Design of a Mechanical Breadfruit Harvester

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Abstract

Present harvesting practices in the Carribean region are fairly primitive and lead to unnecessary fruit and tree damage, as well as the occasional loss of life and limb. An alternative design has been proposed which involves the use of an extendible wooden pole, basket retrieval and a horizontal, rope operated cutting mechanism. This design is simple, inexpensive to build and easy to use. A prototype of the design was built and tested in the Montreal region, and its full potential was evaluated.

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Introduction

Breadfruit (*Artocarpus altilis*) is an important food crop in the Caribbean region. The fruit is large and melon-like in appearance with a tough outer skin surrounding a pulpy interior (Figure 1). The pulp is used in the production of flour or as an ingredient in domestic cuisine. Being of a highly perishable nature, it is best that the product be consumed as quickly as possible after harvesting.

The tree itself is fast growing and can reach a height of 15-25 metres, bearing up to 700 fruit upon maturity. It has broad, evergreen leaves that shelter the fruit. The branches, although strong, are brittle and snap easily. The fruit grow on thick, fibrous stalks that excrete a gummy latex that is a severe hindrance to both the handling and harvesting processes.

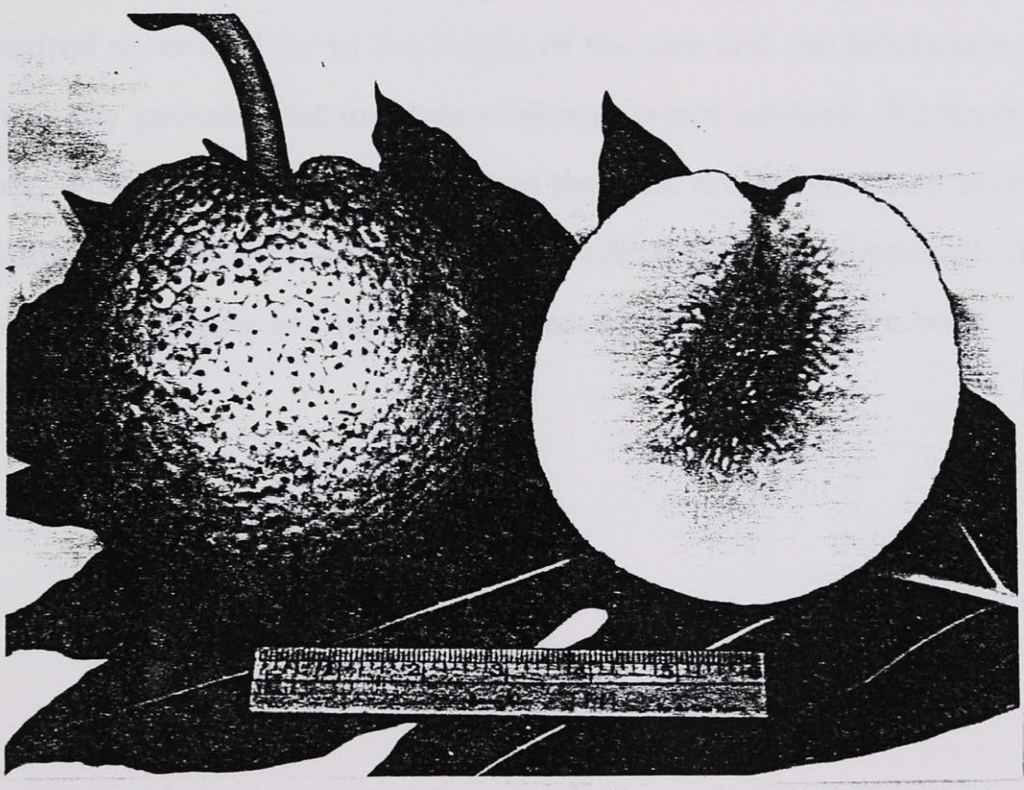


Figure 1: Illustration of a Typical Breadfruit (Reproduced from Martin, 1987)

Maturation of breadfruit on a given tree is variegated, with most of the harvest occurring between August and October and the balance being collected as late as February or early March. Harvesting is thus done selectively, often only picking one or two out of a cluster of four fruits. The single most important consideration in harvesting breadfruit is not to damage the easily blemished flesh, since marketing standards require that the fruit be picked at the proper stage of maturity, and have a firm flesh free of bruises.

Fruits are presently harvested either by climbing the tree or by knocking them down with a long pole (Martin, 1987), and both methods cause severe damage to the ripened product. Alternatives such as poles with bags attached to one end (Weir et al., 1983), or bamboo ladders from which buckets of fruit are lowered to the ground (McKnight, 1960) have been tried, with limited success. Due to the height of the tree and the brittleness of the branches, any process that involves climbing is not advised. Furthermore, the latex, weight, and growing height of the fruit render standard fruit harvesting practices, such as those used in citrus groves, impractical. To date, no innovative designs to improve the breadfruit harvest have been documented.

Objective

To design a mechanical breadfruit harvester that meets the following constraints:

- Because a steady energy supply can not be guaranteed, the *mechanism must not require fuel or electricity to operate.*
- Since the fruit do not all grow at standard heights, the *harvester must be able to pick fruit at heights ranging from 5 to 15 metres.*
- Size and weight are crucial since the *implement is to be primarily operated by women.*
- In order for the fruit to reach the ground undamaged, we *must include a retrieval mechanism which impedes the fall of the fruit.*
- *The device must be simple, inexpensive and easy to build and repair* other words, it must be constructed from materials native to the surrounding region.

Procedure

In keeping with the above mentioned design considerations, several options presented themselves. All of these involved the use of a long extendible pole manipulated by an operator on the ground. It was felt that it was too dangerous for harvesters to climb the tree, and, in addition, use of a pole would reduce any undue damage incurred by climbers. The first option was to attach a scissor-like assembly to the end of a long wooden pole and to use a long netted chute to impede the speed of the falling fruit. A telescopic aluminum pole with a rotating gripper mechanism attached at one end was a second idea. One of the disadvantages of this idea was the harvest time involved due to the fact that only one fruit was collected for each raise of the pole. This led to a third alternative, that of a trampoline recovery system at the tree's base combined with a rotating cutter at the end of an aluminum pole. After weighing these alternatives, a fourth option, which was an amalgamation of those previously presented, was chosen. This idea included a mechanical cutter blade attached to an extendible wooden pole with a sliding basket for fruit recovery.

The alternatives were each evaluated according the criteria listed in Table 1, *Selection of Optimal Design.* The harvest time per fruit and the probability of fruit damage were considered to be the most important design criteria, followed by the cost and the ease with which the harvester could be built and repaired by an average person. For example, we felt it important that the design include parts that could be easily obtained at a hardware store for a minimal cost. Thus, the alternatives that were made with an aluminum pole were discarded because of the difficulty and expense involved in constructing them. We therefore were limited to wood construction. Alternative 1, although inexpensive to construct, was lacking

CRITERIA	WEIGHT	ALTERNATIVES			
		A1	A2	A3	A4
Cost	0.15	0.8	0.2	0.45	0.7
Weight	0.12	0.4	0.5	0.5	0.3
Durability/Strength	0.12	0.35	0.8	0.7	0.5
Harvest time per fruit	0.18	0.5	0.2	0.8	0.75
Ease to repair/build	0.15	0.5	0.25	0.25	0.9
Maintenance (i.e. cleaning)	0.1	0.1	0.8	0.6	0.6
Probability of fruit damage	0.18	0.5	0.85	0.5	0.7
TOTALS	1	0.475	0.493	0.544	0.657

CRITERION FUNCTION:

$$CF = \Sigma a_i x_i$$

where: x_i = criterion for design
a_i = relative weighting factor for the criterion x

Alternative 1: wooden pole, cutting scissors and hooped net
Alternative 2: aluminum extendable pole, gripper mechanism
Alternative 3: aluminum pole, rotating blade, trampoline
Alternative 4: wooden sectionned pole, cutting blade, basket with pulley

Table 1: *Selection of Optimal Design*

in its recovery system. The latex extruded from the fruit stalks would quickly coagulate on the net, impeding the fruit's fall and causing severe cleaning problems. Although a trampoline would greatly reduce the harvesting time per fruit, and not be affected by the latex, it would not provide sufficient cushioning to prevent fruit bruising. Hence, Alternative 4 received high scores on all counts, due to its simple inexpensive construction, lightweight pole and limited fruit damage.

Results

A rough prototype of Alternative 4 was constructed to examine the feasibility of the design. The prototype itself was built from the cheapest materials available in the Montreal region, and does not, therefore reflect our final design specifications. It did, nevertheless, provide us with a good idea of the problems we might encounter.

A close-up of the working mechanisms on the harvester is shown in Figure 2. The cutting mechanism, operated by the yellow string, works in a horizontal plane. Situated directly beneath the blade is the collection basket, which slides up and down the spine of the harvester under the control of the white cord. Operation of the harvester requires two people; one to manipulate the pole and the other to control the two strings.

The pole itself was constructed from four 12 ft (3.65 m) pine dowels, outside diameter 1.25" (0.032 m), that were connected together with threaded stainless steel joints. The length of the dowels is arbitrary and depends on the number of joints available. Varying section lengths will give the harvester a more sensitive operating range. The length of the harvesting pole can be adjusted simply by adding or removing dowels.

Interchangeable threaded joints are force fitted over the ends of each pole, providing one male and one female component to every section. Aluminum, due to its light weight, was initially chosen as the material for joint construction. The drawback, however, was that the joints would have to be made to measure, thereby considerably increasing production costs. Instead, joints would be better constructed from more readily obtainable materials, preferably recycled parts. In addition, aluminum threads have a

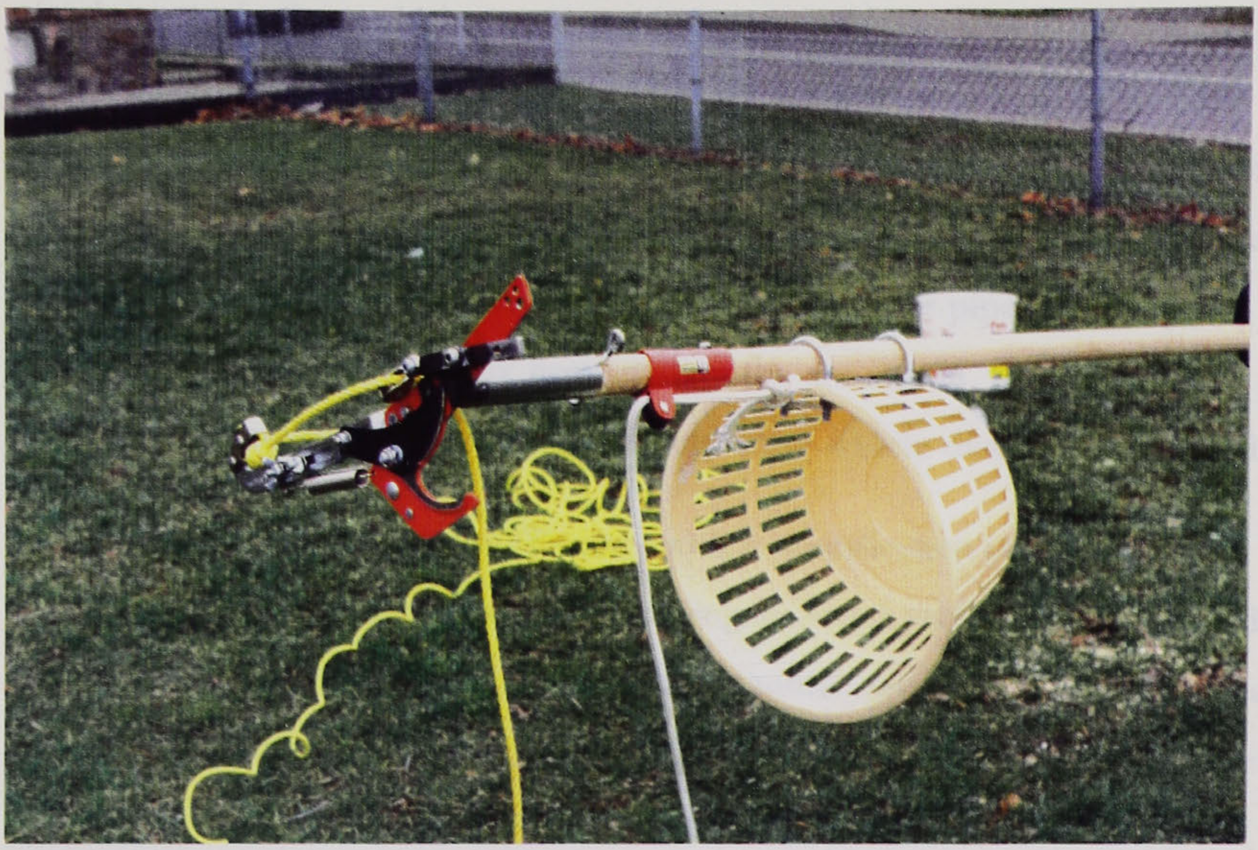


Figure 2: *Close-up of Working Mechanisms*

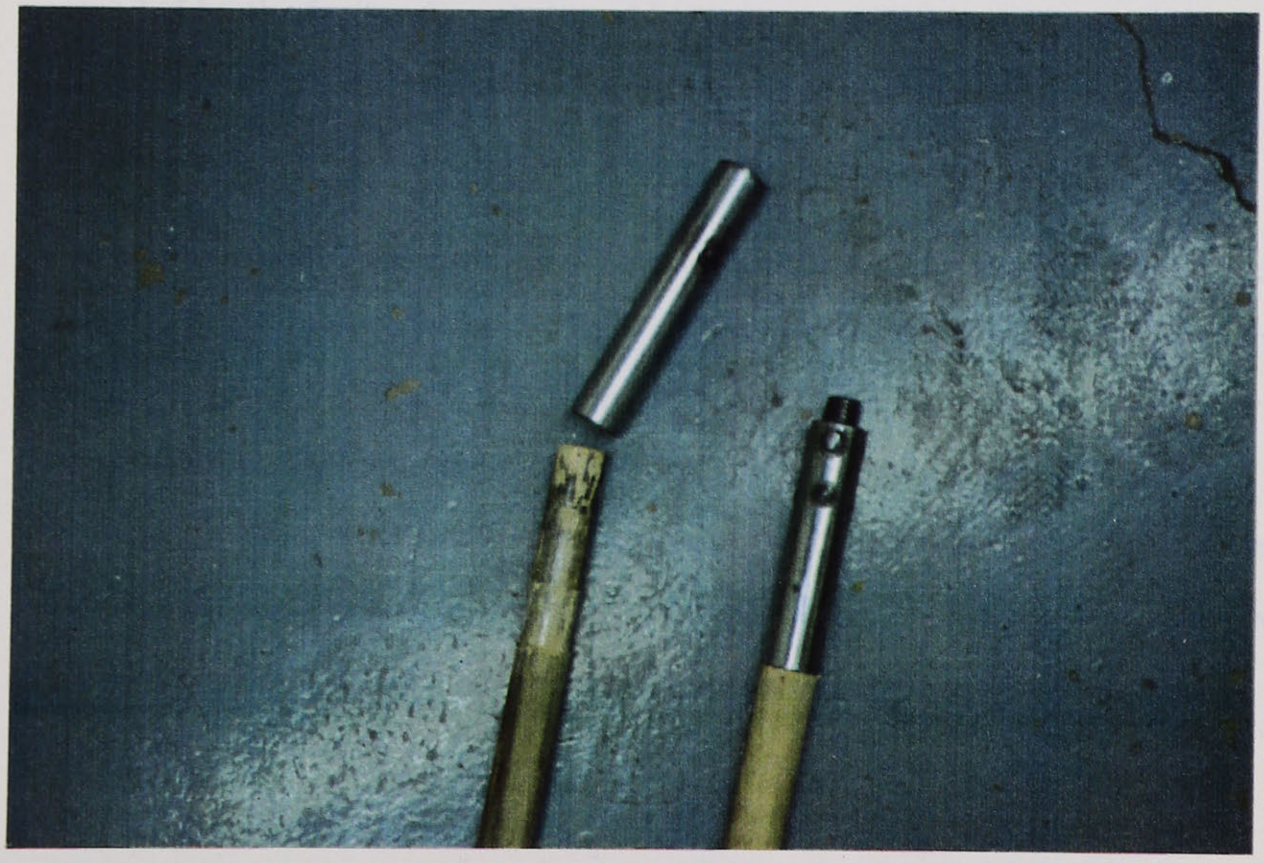
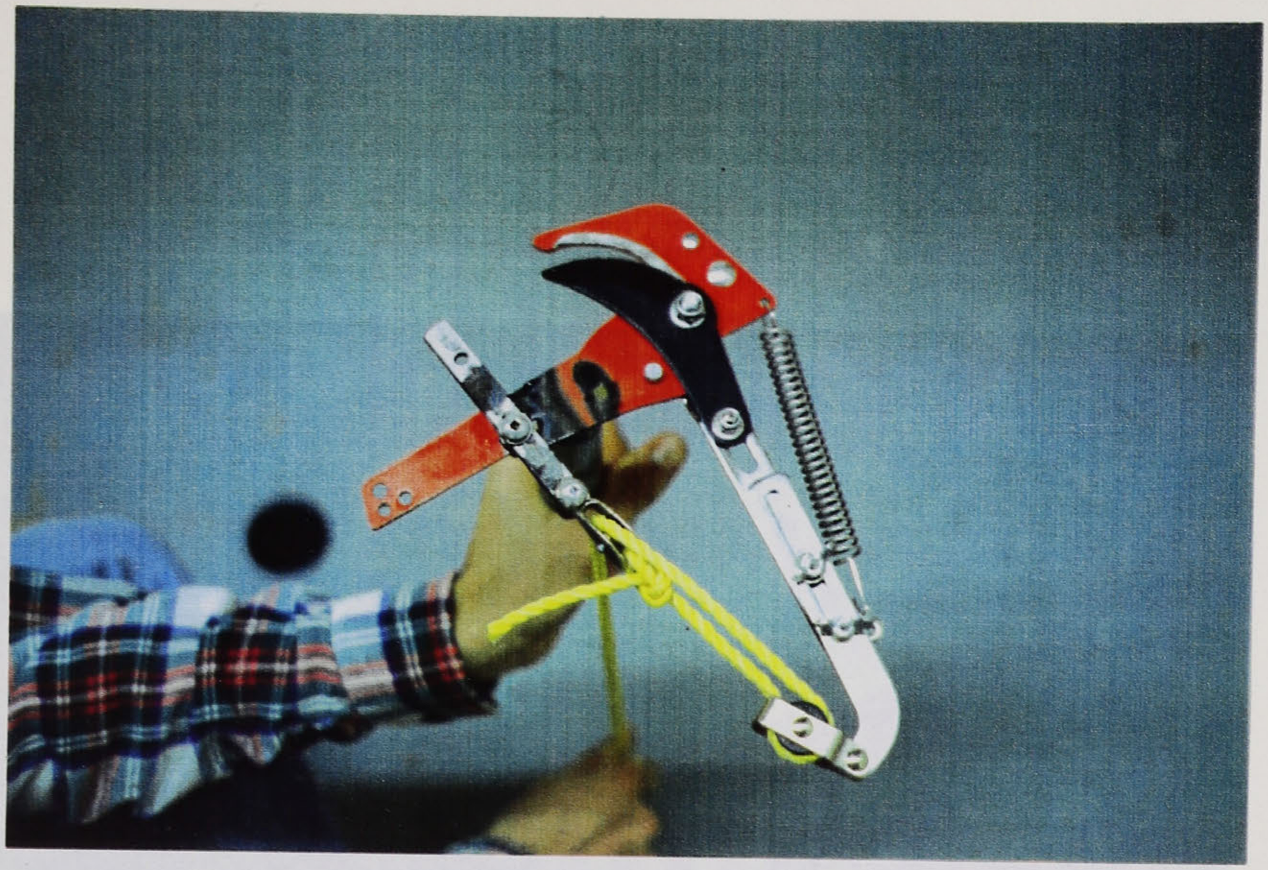


Figure 3: *Pole Connections*

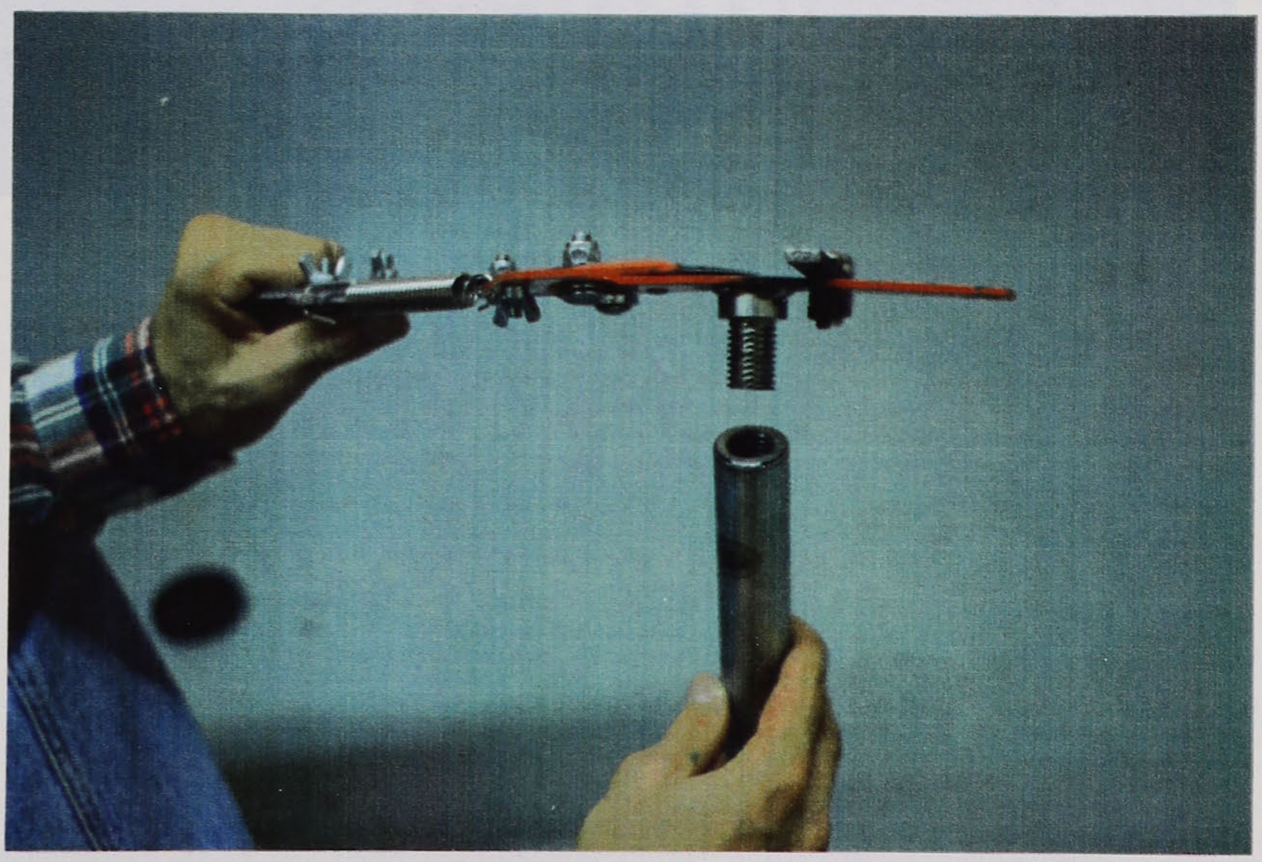
tendency to feather, which would result in excessive wear over time. As an alternative, the joints were constructed as shown in Figure 2, from stainless steel parts. Each joint consists of a steel machine bolt and matching nut, spot welded to the inside 1.25" nominal diameter steel pipe pieces. The hexagonal bolt heads were machined down to fit inside the circular pipe. Although these joints were considerably heavier than the aluminum, they were less expensive to build as they were made from more widely distributed materials.

The cutting mechanism (Figure 4.a) is a modification of a regular Canadian Tire Brand tree pruner. By adding a second pulley on a pin jointed piece, the cutter was adapted to cut on a horizontal, rather than vertical plane. Pulling the string downwards operates the blade through the action arm, the blade is then retracted back to the rest position by the spring. The blade has a Teflon coating that may provide some resistance to adherance of the latex extruded by the fruit stalks. As an added convenience, a bolt was welded to the bottom of the mechanism so that the cutter could be easily removed for cleaning and maintenance (Figure 4.b).

Directly below the cutter is the basket for fruit retrieval. A flexible plastic basket was used in constructing the prototype, as shown in Figure 6. As with the length of pole sections, the choice of basket material, be it a natural, woven fibre or synthetic, is left to the discretion of the builder. The basket should, however, be of sufficient size and strength to hold several breadfruits and also absorb the force of impact. The durability of the basket does not need to reflect that of the pole, since it should be a fairly inexpensive and easily replaceable component.



(a)



(b)

Figure 4: *Close-ups of the Cutting Mechanism,* **(a)** *pulley operation;* **(b)** *threaded connection.*

Figure 5: *Basket Used in Prototype. Note the C-clamps used to slide along pole. Dimensions: diameter 0.5 m, height 0.4 m.*

Through testing the prototype by cutting branches from a number of tall trees in the Montreal region, we were able to assess the feasibility of the design. With two operators, the harvester was simple to manage, with both the blade and the basket functioning as expected. The only difficulty encountered during operation was that of positioning the cutting blade. At heights much greater than 8 m it was hard to see the fruit stalk. In addition, the basket was in the line of sight of the blade. The main structural problem encountered was pole sway. Although the pine dowels provided sufficient support for the cutting mechanism and empty basket, the pole became increasingly unstable at heights greater than 4 metres, particularly if the basket carried a load of breadfruit.

ITEM	WEIGHT (KG)
Cutting Mechanism	0.721
STEEL JOINT:	
Steel Pipe Section x 2	0.224
Nut and Bolt	0.215
ALUMINUM JOINT	0.174
15 m wooden pole	7.244
Total 1 (Aluminum joints)	9.705
Total 2 (Steel joints)	12.355

Table 2: *Weight of prototype materials; totals 1 and 2 represent cumulative weights of the entire harvester with a 15 m pole connected with aluminum or steel joints, respectively.*

Discussion

Upon reconsideration of the pole design, additional calculations were performed to evaluate the behaviour of the pole given different diameters and materials. Minimizing the amount of deflection caused by a moment at one end of the pole, as opposed to maintaining elastic stability, would be of primary importance in the construction of a second prototype. The deflection of poles of different materials, as a function of their weight and elasticity, is compared in Table 3 (refer to Appendix A for sample pole sway calculations). As is clear from the table, bamboo not only has the smallest deflection under the given conditions, but it also has the lowest weight per unit length ratio. The optimal pole diameter was changed from the original 1.25" to 2" to increase the second moment of inertia, resulting in a more rigid pole. We therefore suggest that bamboo be seriously considered as a viable pole material. A sketch of the final design proposal is shown in Figure 6.

MATERIAL	MODULUS OF ELASTICITY (GPa)	WEIGHT/ UNIT LENGTH (kg/m)	DEFLECTION OVER 15 M (m)
Stainless steel pipe	190	14.041	0.035
Aluminum pipe	73	4.966	0.095
Pine dowel	11	1.236	0.245
Bamboo	20	0.075	0.2

Table 3: *Comparison of the properties of 2" diameter poles constructed from common engineering materials.*

Due to the intrinsic properties of bamboo, i.e. the longitudinal fibres, reinforcing nodes and hollow centre, it is difficult to be certain that the pole

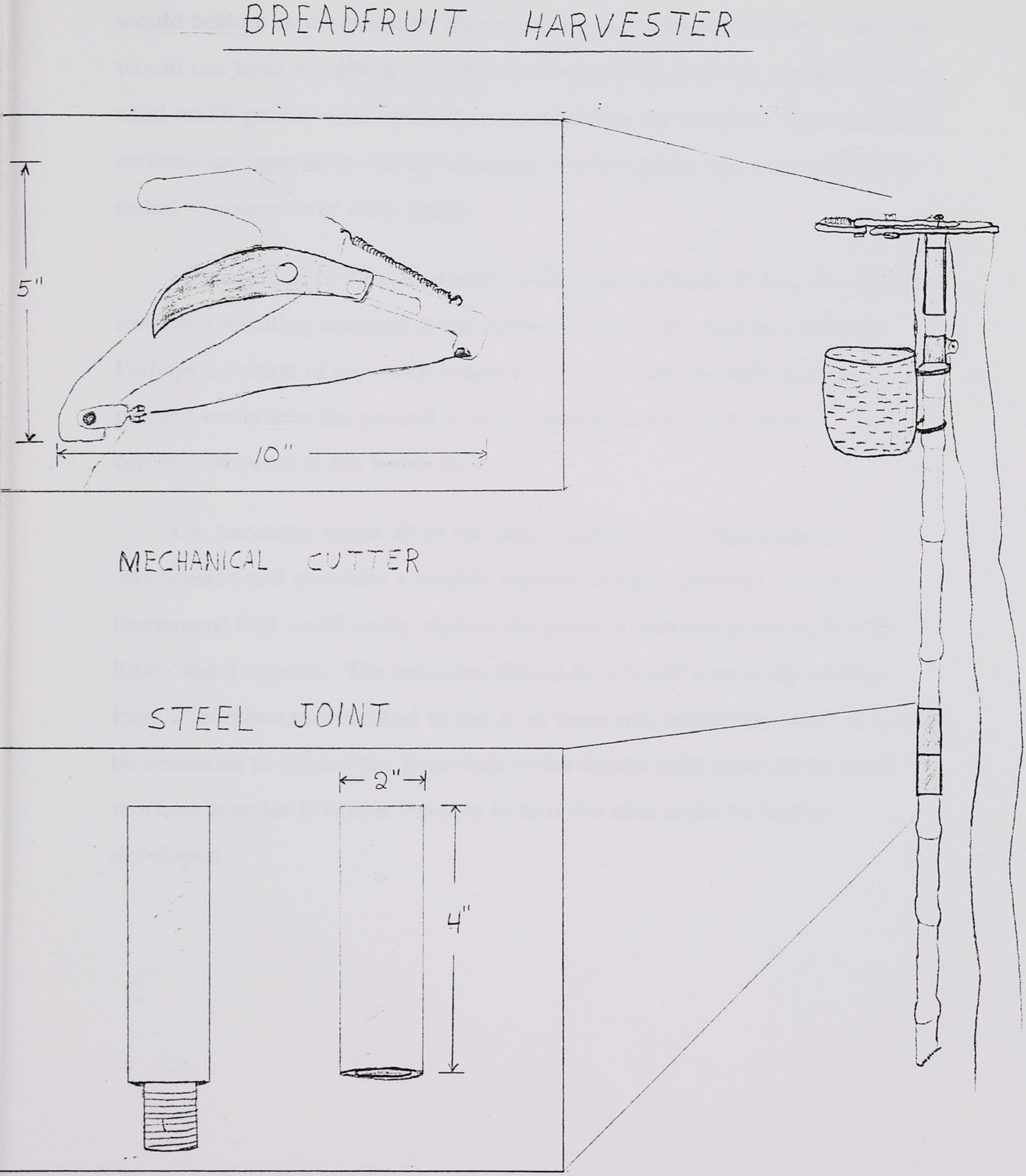


Figure 6: *Artistic representation of proposed mechanical breadfruit harvester.*

would behave as predicted by theoretical engineering calculations. The pole would not have a uniform cylindrical cross-section, and it is possible that the solid nodal points would provide unaccountable for support. Since bamboo sections are tapered it will be necessary to select poles that have minimum radial variation over their length.

In addition to what was built, some kind of device to help the operator resist the resulting moment at the bottom of the pole could be provided. Perhaps a section of pipe with a larger diameter than the pole could be planted easily into the ground at every picking station, providing a convenient pivot at the pole's base.

The harvester meets all of the design criteria. It is lightweight, inexpensive and provides a reliable method of fruit retrieval. It is an implement that could easily replace the present harvesting methods with little capital expense. The next step should be to build a second prototype from 2" bamboo sections and to test it on some real breadfruit trees. It would be beneficial to discuss the potentials of the design with some actual field workers in order to obtain input as to how the idea could be further developed.

Conclusions

1. There exists the potential to further develop the breadfruit harvesting process in the Caribbean region.

2. A long pole with a basket for fruit retrieval is a feasible alternative to the present harvesting methods.

3. A prototype of a breadfruit harvester proved to be tremendously helpful in the visualisation and proposal of solutions to possible problems.

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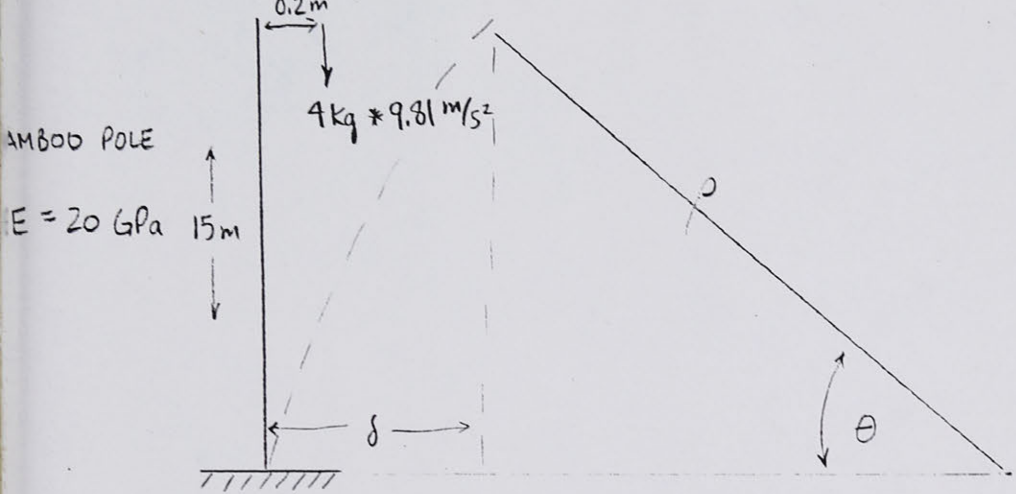
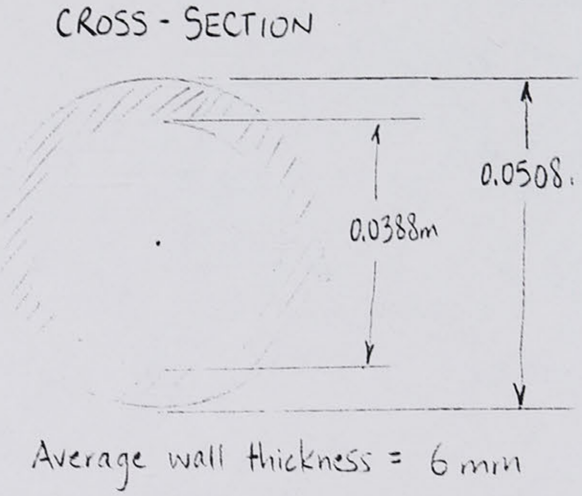
APPENDIX A

To determine the deflection of a 2" diameter bamboo pole, using the radius of curvature method:





ASSUME:

1. length of joints is negligible compared to the length of the pole
2. no bending in joints
3. acceleration due to gravity is equal to 9.81 m/s^2

Moment caused by a 4 kg breadfruit with its centre of gravity located 0.2 m from the pole axis:

4 kg * 9.81 m/s^2 * 0.2 m = 7.848 N-m

Cross sectional moment of inertia, I:

$$I = \frac{\pi}{64}(d_o^4 - d_i^4) = \pi/64\ (0.0508^4 - 0.0388^4) = 2.156\ E\text{-}7$$

Radius of gyration:

$$\rho = \frac{EI}{M} = (20\ E9 * 2.156\ E\text{-}7)/7.848\ \text{N-m} = 549.6\ \text{m}$$

Angle, θ:

$$\theta = \frac{L}{\rho} = 15\ \text{m} / 549.6\ \text{m} = 0.0273\ \text{rad} = 1.56^\circ$$

Deflection:

$$\delta = \rho - \rho\cos\theta = 549.6\ \text{m} - 549.6\ \text{m}\cos(1.56^\circ) = 0.2046\ \text{m}$$