Design and Evaluation of Selected Machine Components to Reduce Injuries caused to California Table Olives Mechanically Harvested

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Introduction

The objectives of this work are to quantify and visualize olive damage introduced by individual components of the Korvan olive harvester. The most recent mechanical harvesting technology developed by AgRight/Korvan removed fruit with 90% efficiency if fruit was accessible (Ferguson *et al.*, 2002). However, in later trials, efficiency was greatly reduced by tree size and shape. Ferguson and Kruger demonstrated 66% efficiency on mature trees with conventional pruning. This efficiency reduced to 54% due the catch frame dropping the fruit. Independent grower trials have demonstrated that this harvester produced unacceptable fruit.

The typical canopy shaker is designed to produce horizontal excitation. However, the horizontal direction is the most flexibly and difficult direction to transmit detachment energy considering the willowy nature of the canopy. The reduce flexibility in the vertical direction makes this direction a promising alternative in removing fruit with less energy and in turn less fruit injury.

A local olive grower and manufacture from the San Joaquin Valley: Dave Smith Enterprises has been modifying a Korvan harvester to mitigate its problems. This existing improved harvester was available for assessment of fruit removal efficiency and injury caused by its individual components. During the third week of October 2006 we acquired data using the Korvan-DSE harvester provided by Dave Smith Enterprises (DSE) while working on Manzanillo cultivars at the UCD experimental station in Lindcove. Unfortunately, this harvester induced considerable olive damage.

Material & Methods

During the third week of October 2006 we acquired data using the Korvan-DSE harvester provided by Dave Smith Enterprises (DSE) while working on Manzanillo cultivars at the UCD experimental station in Lindcove. Unfortunately, this harvester induced considerable olive damage. Our experiment consisted of two parts. The first part consisted of theorizing where olive damage might occur during mechanical harvesting. Each of those locations was isolated so that a sampled quantity of olives experienced damage only at that theorized location. After experiencing damage from the harvester at a specific location, a sample of those olives were collected for grading. Evaluation of the grading data tells us where damage occurred but not how damage occurred.

The second part was designed to show us how the damage occurred. Stereo 500 fps video was recorded and played back at the normal speed of 30 fps to shown where and how the olives were damaged. This stereo video was used to generate the 3D path of selected olives to determine how those olives were potentially damaged. Knowing the 3D location versus time, we were then about to determine when the olive's velocity abruptly changes. The quick change in velocity allows us to determine what, where and when the olive experiences harmful accelerations. At that particular harvester component location changes must be made to reduce olive injury.

In Figure 1 olives are being dropped from eight feet to simulate damage occurring after being detached by the drum at that height. These olives were then gathered and evaluated for injuries by Dr. Carlos Crisosto at UC Kearney Experimental Station and the data analyzed at UC Davis by the Bio-Automation lab (BAL). Olives were also sent to two olive processors. The olive processor's data will be available to us by February 2007. Based on the results of the processor's analysis we will incorporate the interpretation of those results to suggest improved design changes to the Korvan-DSE harvester.

Figure 1 Catch frame drop test at 8 feet

We dropped olives to simulate three heights of spiked drums heights; four, eight and twelve feet. The olives were poured over a wide circulate pattern upon the catch frame so that damage was unbiased by landing position. In other words, it was equally likely that an olive lands on any part of the catch frame. The three different heights were repeated random times relative to each other so that no time biasing occurred. Additionally, this test was repeated in the afternoon adding nine additional drops to our data set. Therefore, our drop test constituted of 18 sets of data. This doesn't include our six control sets of data which were olives that did not interact in any way with the mechanical harvester. These olives were gently hand picked and therefore were expected to experience as little damage as possible.

Once on the catching frame (Figure 2), in normal DSE- Korvan harvester operation, olives are moved back to the rear transport belt by the front transport belt (Figure 3). From the rear of the harvester, the olives are moved by the rear transport belt to a fan trash separator and dumped into a large side storage bin (Figure 4). The damaging effects of transporting the olives to the rear belt and to the storage bin were evaluated. Three times in the morning and tree times in the afternoon separate samples were placed on the front belt and transported to the back belt as seen in Figure 3. The storage bin drop was evaluated with and without the trash fan on. This meant that six samples were generated in the morning (thee trash fan on & three trash fan off) and six samples were generated in the afternoon.

Figure 2 Front transport belt.

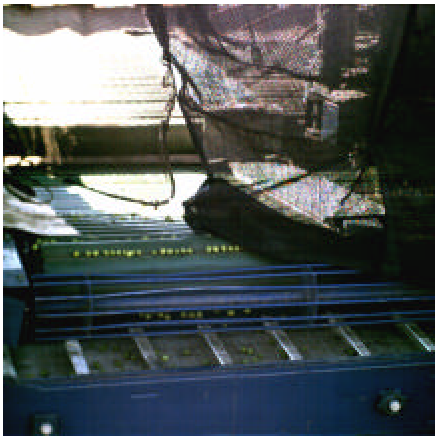

Figure 3 Rear transport belt.

The olive sample generated with the above procedures isolate damage cause by the harvester after the olives detach from the tree canopy. To isolate damage cause by the spiked drums detaching the olives, a soft black fabric tarp was laid across the catch frame. The harvester was then run across either half or a quarter of a tree to detach olives from that portion of that tree as seen in Figure 5. Spiked drum speed was set to 180 or 220 RPM to evaluate the effect of drum speed on olive damage.

Figure 4 Storage bin drop.

After the harvester passed through either half or a quarter of the tree, the olives softly landed upon the black cloth tarp (Figure 6). These olives were hand collected off the tarp and stored for later evaluation. Twenty one samples of olives were collected using this procedure over two days in the mornings and afternoons. As controls for this procedure, hand picked olives were dropped from twelve feet onto the soft tarp covered catch.

Figure 5 Harvester spiked drums interacting with Olive tree canopy

Figure 6 Soft black cloth tarp used to isolate spiked drum and tree interaction

Figure 7 shows the stereo video camera system. The system consists of two high speed cameras each connected to its own high speed solid state image memory controller. Each camera is six inches from the end of the same eight foot wooden beam. After the camera platform is fork lifted into place, both camera are aimed and focused on an indexed target. The exposures for both cameras are set for a compromise between sun and shadow as seen in Figure 8. The targets are removed from the area of focus and the olives are set in motion. After the "Pickle Switch" is pressed, each high speed image memory controller fills with 1024 images, each. Since each image is 1024 X 1024 X 3

Bytes, each sequence of images is over 3 Gigabytes per camera. Each high speed image memory controller is connected to a separate laptop and each laptop to a separate external hard drive. It takes 2 seconds to record the images and 10 minutes to save upon the external hard drive. The indexed target image from each camera for each image sequence needed post processing. An added grid was necessary for the 3D tracking software to obtain a 3D solution from two 2D images.

Figure 7 High speed stereo video recording platform on a forklift

Figure 9 shows the same olive with the two different cameras. The most difficult aspect of determining the 3D path of an olive is finding the same olive in each of the camera views. This olive was especially convenient to track because it was at the same location as the blue flag. Invariably it seemed that an interesting olive in one of the camera's view could not be found in the other camera view. Another time consuming challenge of obtaining an olive 3D path involves drawing the object of interest on each frame of each image.

Stereo high speed images were collected from over 20 spiked drum to tree canopy energy transfer interactions. Interactions with other harvester components were also recorded with the high speed camera system. All image sequences gathered on October 18th and 19th of 2006 were edited with Micro Soft Windows Movie Maker (MSWMM) to include a title screen of the sequence setup. These video files were then transferred to DVD and made deliver to Louise Ferguson and David Smith.

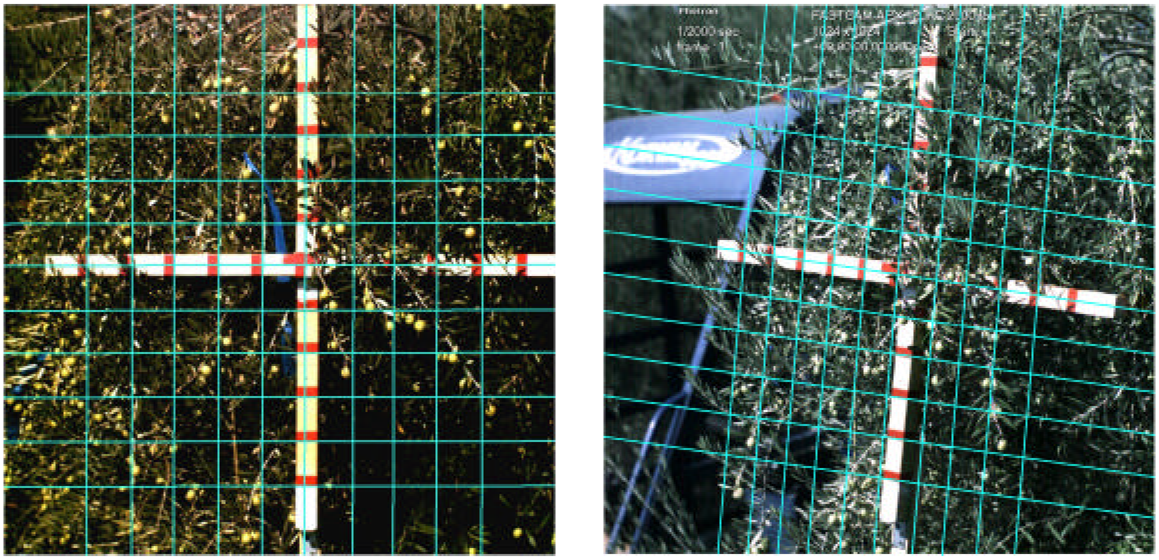

Figure 8 Two high speed cameras with focus on the same indexed target (grid added later in BAL).

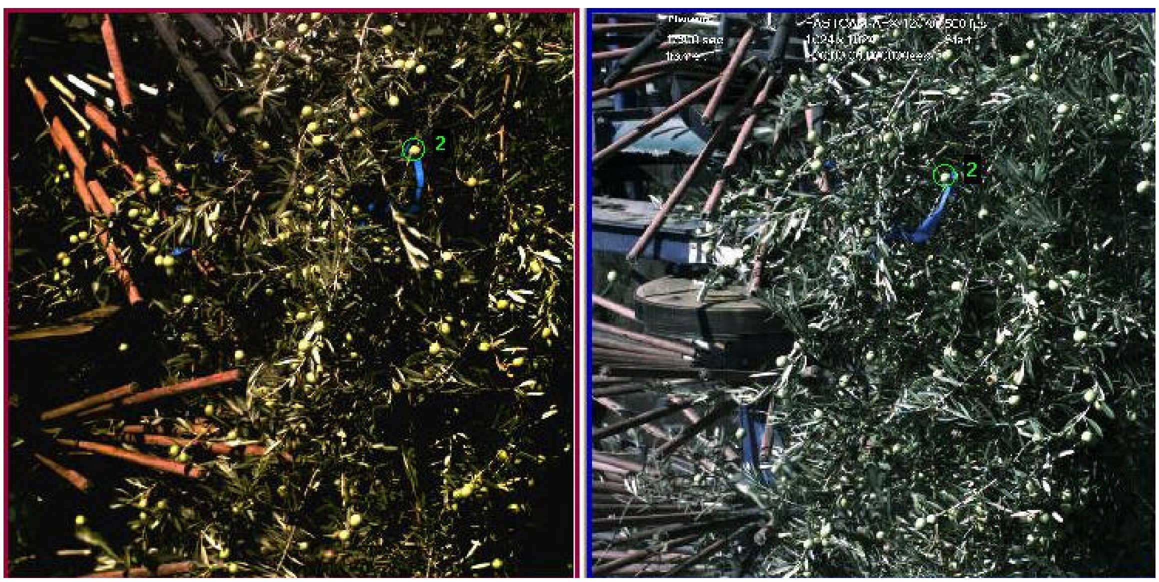

Figure 9 Two high speed cameras pointed to the same tree canopy location and the same olive labeled

Results and Discussions

Most of our current results are based on the sample evaluations done by Dr. Carlos Crisosto at UC Kearney Experimental Station. Olives that were exposed to different Harvester components under different conditions were evaluated by Carlos Crisosto for deep tissue bruising, mechanical skin damage, shrivel and soundness. Since shrivel is not induce by the harvester, we have eliminated these olives from our results. We also combined the deep tissue bruising and superficial skin damage to yield a simple category of damaged olive.

At this point, the collected 2006 data have been analyzed based on graphical interpretation and computed average and standard deviation values. Figure 10 shows the damage evaluated olives for the catch frame tests at three different heights. Unfortunately, there is much damage and variability in the control olives. In fact, there is no difference between the 4 dropped for 4 feet onto the catch frame and the control olives. There also seems to be only a very slight increase in damage caused by the 8 feet drop and the control olives. However, there appears to be a significant difference between the olives dropped from 4 feet and 12 feet. A complete statistical analysis will be further investigated by using SAS in 2007.

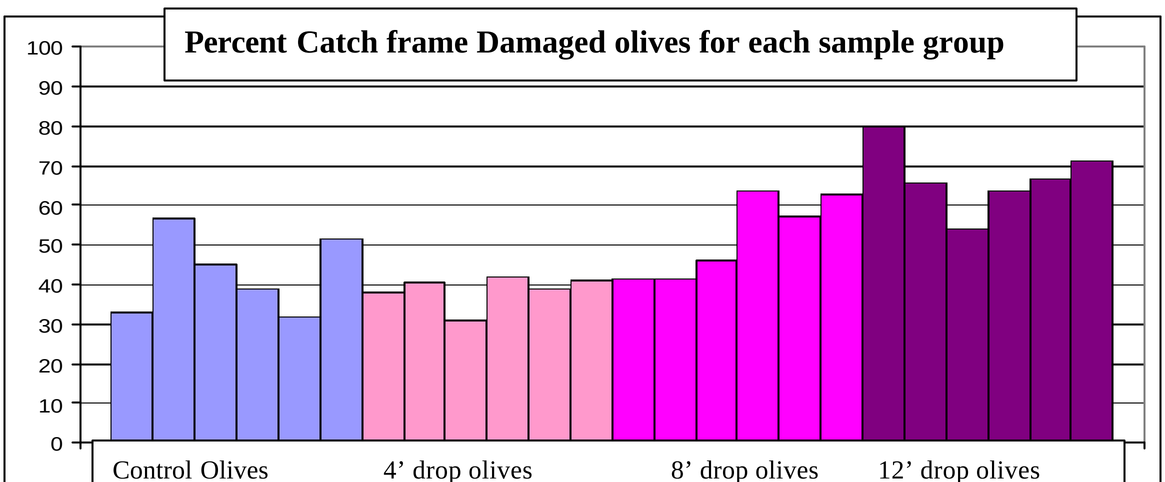

Figure 10 Percent of olive damaged from the catch frame drop at three different heights

Figure 11 shows the evaluated sample results from the bin drop test (figure 4) and the back belt drop test (figure 3). The control olives are also included in this figure. The olives that dropped into the storage bin seem to have less average damage then the control olives. This observation can be justified by the variability of the olive samples used in this study. The average damage for the rear belt dropped olives seems slightly higher then the control olives. This will also be further investigated using SAS in 2007.

Figure 12 shows what percentages of sampled olives were damaged by the spiked drums interacting with the tree canopy. It was theorized that reducing the drum speed would reduce the damage caused by the spiked drums. However, the above figure indicates the opposite. However, this variation is probably due to variations between olive samples. Fortunately, there does appear to be difference between the control plus soft tarp olives and the 180 plus 220 RPM spiked drum detached olives.

Due to the variability of the hand picked olive samples and the high percentage of control olives that showed damage, we divided the olive tests into two groups. We used Figure

13 to decide which test should go into each group. The first group included tests that induced damage to the same level as the six control samples. This included 1) the control group 2) the soft tarp group 3) the bin drop test 4) the rear belt test and 5) the 4 foot catch frame drop test. The second group is those tests that significantly damage the olives more then the control samples. This included the 12 foot catch frame drop tests and the spiked drum interacting with the tree canopy tests. Figure 14 shows the average and standard deviation error bars for the test divided into two groups. The results of this analysis show that the two components that damage olives are high fruit drops onto the catch frame and the spiked drums interacting with the tree canopy to detach the olives.

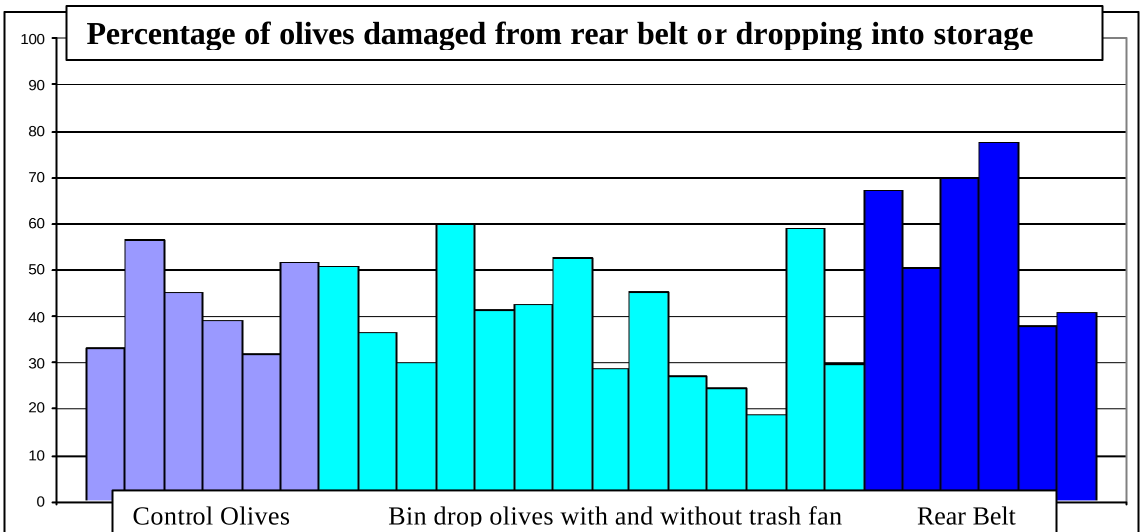

Figure 11 Percent of damaged olives from bin drop and rear belt drop

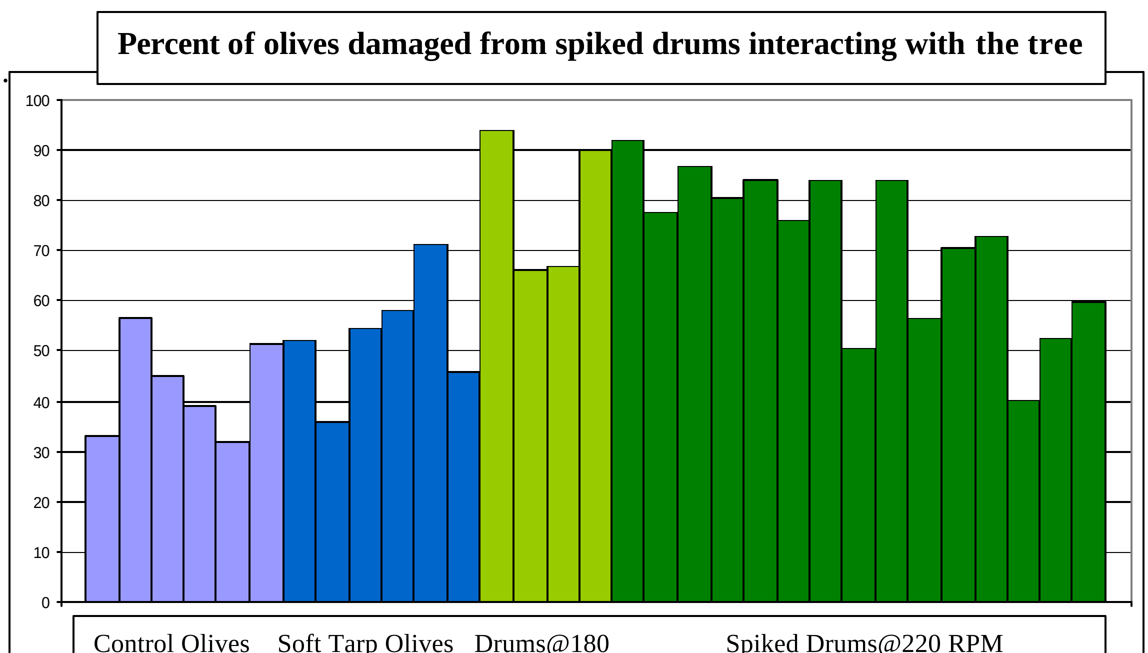

Figure 12 Percentage of damaged olives from spiked drum and tree canopy interaction

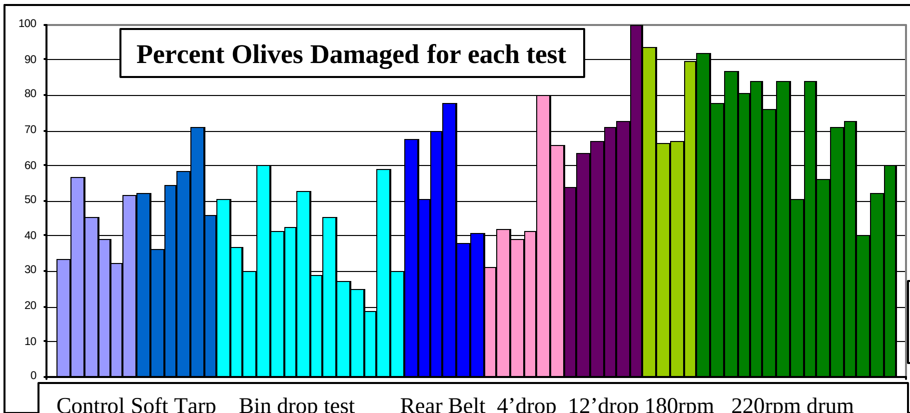

Figure 13 Percent damaged olives from all harvester component isolation tests

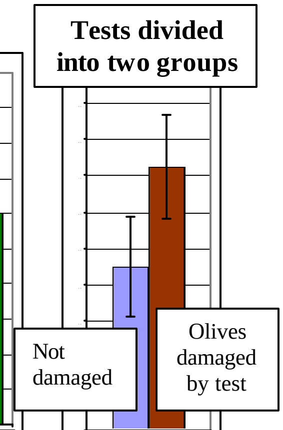

Figure 14 Two group graph

The willowy nature of the olive tree limbs requires application of high vibratory energy levels to release the fruit. However, when more energy is introduced to the system, more damage is introduced to the fruit. Preliminary measurements obtained from the 3D analysis applied to the high speed images recorded in the field have shown medium sized fruits have experienced decelerations in the order of magnitude of 100 g's during the moment of fruit stem detachment. The equivalent inertial forces required to detach these fruits were slightly less then 1 lbf. Fruits fallen through the canopy, have shown multiple hits, and we have measured fruit speeds of the order of magnitude of 20mph in some instances. Extensive image analysis has been planned for 2007.

Olives in figure 15 impact the catch from without and with extra padding. The difference in return heights indicates that the "NoBruze" foam absorbs about 80% of olives kinetic energy as compared to the unpadded catch frame.

Figure 15 Font folding portion of catch frame without extra padding and with white "NoBruze" padding

Figure 16 shows an olive being hit by a drum spike from the left and right camera view. These images illustrate the strong nature of olive detachment by drum spike. However, the majority of the olives seem to be detached by the whipping action of the branched that is accentuated by the whipping action of the olive stem (Figure 17). The willowy nature of the olive branches means that much energy must be transferred to the tree canopy before fruit detachment occurs.

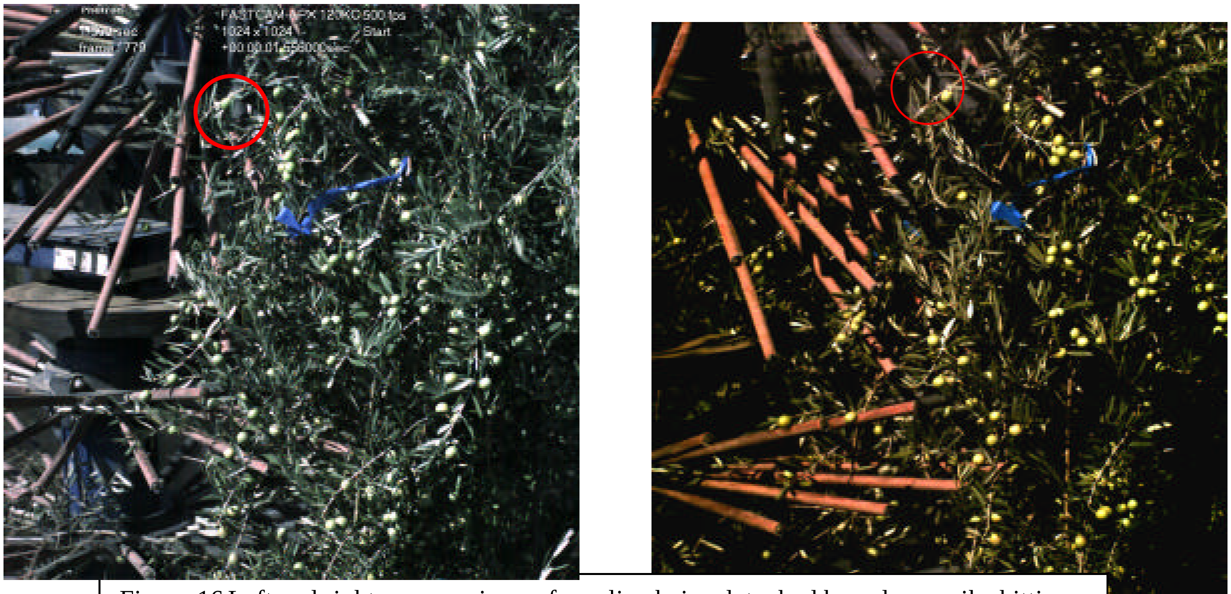

Figure 16 Left and right camera views of an olive being detached by a drum spike hitting

Figure 17 Stem whipping action detached the circled olive

Conclusions

Dr. Louise Ferguson has pointed out that "Injury occurs when olives hit shoots before detachment, impact branches as they fall through the tree, and as they contact the catching frame". The improvement to harvester design will mitigate fruit injury, but it is first necessary to evaluate where olive damage occurs. To quantify the contribution of individual machine components to fruit injury those components must be isolated. To understand how those components damage the olives, further 3D high speed video evaluation is required. Preliminary study, has found that the most significant olive damage occurs before, during and after the detachment process within the tree canopy and when they initially strike the catching frame.

Engineered and implemented designs to mitigate this damage are catching frame padding material, olive velocity reducers to lowering impact and consequently damage to fruits, improvement of the angle of attach of rod to the canopy, and simulation and testing of finger padding materials in the lab to determine adequate levels of firmness, strength and durability. Testing and validating these results still depends on field work and understanding of the improvements implemented. This understanding can be accomplished through lab testing during the harvest off season.

Suggestions for Future Work

We plan to propose additional low cost modifications to mitigate the problems associated with the current harvester design and or operational settings. We collected data during the 2006 season, and we are currently performing an engineering analysis. We plan to continue our analysis of the causes of injury introduced to the fruits by utilizing the 3D high speed images and by interpreting the results of our samples graded by Dr. Carlos Crisosto and those samples delivered to olive processors. We will propose design changes for the most critical and/or easiest components of the harvester that can be modified to produce the most immediate benefits.

We would like to evaluate the fruit injury caused by the components of the available harvester before and after fruit processing. Thus, we can fully evaluate the efficacy of the components in mitigating fruit injury.

Design Ideas for Harvester Improvement

The drawings shown in Figures 18 to 20 represent the current results from the conceptual analysis from this study to improve the conceptual design of the current harvester. Our studies have indicated there would be advantages in tilting the spiked drum axis in both pitch and row directions as indicated in these figures. These figures also make an attempt to show the velocity breakers required to contain and guide olives with undesirable path which would result in extensive injury.

A detailed description of the indicated conceptual design can be provided.

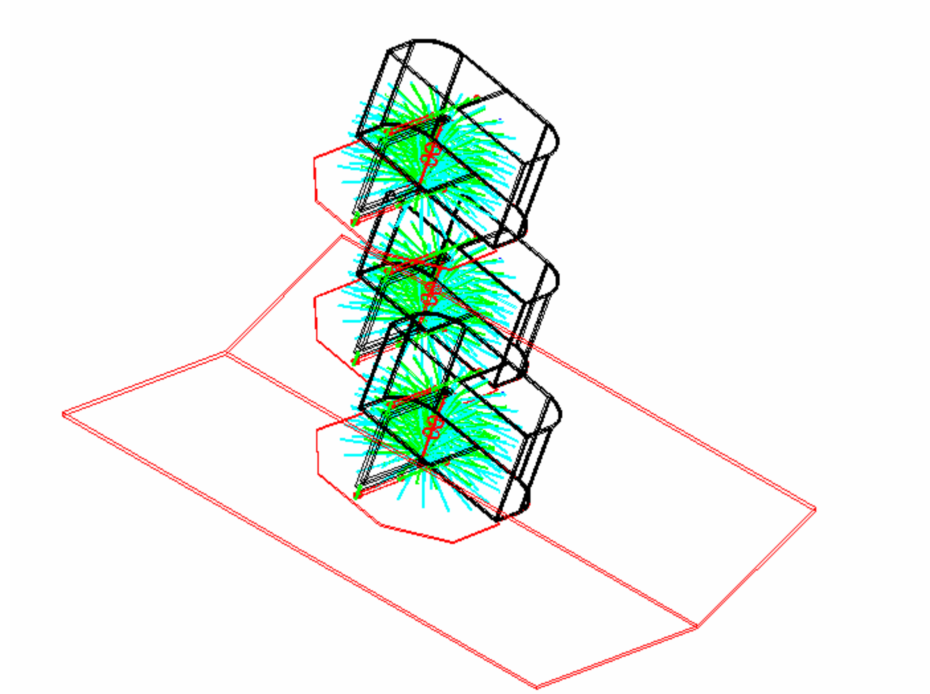

Figure 18 – Simplified isometric view representing proposed low cost design modifications to the current harvester.

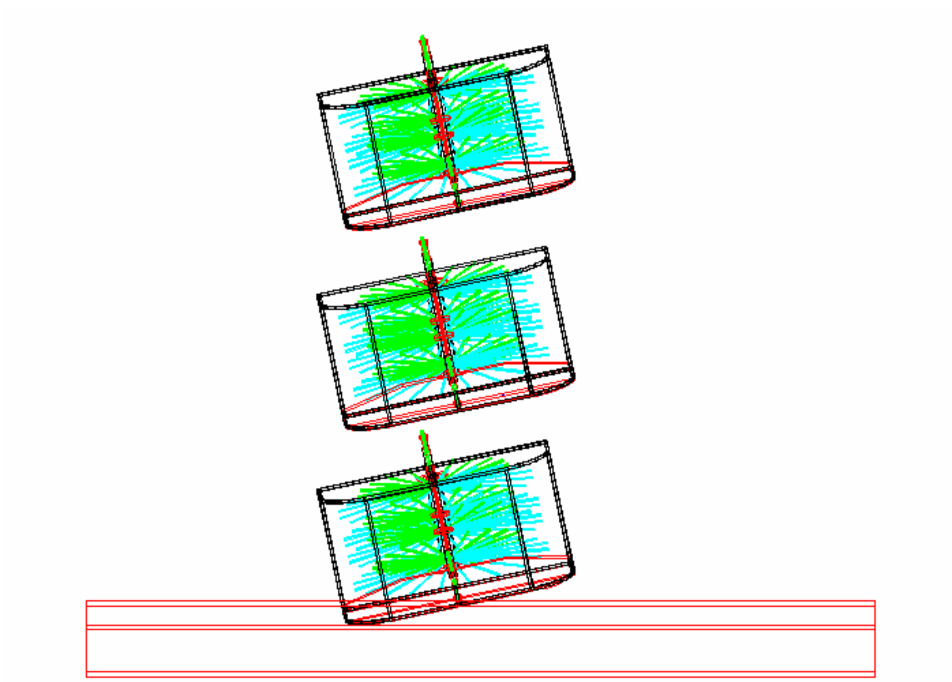

Figure 19 – Simplified side view representing proposed low cost design modifications to the current harvester.

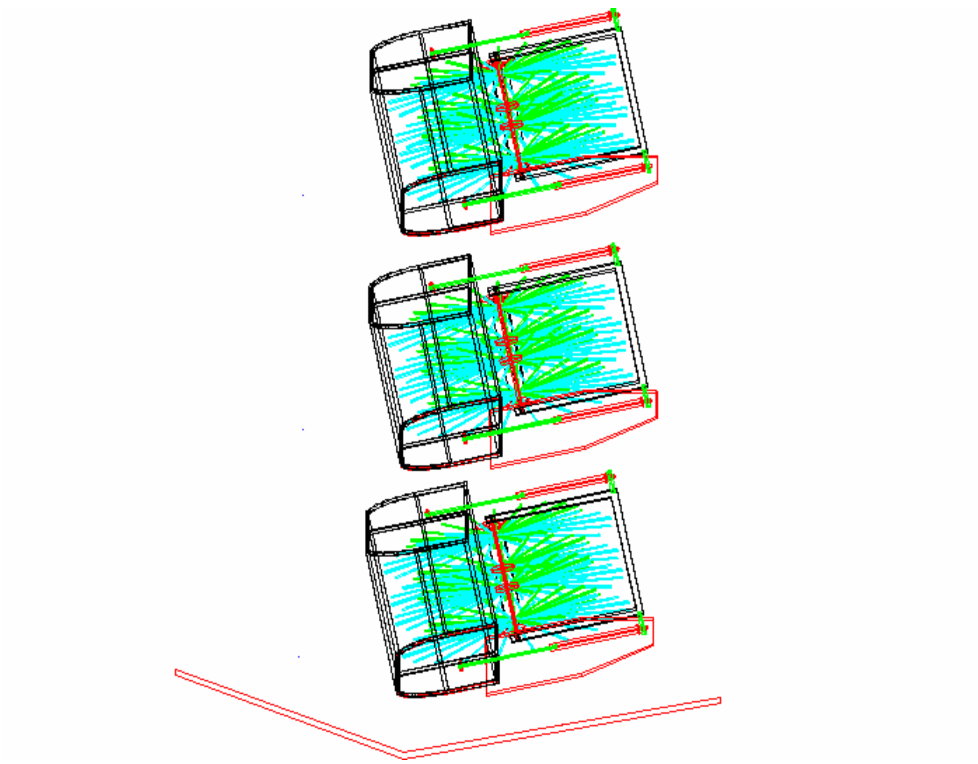

Figure 20 – Simplified back view representing proposed low cost design modifications to the current harvester concept.

<u>Harvester evaluation – 2007</u>

The objective for 2007 is to extend and finalize the engineering analysis on the assessed 2006 data collected with the Korvan harvester, improved by DSE for the 2006 season, on an individual component basis to prescribe modifications for mitigating fruit injury problems and evaluate the results of these modifications for the 2007 season.

The trials of this study for the 2007 season will be conducted in the olive groves owned by Dave Smith in (Tulare County) in October 2007, or in another orchard to be determined by the project leaders. The improved Korvan harvester, modified by Dave Smith, will be available for implementing findings from this exercise and by assessing the damage caused to fruit. During this season, we will collect data to individually assess the mechanical causes of injuries associated with the drum and finger interactions with the canopy and the harvester catching frame design.

The test procedure will consist of similar tests conducted during the 2006 season. However, we will only concentrate in evaluating the components that this year analysis will prove to be most effective in reducing fruit injury. The proposed field trials are described as follows (only components with relevant contribution to injuries will be evaluated):

1. Injury evaluations:
    1.1. Fruit-rod damage.
    1.2. Catching frame damage.

2. Analysis
    2.1Video Analysis

In order to assist in the determination of the causes of fruit injury and fruit detachment a 500 fps high speed video camera will be utilized to record the required procedures. The recorded image of the new parts will be analyzed by existing software.

2.2 Statistical Analysis

A complete randomized block analysis will be performed on to measure fruit injury levels on approximately 100 samples. Samples will be collected from regular orchard operations.

Appendix:

Table 1. Simplified table indicating percentage damaged olives from all harvester component isolation tests performed in 2006.

Test	Other	Bruise	Mech	B&M	Sound
Control# 1		26	7	33	67
Control# 2		39	17	57	43
Control# 3		31	14	45	55
Control#4		25	14	39	61
Control#5		28	4	32	68
Control#6		48	3	51	49
Tarp Test		45	8	52	48
Tarp Test		24	12	36	64
Tarp Test		38	16	54	46
Tarp Test		37	21	58	42
Tarp Test		54	17	71	29
Tarp Test		35	11	46	54
Back Belt	Fan off	33	18	51	49
Back Belt	Fan on	27	10	37	63
Back Belt	Fan off	17	13	30	70
Back Belt	Fan on	47	13	60	40
Back Belt	Fan off	34	7	41	59
Back Belt	Fan on	34	8	43	57
Back Belt	Fan off	47	6	53	47
Back Belt	Fan on	21	8	29	71
Back Belt	Fan off	39	7	45	55
Back Belt	Fan on	24	3	27	73

Back Belt	Fan off	15	10	25	75
Back Belt	Fan off	16	3	19	81
Bin Drop	Fan off	37	22	59	41
Bin Drop	Fan off	11	18	30	70
Bin Drop	Fan off	33	34	67	33
Bin Drop	Fan off	34	16	50	50
Bin Drop	Fan off	52	18	70	30
Bin Drop	Fan off	62	16	77	23
Drop Test	4'	20	18	38	62
Drop Test	4'	33	8	41	59
Drop Test	4'	18	14	31	69
Drop Test	4'	36	6	42	58
Drop Test	4'	30	9	39	61
Drop Test	4'	30	11	41	59
Drop Test	12'	41	39	80	20
Drop Test	12'	39	26	66	34
Drop Test	12"	23	31	54	46
Drop Test	12'	55	9	64	36
Drop Test	12'	49	18	67	33
Drop Test	12'	56	15	71	29
Tree Test	180	55	18	73	27
Tree Test	180	35	65	100	0
Tree Test	180	42	52	94	6
Tree Test	180	32	34	66	34
Tree Test	220	49	18	67	33
Tree Test	220	62	27	90	10
Tree Test	220	56	36	92	8
Tree Test	220	49	29	78	22
Tree Test	220	62	25	87	13
Tree Test	220	42	39	80	20
Tree Test	220	51	34	84	16
Tree Test	220	43	33	76	24
Tree Test	220	65	19	84	16
Tree Test	220	30	20	50	50
Tree Test	220	56	28	84	16
Tree Test	220	41	15	56	44
Tree Test	220	49	22	71	29
Tree Test	220	34	39	73	27
Tree Test	220	11	29	40	60
Tree Test	220	34	18	52	48
Tree Test	220	35	25	60	40