, only the fruit touches the friction surface. The frictional force is measured by a Baldwin-Lima-Hamilton fifty-pound load cell. The connection to the load cell is provided by a drop piece made of oak wood which has the necessary rigidity to prevent vibrations and also a break-away safety feature. The signal from the load cell is fed into a Brush amplifier and the output is recorded on a Hewlett-Packard X-Y recorder (Figure 3). The X-Y recorder has an internal time base which is used as the table displacement input.

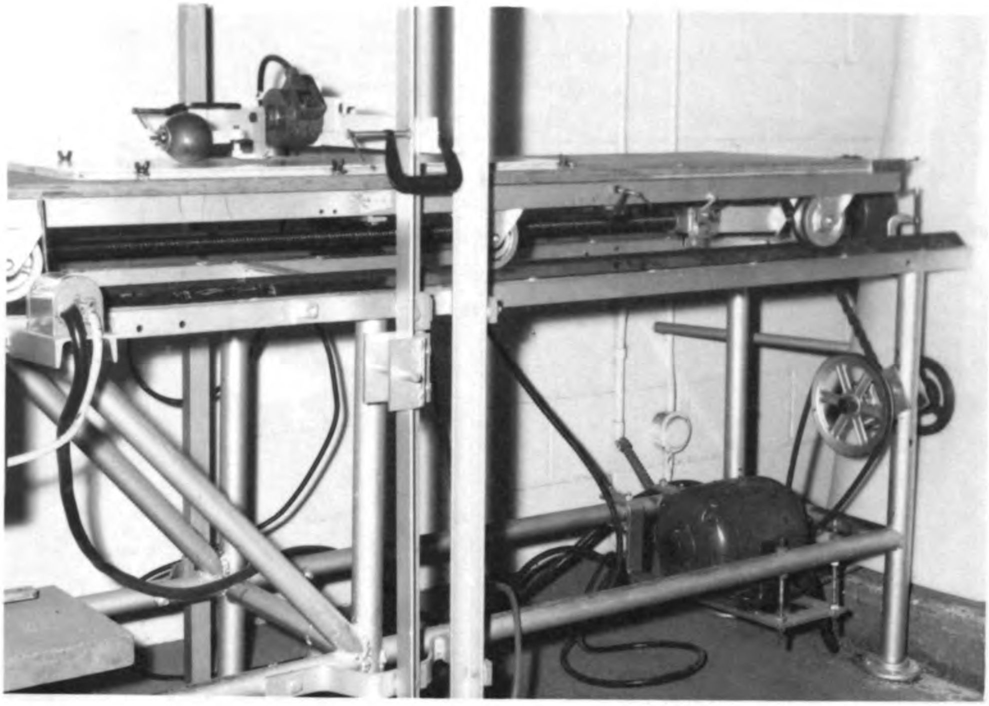


Figure 1. Platform used for friction tests.

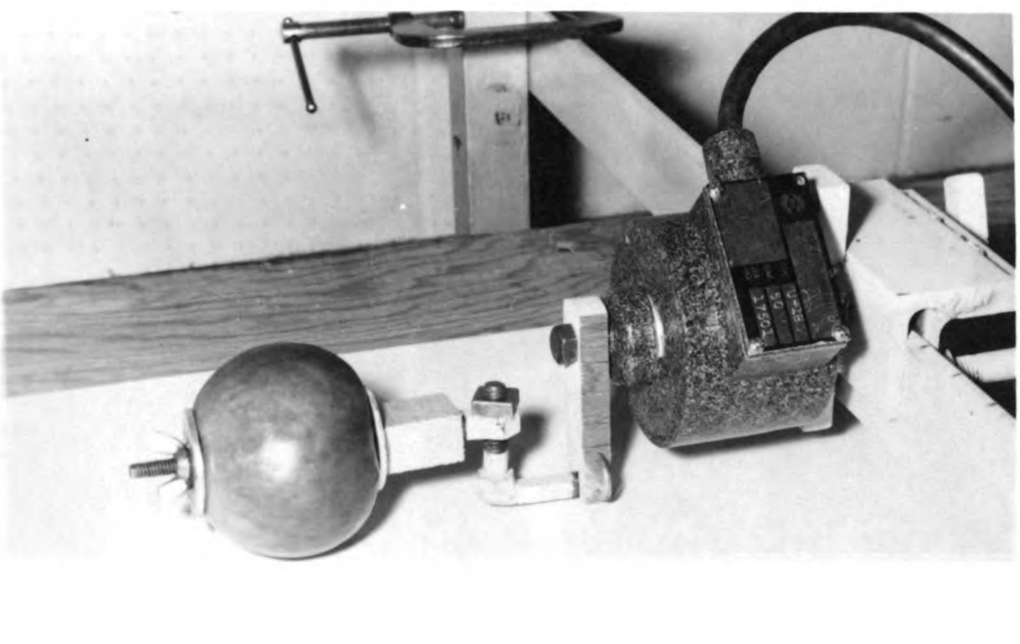


Figure 2. Apparatus for holding the fruit for friction tests.

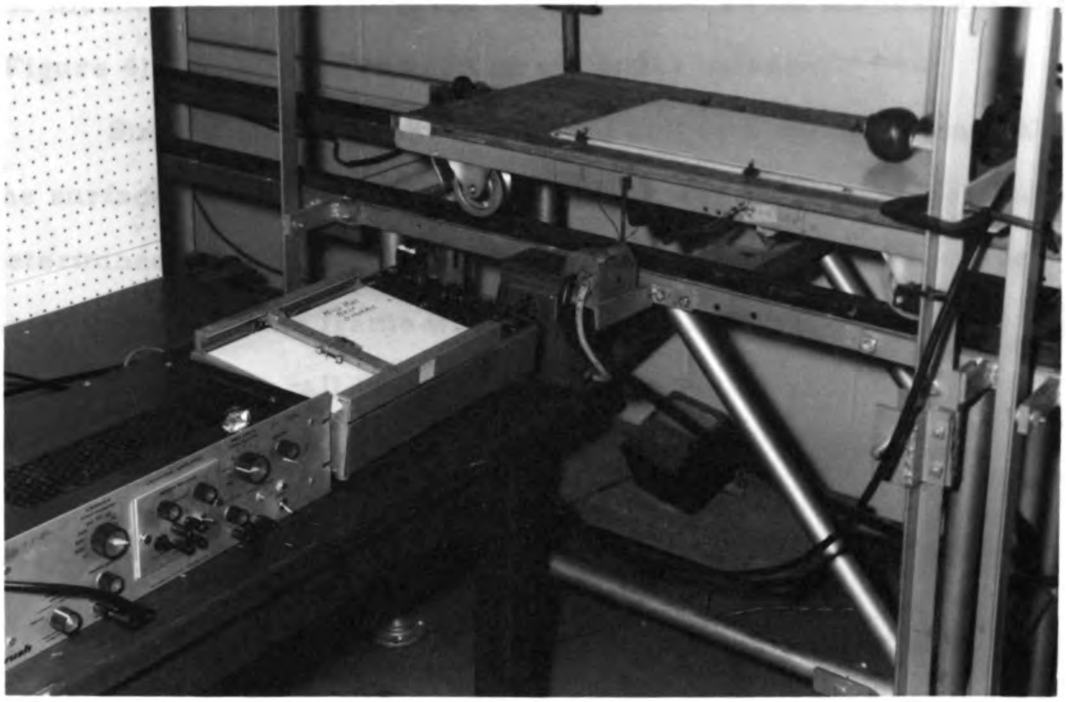


Figure 3. Instrumentation used for friction measurements.

Figure 4. Measurement of normal force for friction tests.

In order to measure the normal force, the fruit is placed on the mount and supported in the same manner as on the test surface (Figure 4). The force is read on a Mettler balance.

Since the connection to the load cell is a small distance above the surface, a small amount of force transfer occurs. This can be determined from the following force analysis. Figure 5 is a free body diagram of the frame which holds the fruit, in which:

- L - overall length of the fruit support
- M - the combined center of gravity of the fruit and the support
- X - the distance of M from the point of contact of the fruit on the friction surface
- h - the height at which the support is connected to the fruit
- d - the height above the friction surface at which the fruit support is pinned to the drop arm of the loaded cell
- F_n - normal force on the fruit from the surface
- F_f - friction force of the surface on the fruit
- R_H - horizontal reaction at the pin
- R_v - vertical reaction at the pin
- A - pinned end of the support

In 5a, the summation of moments about A gives:

$$\Sigma M_A = 0 = M(L-X) - F_n L$$

so, $$F_n = \frac{M(L-X)}{L} \quad . \quad \text{(No Friction Force)}$$

Now, add a friction force (Figure 5b). Summing moments again about point A yields:

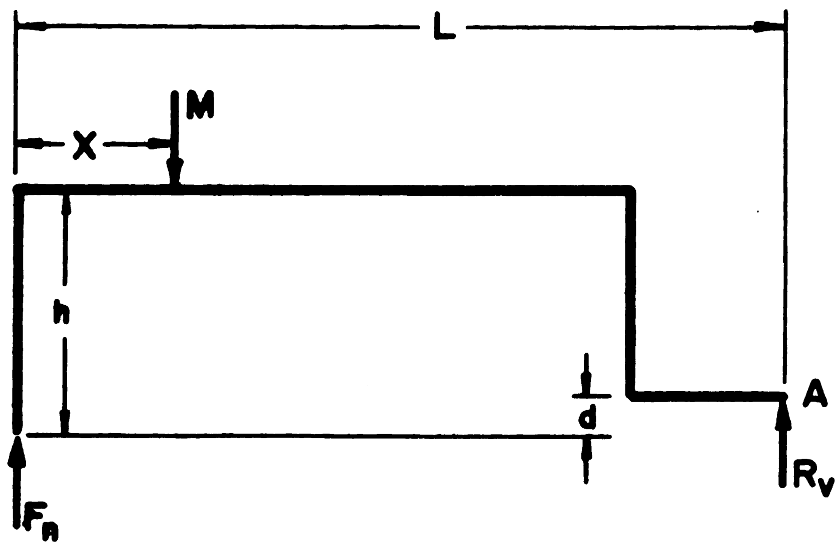


Figure 5a. Fruit support without friction force.

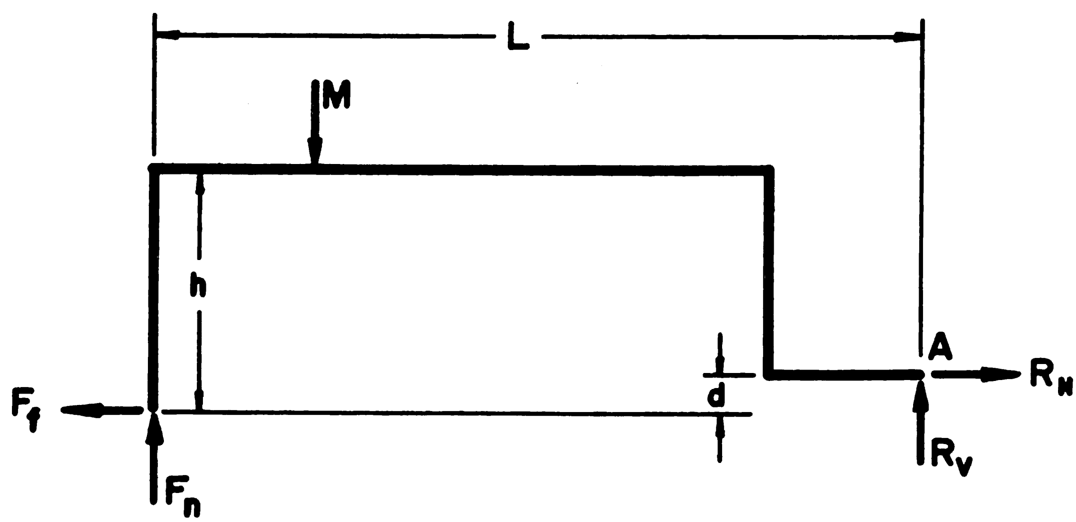


Figure 5b. Fruit support with friction force.

$$\Sigma M_A = 0 = M(L-X) - F_n L - F_f d$$

therefore,

$$F_n = \frac{M(L-X)}{L} - \frac{F_f d}{L} \quad .$$

With the addition of a frictional force, the normal force is changed by the amount $F_f d/L$. In this test the factor of d/L was kept at about 1/20 and then multiplied times F_f (recorded) and subtracted from F_n before the coefficient of friction was calculated. For most tests the frictional force varied between 50 and 150 grams. Therefore, the normal force transfer is about 2.5 to 7.5 grams.

The apples and pears used in this test were all taken from storage. The apples were "fancy" varieties from Washington, Michigan, and New York, and the pears came from Michigan. The fruit used for the various experiments were chosen for being visibly free of large surface bruises or breaks. The Washington Winesap apples were coated with an oily protection for shipping and consequently were not used for friction tests.

The procedure used to measure the frictional force was basically the same for each fruit. First, the fruit was taken out of cold storage and washed with water to remove any chemical treatments or dirt from the surface. This did not remove the wax cuticle which protects the apples and pears. After washing, the fruit was left in a 70°F room for about 12 hours before the tests were made.

When the fruit was ready, the load cell was calibrated (Figure 6) by hanging gram weights on a string which was pinned to the same

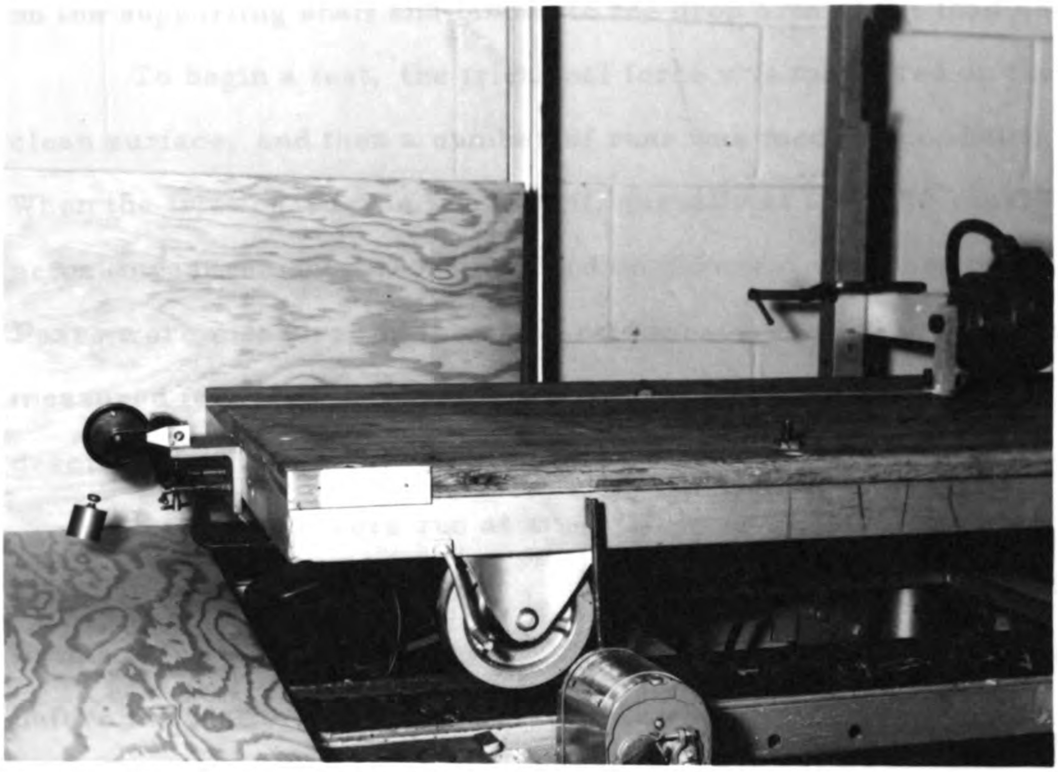


Figure 6. Calibration of load cell for friction tests.

wooden drop as the fruit would be. The force from the weights was directed in a horizontal direction by the means of a pulley mounted on the end of the platform. The calibration indicated that the load cell remained linear over the entire range used.

After the load cell was calibrated, the surface to be used in the test was cleaned with acetone. Then the fruit was placed on the supporting shaft and pinned to the drop arm of the load cell.

To begin a test, the frictional force was measured on the clean surface, and then a number of runs was made to condition it. When the frictional force leveled off, (usually at about 30 runs) the actual measurements were recorded on different varieties of apples. Pears were measured in the same manner. After each fruit was measured for frictional force, the normal force was measured as described above.

Static tests were run at a very slow speed by driving the platform by means of an electric motor connected to a speed reducer. In this test, the fruit remained stationary on the surface one minute before the platform was moved. This time factor was the only difference between the two types of tests,

The four surfaces chosen for the friction tests were Teflon, food belt, Ethafoam, and stainless steel (Figure 7). These surfaces were tested because of their applicability to fruit handling systems.

In order to describe the stainless steel and Teflon surfaces more specifically, a Bendix Microcorder was used. This instrument utilizes a stylus which is mechanically driven across the surface at a specified rate (Figure 8). The stylus follows the profile of the

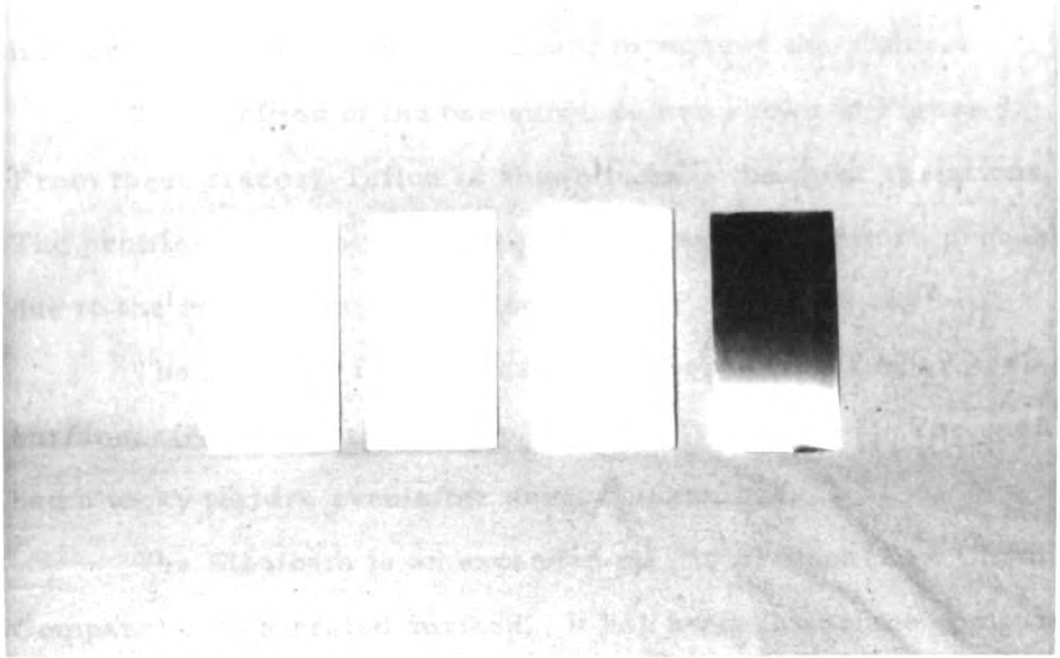


Figure 7. Surfaces used for friction tests. Teflon, food belt, Ethafoam, and stainless steel from left to right on the picture.

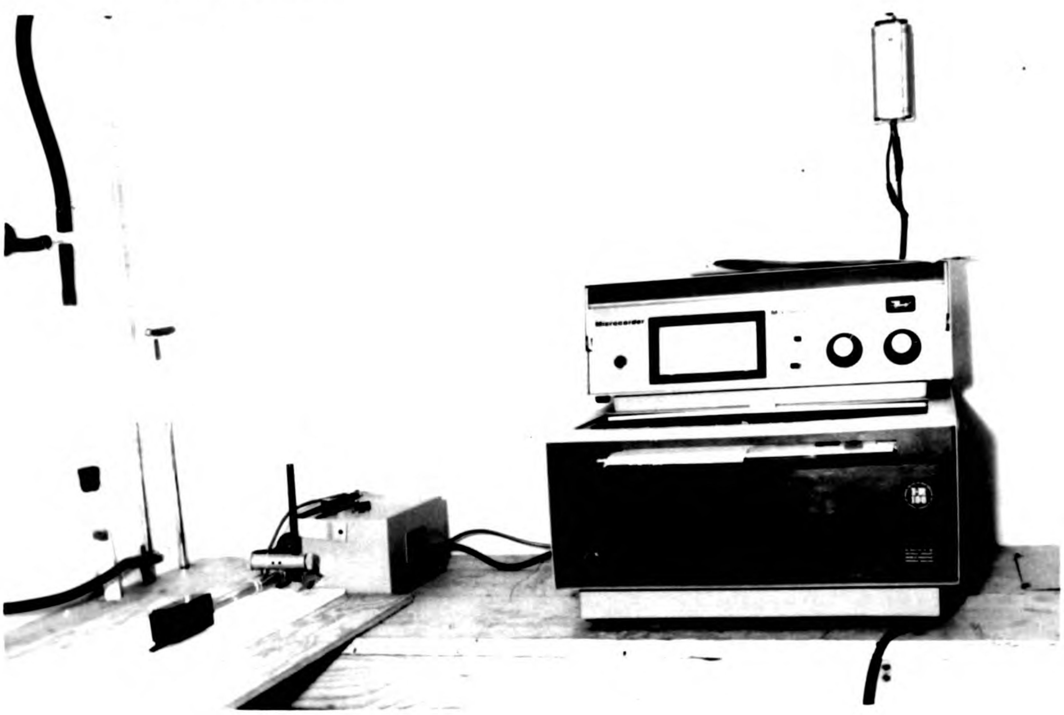


Figure 8. Bendix Microcorder used for surface profile measurements.

surface and the movement is recorded on a strip chart recorder. (The Ethafoam and food belt could not be measured with this instrument because they are too soft to support the stylus.)

The profiles of the two surfaces are shown in Figure 9. From these traces, Teflon is shown to have the most variations. The profile of the stainless steel was a wave like pattern probably due to the roll marks on the steel.

The food belt is a canvas backed belt with a rubber sealed surface. (A. J. Sparks and Co., White-Tex No. 142) The surface had a tacky texture even after several cleanings.

The Ethafoam is an expanded plastic product (Dow Chemical Company) with a sealed surface. It has a rough surface compared to the others, but it was soft enough to deform noticeably under the weight of an apple.

3.2. Center of Gravity Measurements

For finding the center of gravity (C.G.) for an object sitting on a simply supported beam, the following force analysis was used. In Figure 10 (a and b):

L - the overall length of the beam

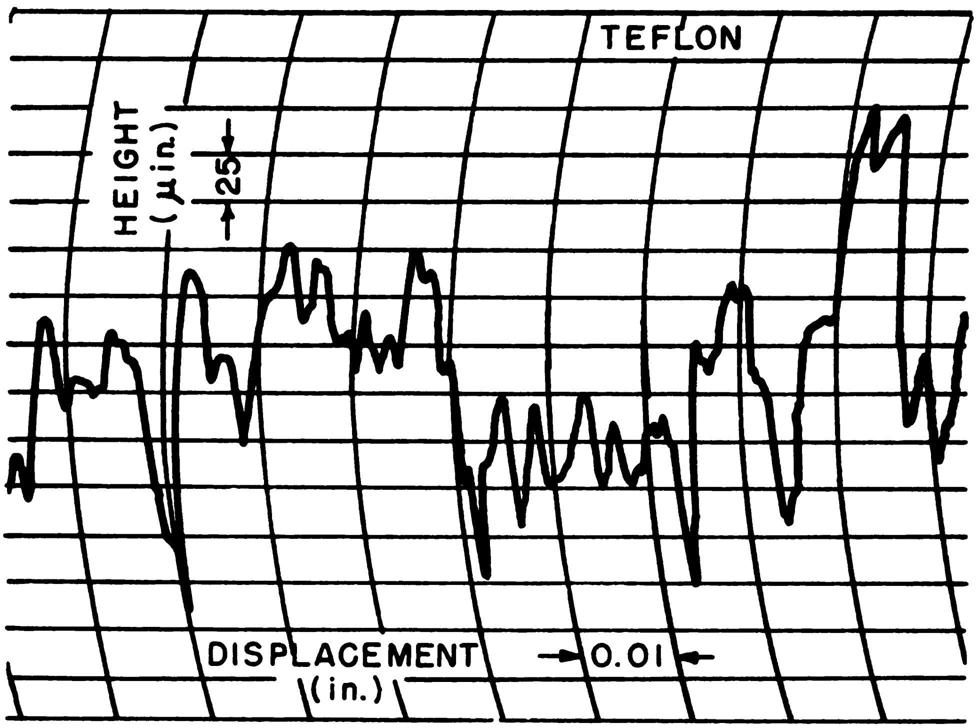
W_B - the weight of the unloaded beam

W - the weight of the fruit

Y - the distance of the center of gravity of the beam from the right end of the unloaded beam

X - the distance of the center of gravity of the fruit from the right end

R_o - reaction at the left end of the unloaded beam



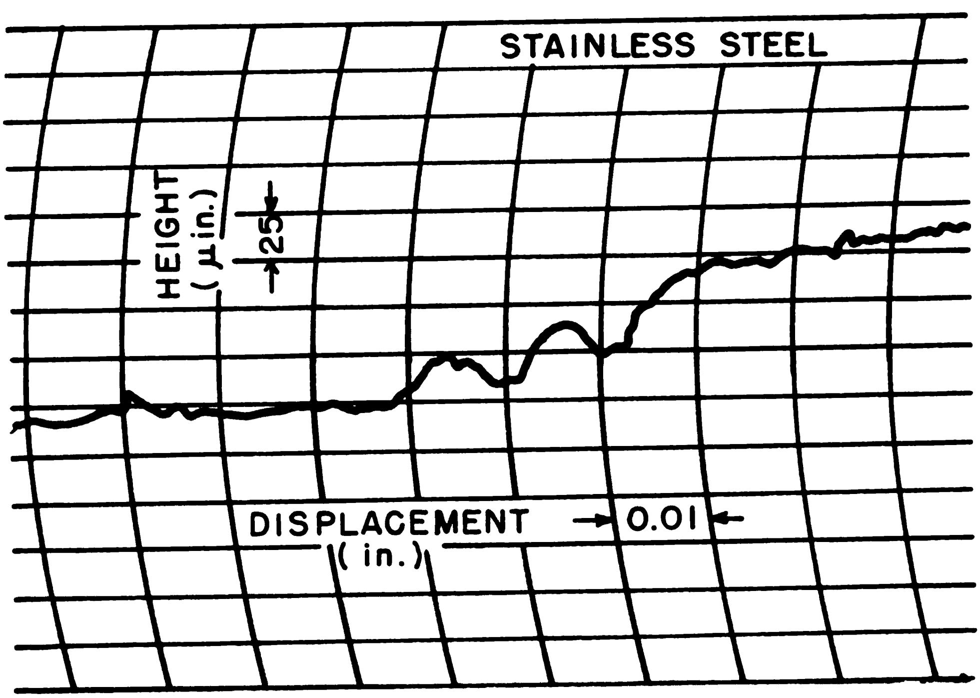


Figure 9. Surface profile curves for Teflon and stainless steel.

F_o - reaction at the right end of the unloaded beam

R_L - reaction at the left end of the loaded beam

F_L - reaction at the right end of the loaded beam

By summing moments about A:

$$\Sigma M_A = 0 = R_o L - W_B Y$$

so $$W_B Y = R_o L \quad . \tag{1}$$

From the loaded beam in Figure 10b, we get

$$\Sigma M_A = 0 = R_L L - WX - W_B Y \quad . \tag{2}$$

However, by substituting (1) into (2),

$$(R_L - R_o)L - WX = 0$$

$$X = \frac{(R_L - R_o)L}{W} \quad ,$$

where X is the distance to the C. G. position.

To measure the center of gravity position of an apple or pear, an eight inch long beam was constructed with a support for apples and pears (Figure 11). The beam was made of wood and was rigid as well as light weight.

To determine the position of the C. G. along the core, the length of the fruit was measured with a slider device shown in Figure 12. The fruit was then placed on the beam support and the beam was placed in the position shown in Figure 13. One end (right) was placed on a fixed stand while the other was weighed. The ringstand provided for verticle adjustment which was needed to level the beam prior to reading the weight.

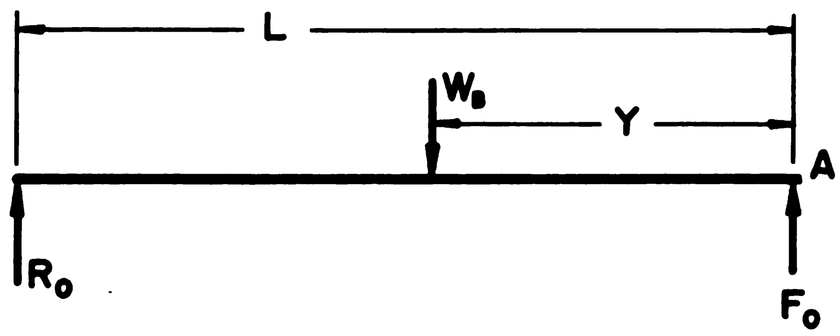


Figure 10a. Diagram of unloaded beam for center of gravity measurements.

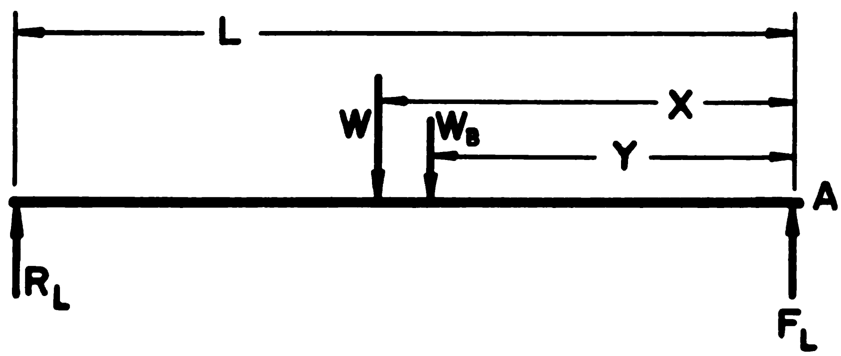


Figure 10b. Diagram of loaded beam for center of gravity measurements.

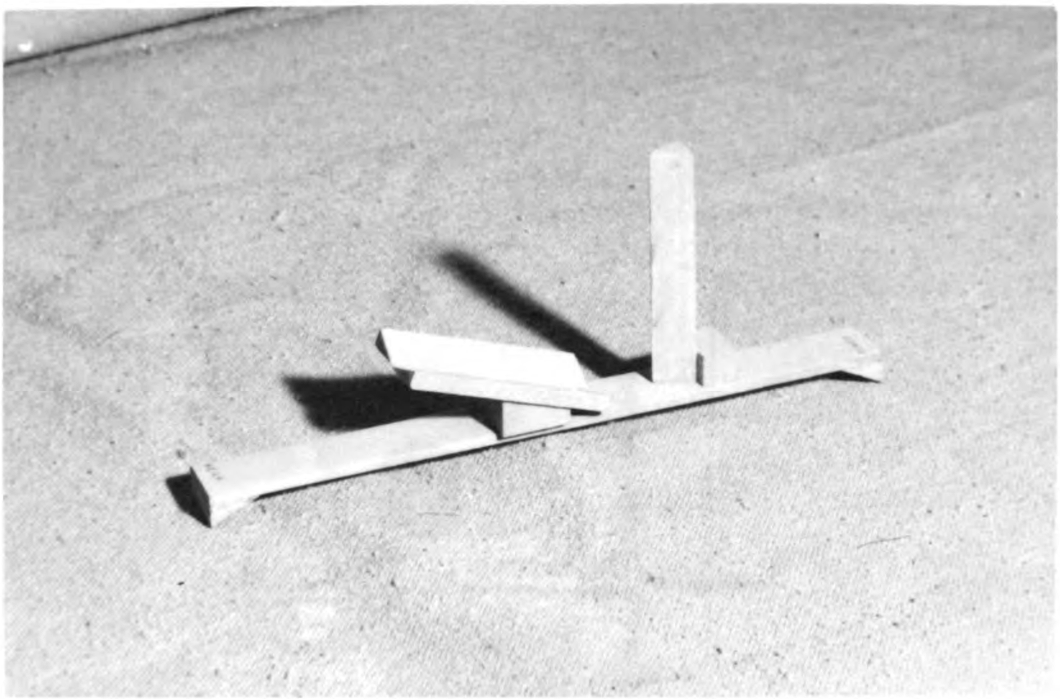


Figure 11. Beam for center of gravity measurements.

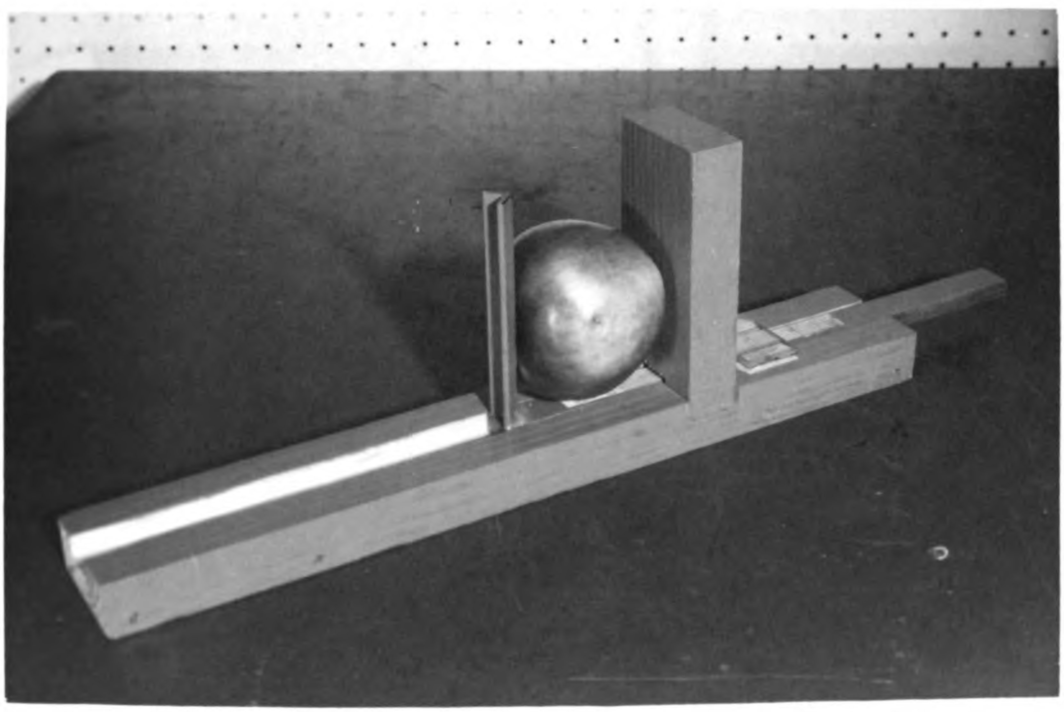


Figure 12. Device for measuring the length of an apple or pear.

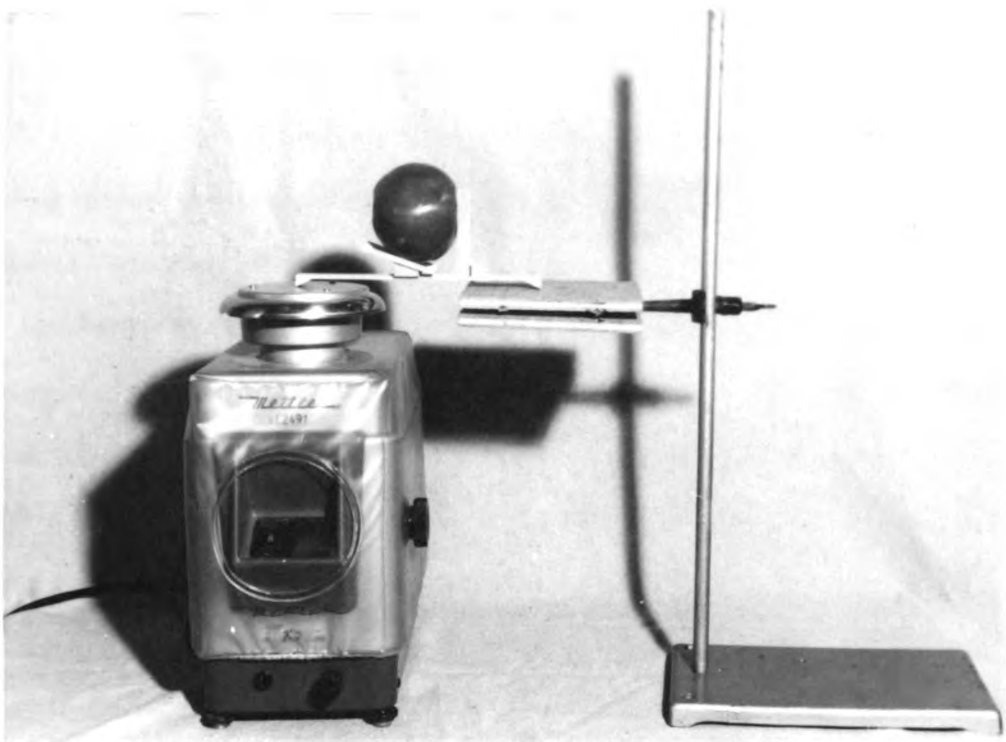


Figure 13. Measurement for the location of the center of gravity.

After measuring the loaded beam, the free weight of the left end of the beam was determined with no fruit on the support (R_o). By subtracting the free weight of the beam from the loaded weight, the derived equation would give the C. G. location from the right end. By knowing the exact location of the fruit support, the C. G. position relative to the end touching the support could be determined.

IV. RESULTS AND DISCUSSION

4.1. Preliminary Tests for Friction Coefficients

A series of tests was run on a smooth aluminum surface using Michigan McIntosh Apples to determine what type of tests should be run on the other surfaces. These tests were performed to determine some of the factors involved with friction coefficients.

The first test was a dynamic test run at a table speed of 200 inches per minute to determine if the coefficient would change as the number of passes on a surface increased. The test showed conclusively that as the aluminum built up with residue from the apples, the coefficient of friction increased. This increase leveled off at about 30 runs.

Another test was run on aluminum which was cleaned with acetone between each pass of an apple. This test was used to determine whether or not the results from a supposedly identical surface would vary. Eight different apples were run and the results are shown in Table 2.

Table 2.

Coefficient of friction of Michigan McIntosh Apples on a clean aluminum surface

Apple number	Coefficient of friction
1	0.55
2	0.49
3	0.52
4	0.59
5	0.53
6	0.61
7	0.55
8	0.55

The average coefficient of friction was 0.55 with a standard deviation of 0.038. This seemed very good for a biological material.

With these two small test runs, an idea for a test on the various surfaces was outlined to determine the variation between clean and conditioned surfaces using a dynamic loading rate and a static loading rate (200 inches per minute and 0.33 inches per minute respectively). The four surfaces used were stainless steel, Teflon, Ethafoam, and food belt, as described previously. Ten Michigan Spy Apples were used on each surface. Table 3 shows the results of this test.

With reference to the coefficients of friction in Table 3, it can be determined that apples do act as most biological materials - quite variable. However, a more important fact discovered was the discrepancy between the values of static coefficient of friction obtained to what they should theoretically be. Almost all theories of friction suggest that the static coefficient should be larger than the dynamic coefficient which was not the case in this study.

A closer look at the static coefficient of friction from this test is in order. From the graph in Figure 14, it is important to note that the initial motion of the platform causes a sharp peak on the static friction force curve. It was assumed that this was due to a sticking of the apple to the friction surface caused by a one minute delay period used to "settle" the fruit on the surface before motion was initiated. Therefore, the peak force necessary to move the apple was reduced by shortening this one minute delay (Figure 15).

Table 3

Coefficient of Friction of Michigan Spy Apples

		Surfaces							
		Teflon		Stainless Steel		Ethafoam		Food Belt	
Load Rate	Surface Condition	average	standard deviation	average	standard deviation	average	standard deviation	average	standard deviation
static	conditioned	0.22	0.01	0.33	0.04	0.32	0.05	0.67	0.52
static	clean	0.25	0.04	0.30	0.04	0.33	0.06	2.00	0.72
dynamic	conditioned	0.16	0.05	0.50	0.12	0.80	0.19	1.95	0.34
dynamic	clean	0.18	0.03	0.38	0.09	0.42	0.07	1.58	0.25

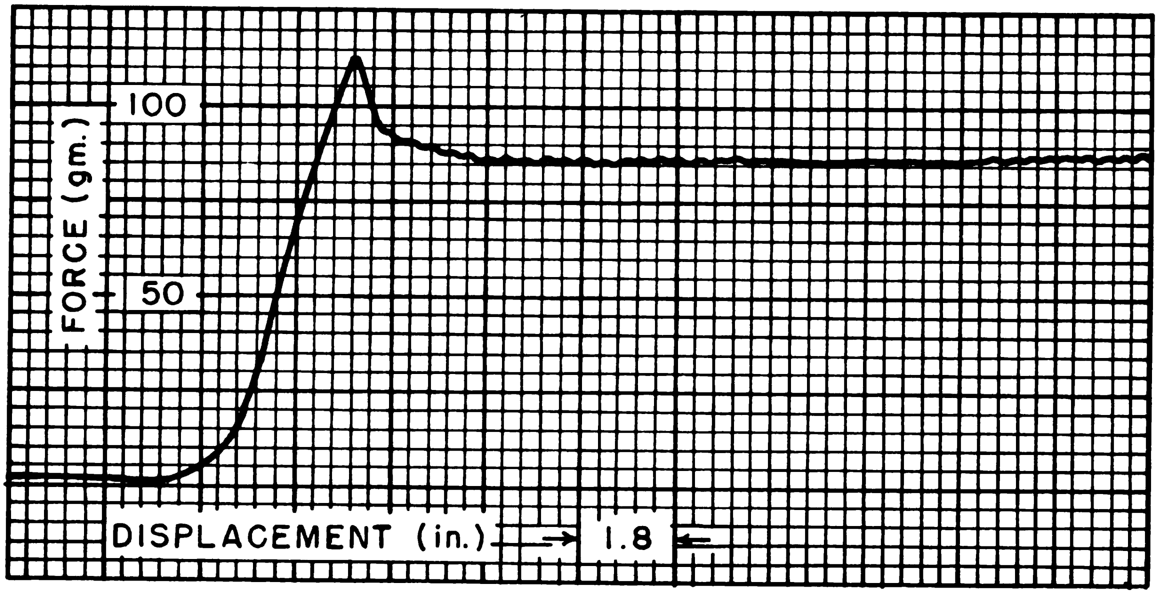


Figure 14. Force versus displacement curve for a very slow platform velocity after a one minute delay.

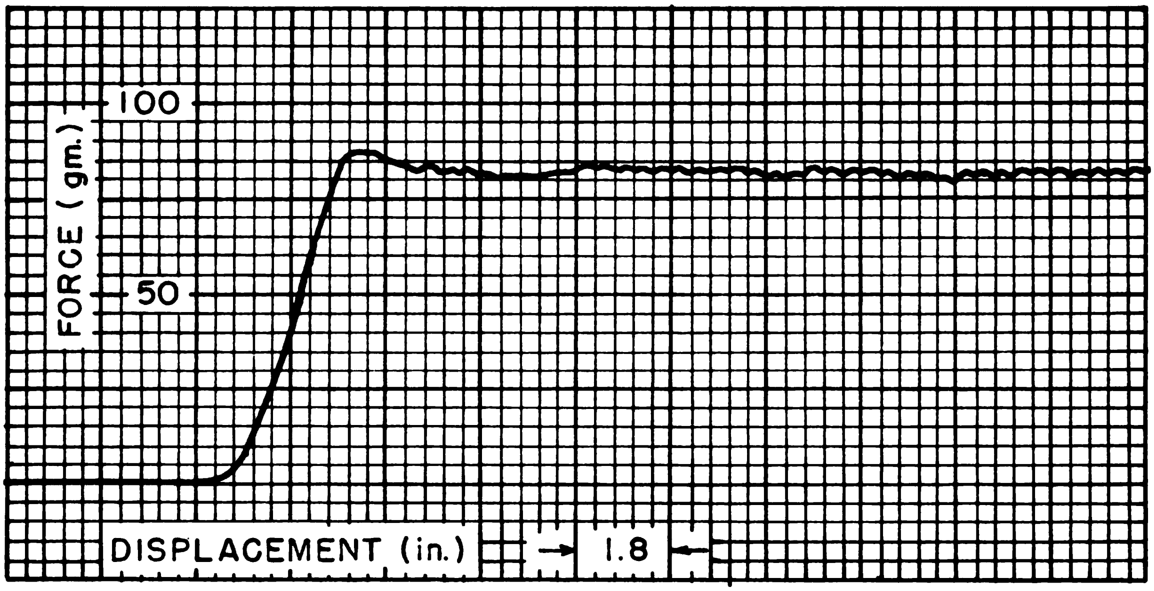


Figure 15. Force versus displacement curve for a very slow platform velocity after a five second delay.

From this fact, it was assumed that the time period permitted the apple to build a slight bond with the surface used in the test.

Since at the slow velocity the coefficient of friction was less, it follows that the platform speed affected the coefficient of friction. However, a variation of speeds between 10 inches per minute and 200 inches per minute did not vary the coefficient of friction. Since there was a distinct difference in the coefficient of friction at 10 inches per minute and 0.33 inches per minute, there would probably be a speed at which this change takes place, or perhaps the change takes place over a range of speeds. Since it was of more interest to determine a coefficient of friction to be used for design purposes, this factor was not investigated further.

The static loading rate did not give a coefficient of friction that would be valuable for design purposes, so static tests were not performed on the other surfaces. Also, since a clean surface would not be present on equipment used for handling fruit, the surfaces were conditioned before the final tests were run. A sample of ten specimens was used in each test.

4.1.1. Results of Coefficient of Friction

All the tests performed for friction were run at a platform speed of 200 inches per minute on a conditioned surface. The conditioning took place in about 30 to 100 runs. The minimum of 100 passes was made before data were taken. The pears conditioned a surface in about the same number of runs as the apples did.

Table 4 and Figures 16, 17, 18, and 19, show the coefficients of dynamic friction for the different varieties of apples and pears.

Table 4

Dynamic Coefficient of Friction

Varieties	Surfaces							
	Teflon		Stain. Steel		Ethafoam		Food Belt	
	ave.	dev.	ave.	dev.	ave.	dev.	ave.	dev.
Mich. McIntosh	0.11	0.02	0.60	0.09	0.49	0.03	1.97	0.18
Mich. Red Delicious	0.13	0.01	0.39	0.08	0.63	0.12	2.03	0.33
New York McIntosh	0.12	0.02	0.67	0.12	0.86	0.10	1.83	0.20
Wash. Red Delicious	0.18	0.03	0.57	0.10	1.04	0.21	2.17	0.58
Wash. Red Romes	0.17	0.02	1.04	0.25	1.22	0.08	2.78	0.51
Mich. Bartlett Pears	0.15	0.01	0.32	0.09	0.41	0.04	1.48	0.21

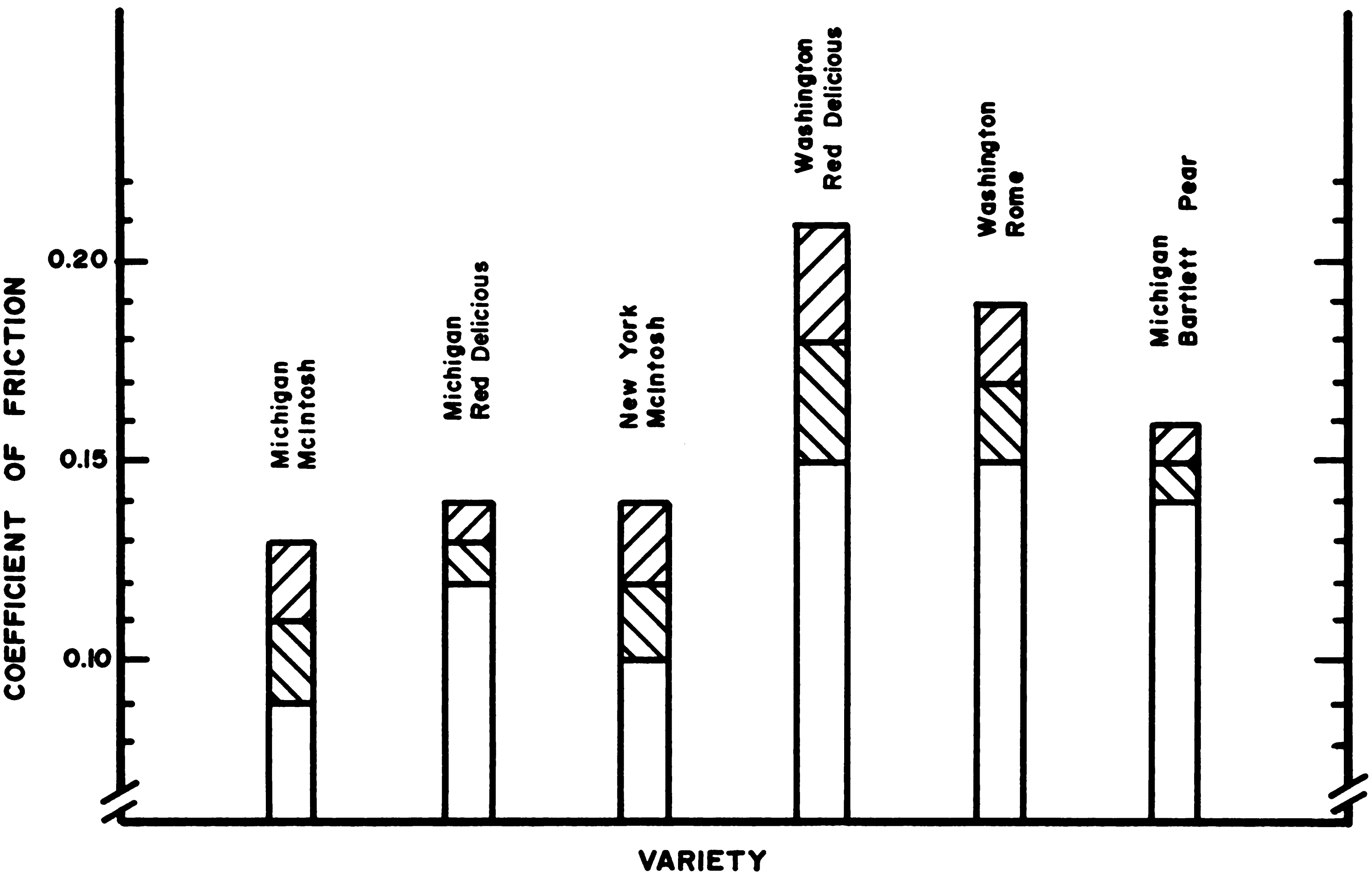


Figure 16. Dynamic coefficient of friction on Teflon. (The cross hatched portion of the bar represents the average value plus or minus one standard deviation.)

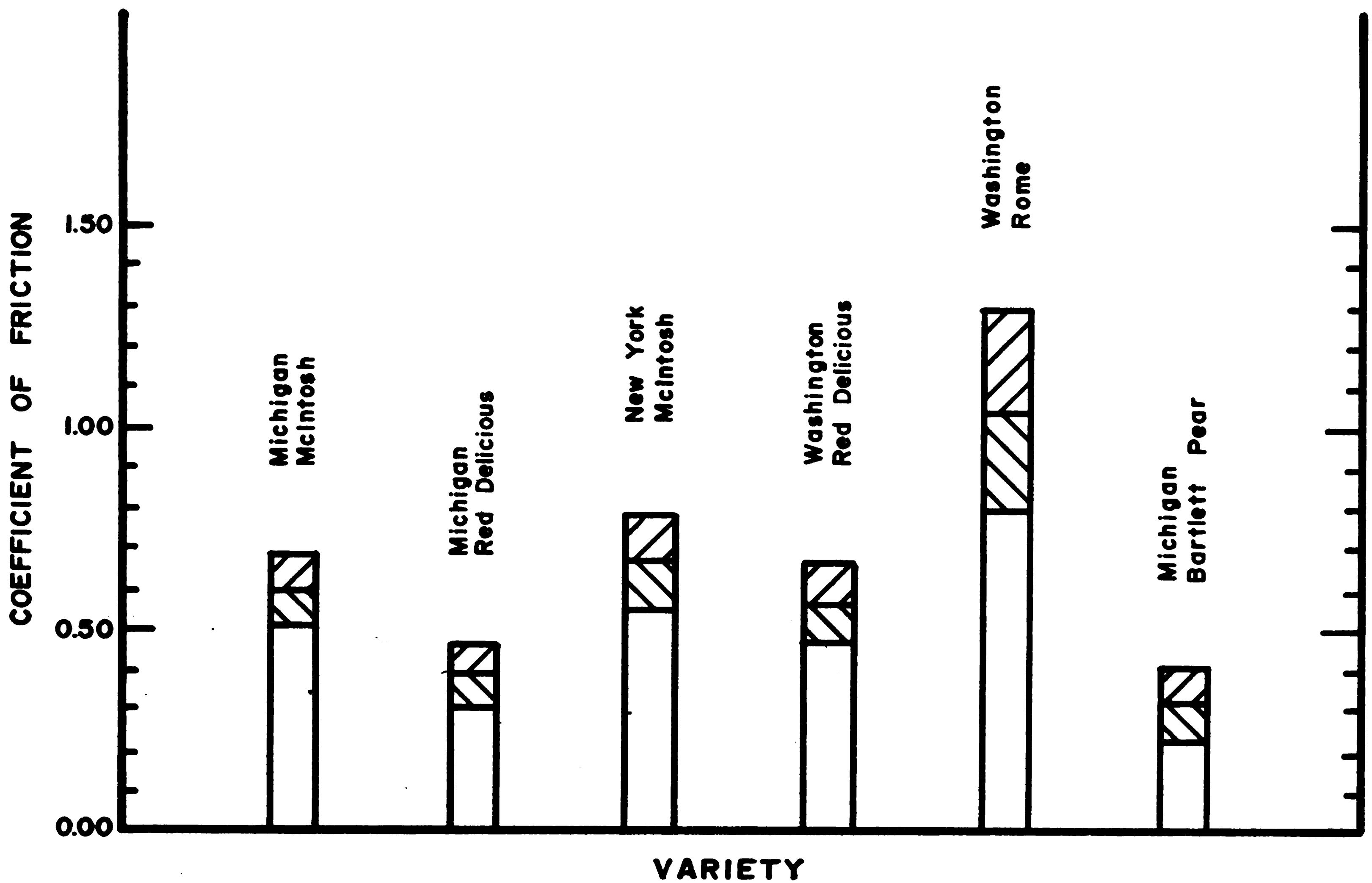


Figure 17. Dynamic coefficient of friction on stainless steel. (The cross hatched portion of the bar represents the average value plus or minus one standard deviation.)

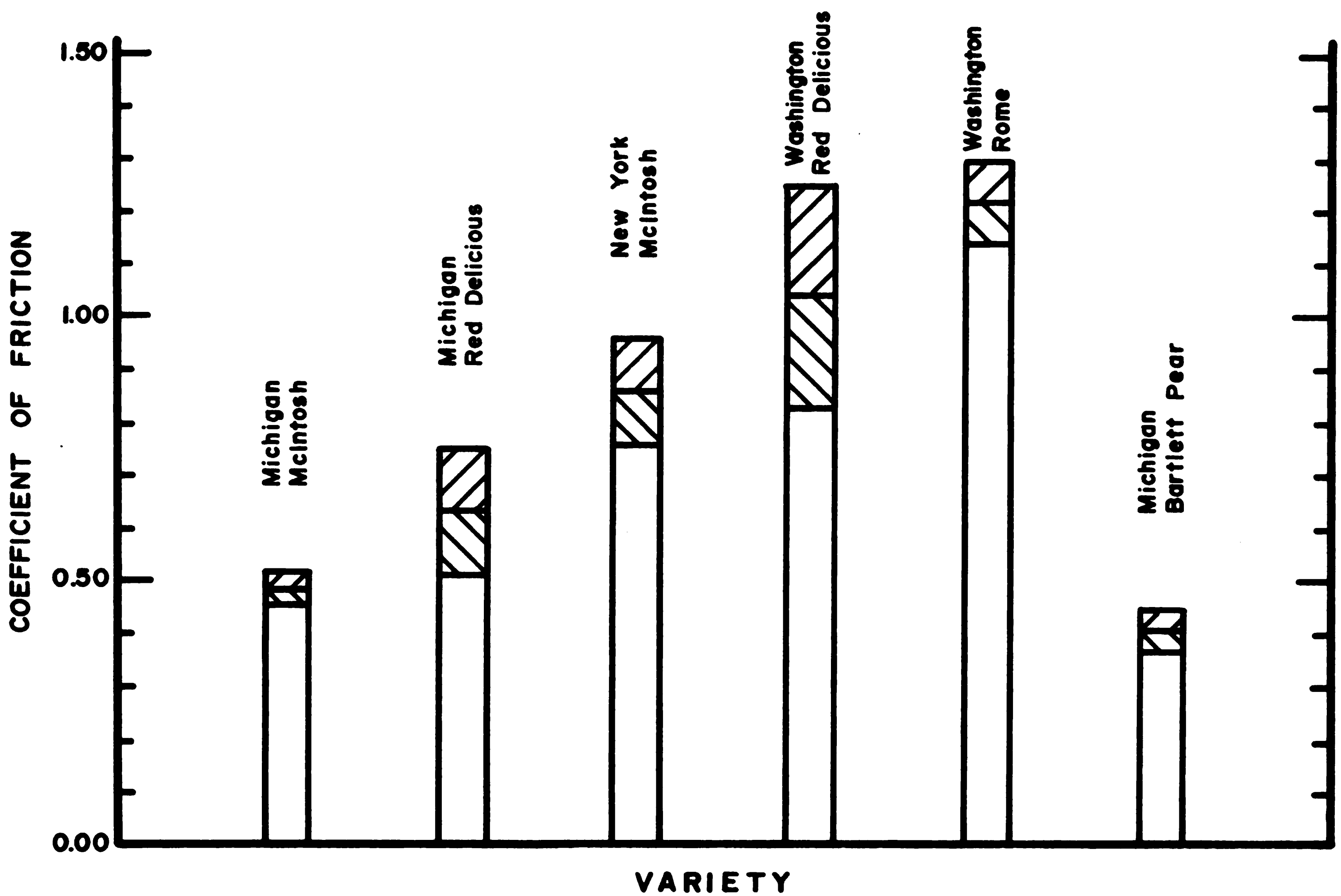


Figure 18. Dynamic coefficient of friction on Ethafoam. (The cross hatched portion of the bar represents the average value plus or minus one standard deviation.)

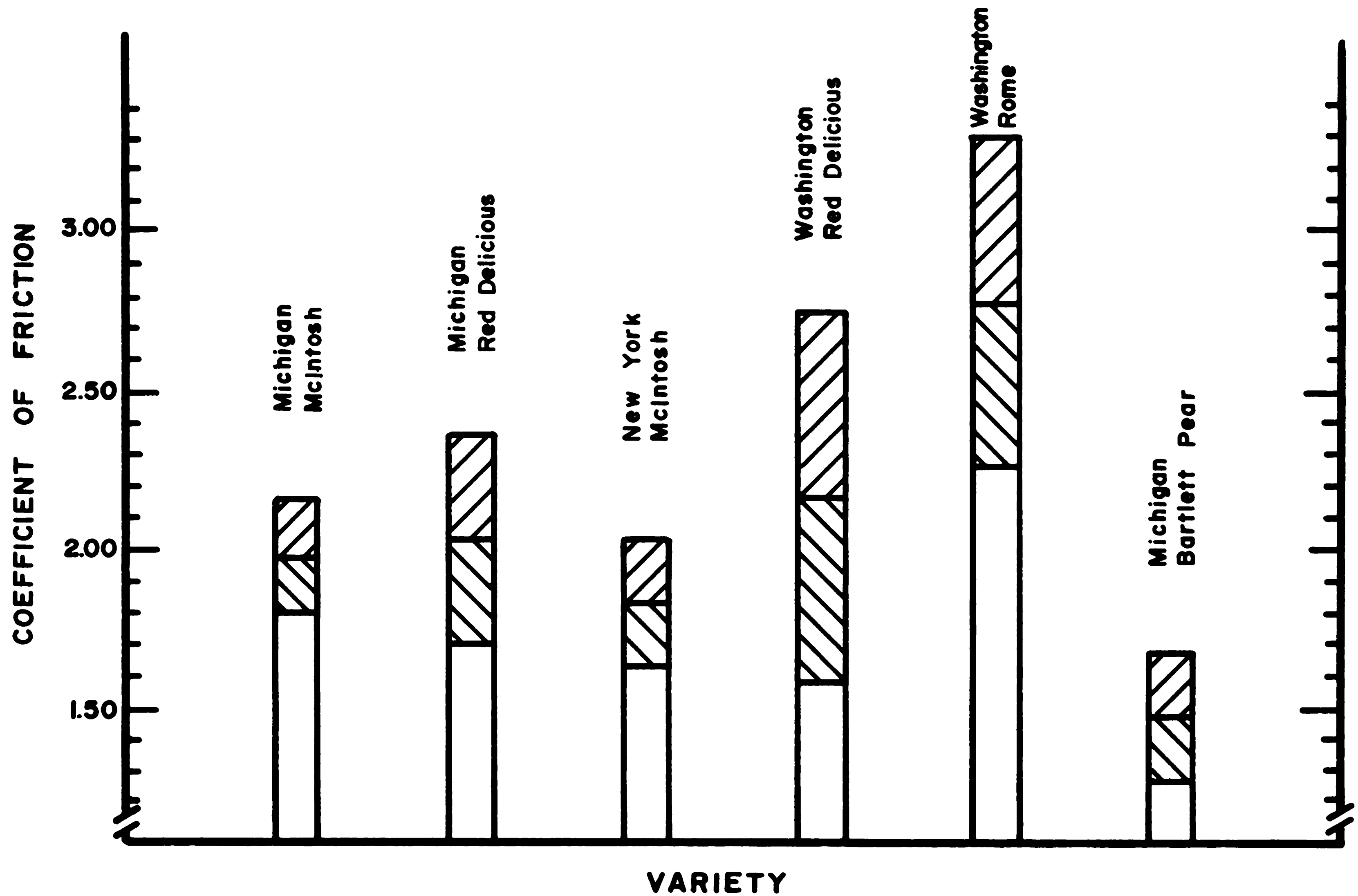


Figure 19. Dynamic coefficient of friction on food belt. (The cross hatched portion of the bar represents the average value plus or minus one standard deviation.)

The coefficient of friction varied a great deal from one variety to another. The food belt had the largest standard deviations for the separate varieties. Teflon was the most consistent surface for all the varieties tested. For any critical design where a constant external force was needed, Teflon is the best surface to use. Also, the effect of conditioning was almost negligible on Teflon.

Even with these coefficients of friction measured on a conditioned surface, the frictional force obtained on a surface used for fruit handling equipment would probably vary considerably. This variation would occur from temperature change, moisture, surface dirt, and fruit conditions.

The tests in this study were run at room temperature (70-50°F) on a dry conditioned surface. With the introduction of dirt or juice from the fruit, the coefficient of friction would surely change. The values cited here should be used only as estimates, and variations due to the factors discussed should be expected. The one exception to these changes might be Teflon. Since the surface contaminates do not stick to Teflon, the coefficient might remain relatively constant.

4.1.2. Effect of Friction on Apple Skin

Since there was some of the cuticle layer removed from the apples and pears during the friction tests, an attempt was made to determine what effect this had on the fruit by observing cross sections of the skin under a microscope.

The surfaces which were expected to do the most damage to the fruit were stainless steel and Teflon since they were the most rigid. However, it was observed that residue from the fruit did not stick to the Teflon, so the first slide made was of the section run on stainless steel.

A Michigan Red Delicious Apple was run across the stainless steel surface used in the friction test. A cross section was taken of the portion of the skin that made contact with the friction surface. The cross section was then observed under the microscope to determine if the wax covering on the fruit had been removed.

From Figure 20 and Figure 21, the difference between a normal section and a section run on stainless steel can be observed. However, the effect on the apple was very slight. The only noticeable characteristic caused by the friction test was the smoothing out of the cuticle layer. The rough portion of the surface shown in Figure 20 is no longer observable in Figure 21, but there is still a covering of wax on the fruit.

4.2. Results for Center of Gravity Measurements

After the location of the C.G. relative to the stem end was determined, it was of interest to find a relationship of this length to the total length of the apple. The following ratio was calculated

$$A_{cg} = \frac{\text{Length of C.G. from stem end}}{\text{Total length of the apple}}$$

The average ratios and standard deviations are shown for the different

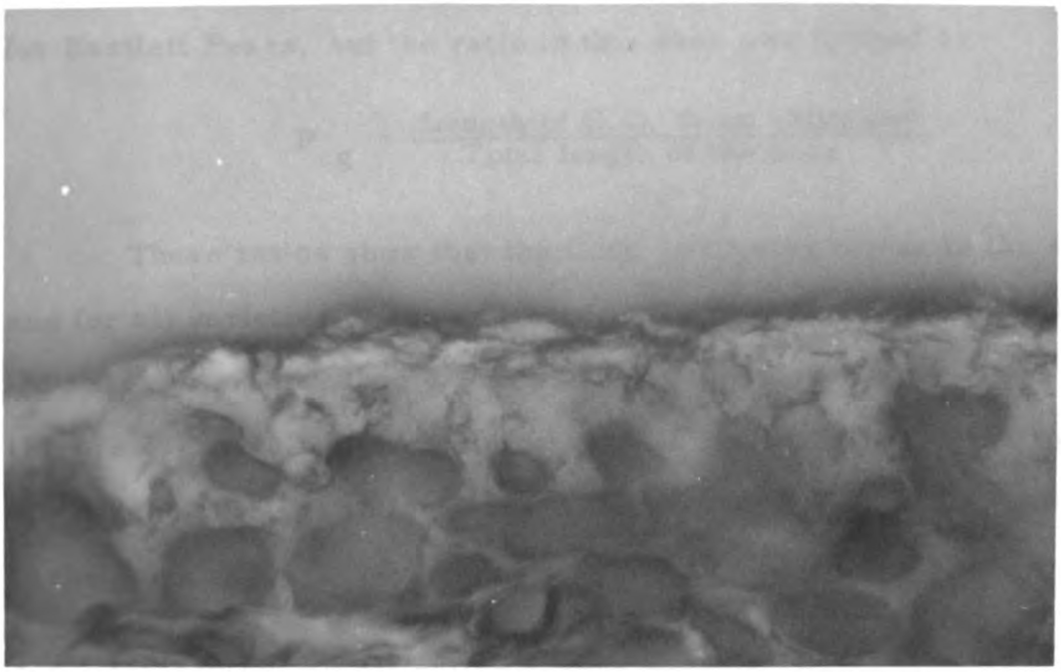


Figure 20. Microscopic view of a cross section of an apple skin showing a rough cuticle. (250X)

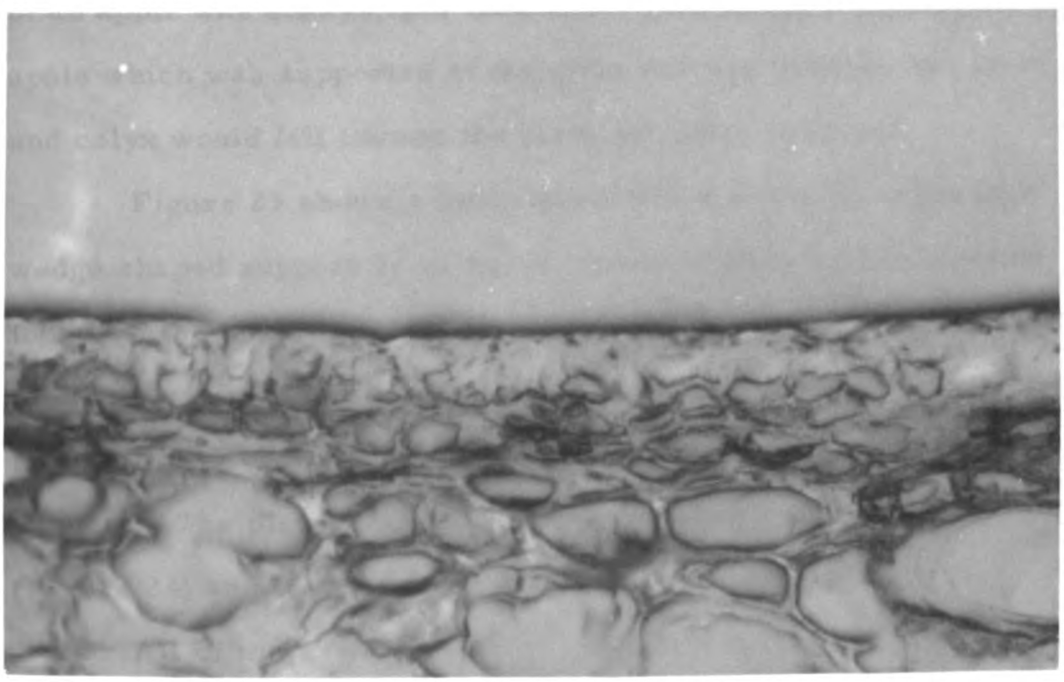


Figure 21. Microscopic view of a cross section of an apple skin with a smooth cuticle after it has been run across a stainless steel surface. (250X)

varieties of apples in Table 5 and Figure 22. Also shown is a ratio for Bartlett Pears, but the ratio in this case was formed by:

$$P_{cg} = \frac{\text{Length of C. G. from calyx end}}{\text{Total length of the pear}}$$

These ratios show that the C. G. is located closer to the stem end for all varieties of apples tested. The only two varieties that have a ratio greater than 0. 5 after adding one standard deviation (Figure 22) are Michigan McIntosh Apples and Michigan Northern Spy Apples. The ratio for pears indicates that the C. G. is closer to the calyx end.

4.3. Mechanism for Orienting Apples Stem Down

From the results of the C. G. measurements, it was noted that the ratio of C. G. position from the stem end to the total length of an apple was always less than 0. 5. This would indicate that an apple which was supported at the point midway between the stem and calyx would fall toward the stem end when released.

Figure 23 shows a mechanism which holds an apple on a wedge shaped support by using two parallel plates. The overall length of the apple was measured between the two plates, and then the fruit was positioned on the wedge as shown in the picture, such that half of the overall measured length was on one side of the support. The plates were then rapidly pulled away from the apple (Figure 24) and the direction of fall was recorded.

All of the varieties tested fell stem down 100% of the time except for Michigan McIntosh, which fell stem down 80% of the time.

Table 5

Center of Gravity Ratio

Variety	Ave. Ratio	Std. Dev.
New York McIntosh	0.48	0.01
New York Red Rome	0.47	0.01
Washington Winesap	0.47	0.02
Washington Red Delicious	0.47	0.01
Washington Red Rome	0.48	0.01
Michigan McIntosh	0.49	0.01
Michigan Red Delicious	0.47	0.01
Michigan Spy	0.48	0.02
Michigan* Bartlett Pear	0.43	0.01

* The ratio is the distance from the calyx end over the entire length of the pear.

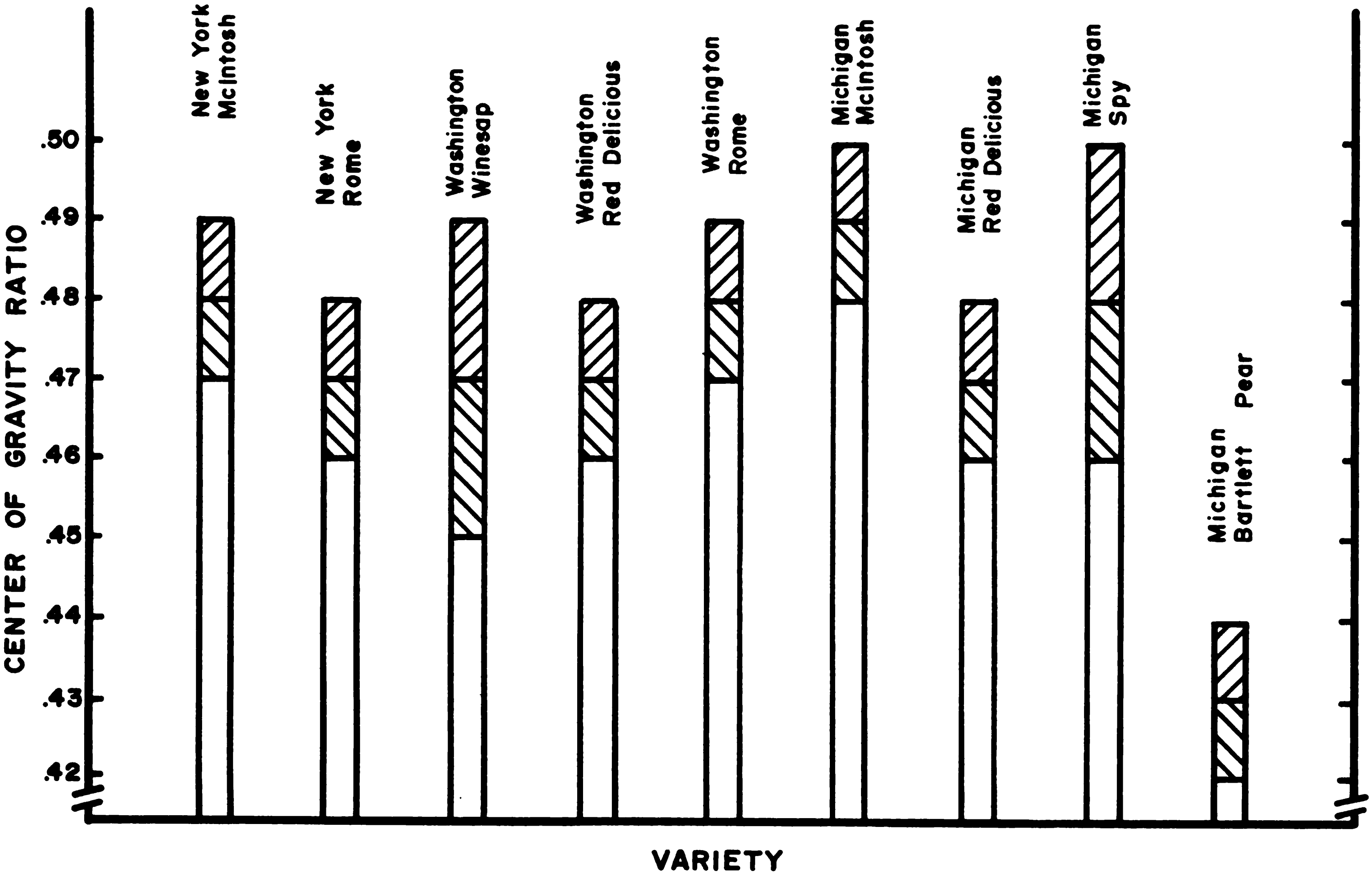


Figure 22. C.G. ratio versus variety. (The cross hatched portion of the bar represents the average value plus or minus one standard deviation.)

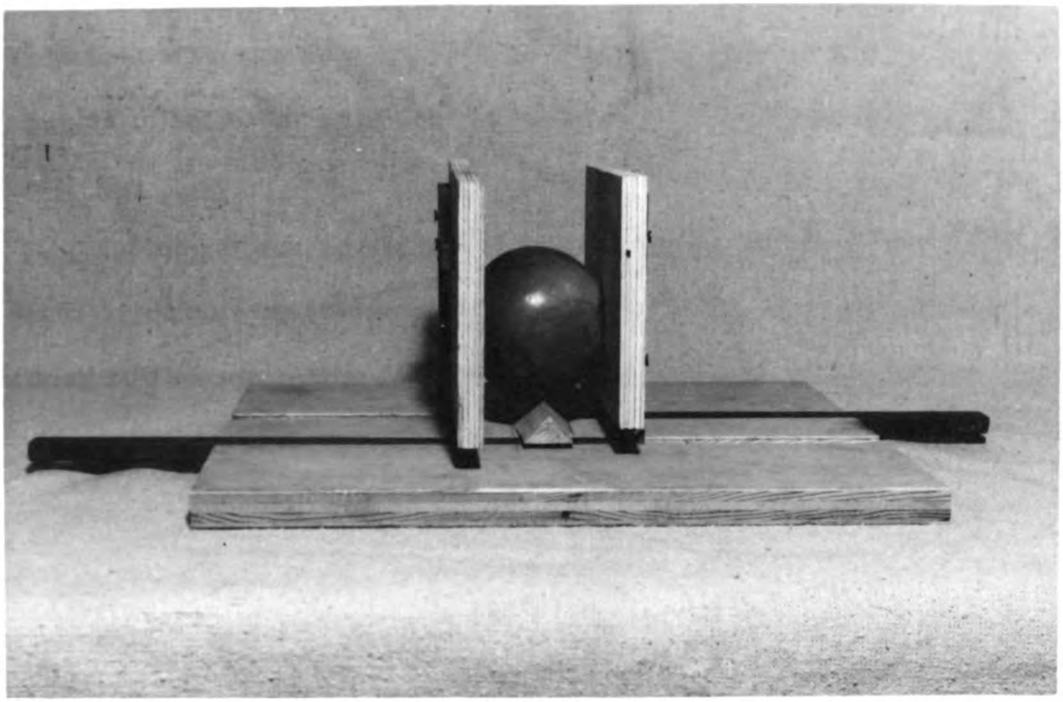


Figure 23. Mechanism for orienting apples stem down (in a closed position).

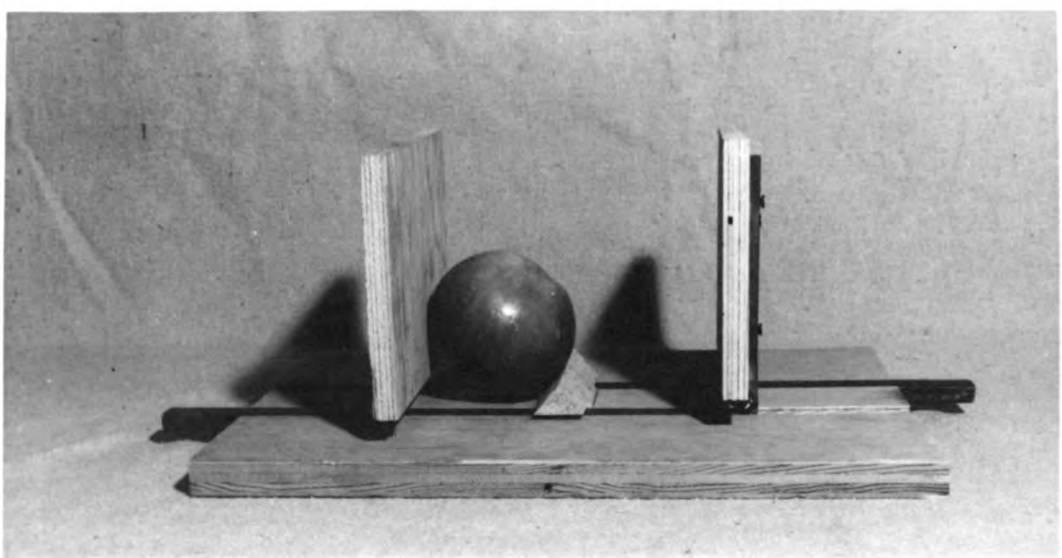


Figure 24. Mechanism for orienting apples stem down (in an open position).

This test was run on a sample of 10 apples of each variety. The results of this test support the information obtained from the C.G. test.

Since there are several machines which will orient apples stem or calyx up, (see the patent review) this method could be added to the operation to obtain a stem down orientation.

V. SUMMARY AND CONCLUSIONS

Orientation of apples and pears is of interest to packers and processors for inspection and labeling purposes. A study was initiated to determine some of the basic fruit characteristics which would be important to orientation. From this investigation, size, shape, coefficient of friction, and location of the center of gravity were found to be relevant to positioning. A thorough study was made of the coefficient of friction and the location of the center of gravity.

The coefficient of friction was measured for several varieties of fruit by attaching the specimen to a load cell and moving a horizontal platform beneath it. The coefficient of friction was determined on four surfaces: stainless steel, Teflon, Ethafoam, and food belt. Preliminary tests indicated that the frictional force increased as the number of runs across a surface with a fruit increased. This phenomenon continued until about 30 passes across the surface had been made. Therefore, the surfaces were conditioned by making at least 100 runs across them with a fruit before the final data were taken.

In addition, an attempt was made to measure the static coefficient of friction by using a very slow platform velocity. But, this gave unreliable results. The static coefficients determined in this test were less than the dynamic coefficients. This is contrary to the theory of friction, so a closer investigation was performed which indicated that the coefficient of friction was less

at very slow velocities. The final tests were run at a platform velocity of 200 inches per minute on a conditioned surface. Values for these coefficients of friction proved to be quite variable, and therefore, only usable as estimates for machine design parameters.

Measurements for the location of the center of gravity were made by placing the fruit on a small beam, weighing one end, and summing the moments about the fixed end. By knowing the weight of the unloaded beam and the weight of the fruit, the location of the center of gravity could be determined. Ratios were made of the location of the center of gravity along the core to the total length of the fruit. These ratios are important for locating the stem end of a fruit once a stem or calyx end orientation has been made.

5.1. Conclusions

Test results show that:

1. The coefficient of friction is quite variable and is affected by velocity and surface condition.

2. For design purposes, Teflon has the best coefficient of friction characteristics because it is least variable and conditioning of the surface has little effect.

3. The location of the center of gravity was found to be closer to the stem end in apples and nearer the calyx end in pears.

5.2. Suggested Future Work

The properties of apples and pears, which have been presented, are very useful for a force analysis on a fruit. The external force can be applied as a frictional force and the body force (weight) acts

through the center of gravity. However, before an analysis of these forces can be made, physical dimensions of the fruit along with the shape must be specified. These size and shape factors have to be correlated with the location of the center of gravity so that a stable position of the fruit can be determined. Further study is needed to determine if this stable position could be altered by using frictional forces so that a certain oriented position would result.

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