Executive Summary:
The patented EPS Whole Tree Harvester™ described herein is designed to continuously move forward at 6 mph (9 ft/s) while cutting and accumulating trees grown in long straight rows on relatively flat ground with slopes of less than 15%. When a full load of trees (30 tons) is accumulated (in a vertical position) on the harvester, the trees are off-loaded onto a trailer. Overall the tree harvester is 52 ft long, 28 ft tall and 16 ft wide, and weighs 45 tons unloaded. The sub-systems of the harvester are: 1) frame and tracks, 2) power and hydraulics, 3) cutting head, 4) cab and controls, and 5) tree accumulator and unloading mechanism.

The first four subsystems of the EPS Whole Tree Harvester™ were fabricated at several different shops, and assembled at the Whirl-Air-Flow Co. shop in Big Lake. The assembly included modifications to improve synchronization of the tracks based on the first tests conducted in January 2008. On March 5 & 6, 2009 it was demonstrated that the harvesting head and track system were fully functional by testing the speed and synchronization of the tracks and by cutting through a 13 inch tree on March 6, 2009 MN. The synchronization of the tracks’ speed were measured and found to meet expectations. The rear tracks’ tension was increased to decrease slipages during a skid steer test. The tree cutting function was tested by tightly mounting the 13 inch diameter tree to a heavy steel plate to hold the tree upright. As the test was done indoors with many observers monitoring the test, the tree top was attached to a loose chain from an overhead crane as a safety precaution. A video-tape of the March 6 demonstration confirms that the 13 in diameter tree was very quickly severed by the cutting blades (within approximately 1/3 of a second) using the momentum of the 45 ton harvester rather than using a hydraulically driven saw or hydraulic piston driven snipping cutters.

Technical Progress:
13a. Testing and modification of the high-speed harvesting machine.

The patented EPS Whole Tree Harvester™ and previous modifications made after the January 2008 tests will be briefly discussed prior to describing the current tests.
Description of the Tree Harvester
The harvester is designed to continuously move forward cutting and accumulating trees grown in long straight rows on relatively flat ground. When a full load of trees (30 tons) is accumulated (in a vertical position) the trees are off-loaded onto a trailer. The harvester is self-propelled and operates on four tracks that distribute the load on the soil to less than 11 psi. The sub-systems of the harvester are: 1) frame, skid pan and tracks, 2) power and hydraulics, 3) cab and controls, 4) cutting head, and 5) tree accumulator and unloading mechanisms. Overall the harvester is 52 ft long, 28 ft tall and 16 ft wide, and weighs 45 tons unladen. The harvester is designed to handle trees up to 30 in. diameter and 120 feet tall, but the immediate goal is to cut trees more typical of Minnesota tree farms that have trees from 6 to 15 inches in diameter. The harvester is designed to travel up to 6 mph (9 ft/s) while cutting trees in the field and 12 mph unladen on a road.

A pair of front tracks and a pair of rear tracks supports the steel frame of the harvester. Each pair of tracks is equipped with 200 hp, two-speed hydraulic motors with disk brakes. The front tracks pivot to allow a turning radius of +/-15 degrees used primarily for steering within the row. The other sub-systems are mounted to the frame. The harvester body consists of six major sub-sections: the right side of the tree accumulator with the car bodies, chain drives and rail; the center skid-pan and harvesting head; the left side of the accumulator with chain drive unloading rails with phase shifter and motor drives; the diesel engines and hydraulics; the front tracks and struts; and the cab with operator seat and automatic controls.

Two 400 hp Caterpillar diesel engines power the seven hydraulic pumps that drive the 10 hydraulic motors and eight hydraulic cylinders and associated auxiliaries. One engine powers two 200 hp closed loop hydraulic pump-motors combinations that drive the rear tracks and two open loop pumps that drive small motors and auxiliaries. The other engine powers three 200 hp closed loop hydraulic pumps which in turn power two front track motors and four accumulator drive motors.

An Allen Bradley logic controller controls the two diesel engines, the four track motors, the hydraulic pumps, the tree accumulator paddles, suspension adjustment for slope of the ground, and end gate off-loading. The electric power supply consists of two 230 volt AC generators and a rectifier for 24 and 12 volt DC supplies for the controls.

For transport the harvester can be disassembled into five sections: 1) rear tracks, axels, engines, pumps and associated structural frame; 2) skid pan, cutting head and blades, head hydraulic cylinders, and associated structural support; 3) right side of accumulator with paddles and chain drives, hydraulic oil tank with drain, supply and return lines, filters and valves; 4) left side of accumulator with unloading chains and drives, and 5) front tracks, struts, steering cylinders, and operator cab with control system. These sections are bolted together by 11 major 1 in. thick flanges and can be assembled or disassembled in the field.

Modifications made after the January 2008 tests
The tests conducted on the harvester in January 2008 showed that improvements were needed for better operation of the tracked wheels. The following improvements were made:
(1) The mechanical stops on the rear skid steer tracks were changed to electronic stops on the pumps and engines associated with the tracks.
(2) The speed control system for all four tracks was fine-tuned. This required considerable time. An earlier computer algorithm was simplified and installed to synchronize all four tracks.
(3) The track speed feedback was modified on both sets of tracks to report the track belt speed that can differ from drive wheel speed due to slipage.

Description of the 2009 Harvester Tests
Tests conducted on March 5 & 6 at the prototype fabricator, Whirl-Air-Flow Co. in Big Lake, MN, evaluated the overall operation and control systems of the harvester, the simplified synchronization of the track systems, and the cutting effectiveness of the cutting blades.

The harvester was lifted off the floor with hydraulic jacks to measure the speed of the tracks and the rpm of the hydraulic motors. Figure 1 below shows the tracks off the floor for testing.

Both diesel engines on the harvester were started and hydraulic fluid was pumped to each track motor by the four, 200 hp, hydraulic pumps (one in each track). Each one of the two diesel engines mounted on the harvester is linked to its respective set of tracks. The left engine powers the rear tracks and the right engine powers the front tracks. Both sets of tracks were operating simultaneously, and measurements were taken on the track speed and on the hydraulic motor RPM of each set of tracks. Video was made of this testing operation.

The track speed and synchronization was found to perform well, in other words, the unit would be able to move forward and backwards and turn as needed in field conditions without undue skidding. However, with the information gained from the test, some further tuning of the algorithm will be done to improve the smoothness of operation.

The tree-cutting test was performed by operating the harvester inside the Whirl Air Flow shop. Figure 2 shows a 13 inch diameter, tree was mounted onto a 1 inch thick, 1 foot wide, 10 foot long steel plate with 296 deck screws. Figure 3 shows the smooth cut and the mounting screw holes in the bottom of the tree “stump”. The tree stood upright to mimic a field test “on-the-stump.” For safety purposes, the tree was attached to a loose chain approximately 10 feet above the floor. The steel plate was connected via 5/8 inch steel cable to three 10 inch building support columns in the shop with a 4 inch hydraulic cylinder placed in-line. The steel plate with the upright tree attached was allowed to slide along the floor several inches during the test until the cable tightened and held the tree rigid for cutting. The cable tightening was documented by video taken of the test. The 1½ inch
rod end of a 4 inch diameter hydraulic cylinder was attached to the other end of the cable and the body end of the cylinder was attached to three stationary support columns by chain. As the harvester moved forward it severed the tree. This operation was videotaped and watched by our RDF project manager. Figure 4 above shows Xcel management monitoring the test.

The cutting force was measured and recorded by the pressure transmitter and laptop computer. The pressure transmitter mechanically failed during the March 5 pre-test and was replaced. A reading was obtained during the full test on March 6 and indicated a peak pressure of 555.3 psig. Figure 5 shows the time/pressure relationship created by the severing of the tree. The vertical axis indicates pressure in psig and the horizontal in milliseconds.

The harvester accelerated quickly and was moving forward at a speed of about 3.9 mph (5.8 ft/sec), which is about 2/3 normal operating speed, while the rotary blade cut through the tree. The actual cutting time according to the graph above indicates a start to finish cutting time duration of .304 seconds. Speed was purposely limited due to safety reasons.

The tree-cutting test was an unqualified success. The cut was very smooth with no sign of the tree splitting near the cut point (fig 6). The pressure measured on the rod side of the cylinder was mathematically converted to force and indicated a resistive peak force of approximately 6000 lbs on the harvester as the 13 inch tree was severed. The measured force was a much lower force than anticipated based on previous calculations. Pinch cutters with 8 inch pistons used in some logging operations are designed to handle blade forces upwards of 150,000 lbs. Although it was expected that we would see less than 30,000 lbs of force based on design data, concerns existed that the operator would feel a slight, but annoying jolt as the tree was cut. Fortunately, the jolt was absent. The harvester track breaks also performed well as they stopped the harvester within about 5 feet.
All aspects of the harvester worked well. The diesel engines and hydraulic motors worked smoothly without any unusual noises, there were no visible leaks in the hydraulic systems, the driver in the cab was able to operate all systems efficiently using the joy stick and the touch screen, the unit accelerated and de-accelerated quickly, the tracks worked effectively, and the blade performed very efficiently for cutting a large tree. It should be noted that the blades only move while they are being pushed through the tree(s) by the forward movement of the harvester. There are no motors on the blades. When the harvester is cutting down trees (from 30 to 3 inches in diameter), the actual cutting time for each tree will be very brief, calculated to be about \( \frac{1}{4} \) to \( \frac{1}{20} \)th of a second depending on the size of the tree.

**Additional Milestones:**

Milestones 1-12 and 14, 15, 16, and 18 have been completed, reports submitted, and progress payments received by EPS  
* M19 – Annual Land Rental; report submitted Mar. 18, 2009  
* M20 – Annual Tending and Monitoring of Trees. Planning has begun for tending activities needed for spring and summer of 2009.  
* M22 – Tractor Rental; report submitted Mar. 18, 2009

**Project Status:**

In the next phase of harvester assembly, the accumulator motors, chain drive system, accumulator arms and computer monitoring control systems will be added. The accumulator pumps are already in place. A row of trees has been located for conducting a harvesting test in the field with the accumulators installed. The plan is to conduct the field test in fall of 2009 and this will complete milestone 17.

While significant progress is being made on this project, the harvester assembly costs and plantation management costs have been much higher than expected. EPS has been diligently trying to control costs and continues to do so, but it is very unlikely that those costs can be reduced to within 10% of the level assumed by the proposal.

With the completion and submittal of milestone 13, represented by this report, it is expected that the milestone progress payment of $67,790 and the Annual Deferred Retainage of $22,566, originally planned for release by January 2008, will now be paid to EPS.

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