FORCE OF IMPACT ASSOCIATED WITH TREE FAILURES

CHARACTERIZING BRANCH FAILURE LINE STRIKES

ISA Annual Conference, Orlando, FL

10 August 2015

PROJECT TEAM

John Goodfellow, BioCompliance Consulting lead the team and was principle investigator.

Joe Potvin, EE PE, Electric Power Research Institute (EPRI) participated directly in the field phase of this investigation and contributed to the data analysis.

Andreas Detter Brudi & Partner TreeConsult, Gauting, Germany, participated directly in the field phase of this investigation and contributed to the data analysis. participated directly in the investigation including field work and analysis of data.

Ken James, Ph.D., Environmental Engineer, ENSPEC Pty Ltd, Victoria, Australia, provided advisory support during field work, and assisted in the data analysis.

PROJECT SPONSORS

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

TREE FUND
Tree Research & Education Endowment Fund

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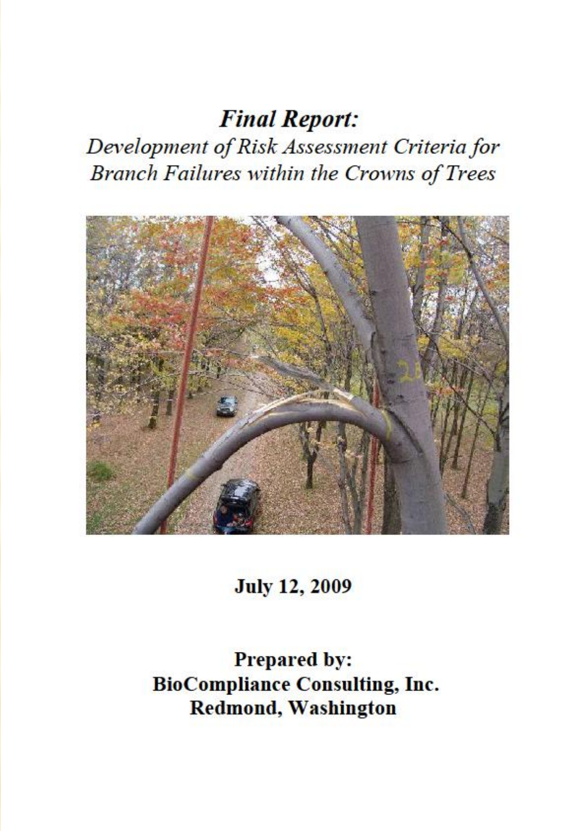
International Society of **Arboriculture**

PROBABILITY OF ADVERSE TREE-CONDUCTOR CONFLICTS

There are two basic failure modes in which trees create risk:

1. **The Electrical Mode of Failure** occurs when a tree or parts of the tree provide a short circuit fault pathway between areas of unequal electrical potential.
2. **The Mechanical Mode of Failure** is caused by structural failure of the tree or parts of trees (branches) causing physical damage to energy delivery infrastructure.

BRANCH FAILURE STUDY 2009

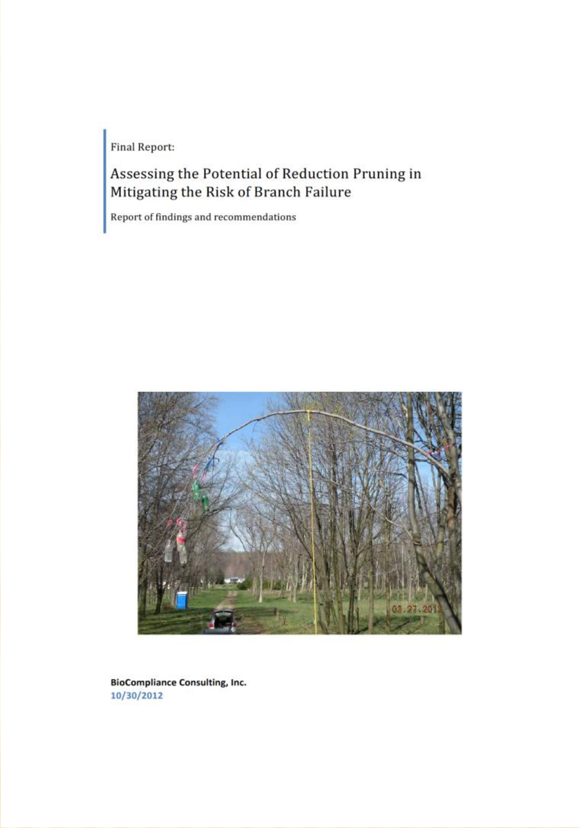


Final Report:
Development of Risk Assessment Criteria for Branch Failures within the Crowns of Trees

July 12, 2009

Prepared by:
BioCompliance Consulting, Inc.
Redmond, Washington

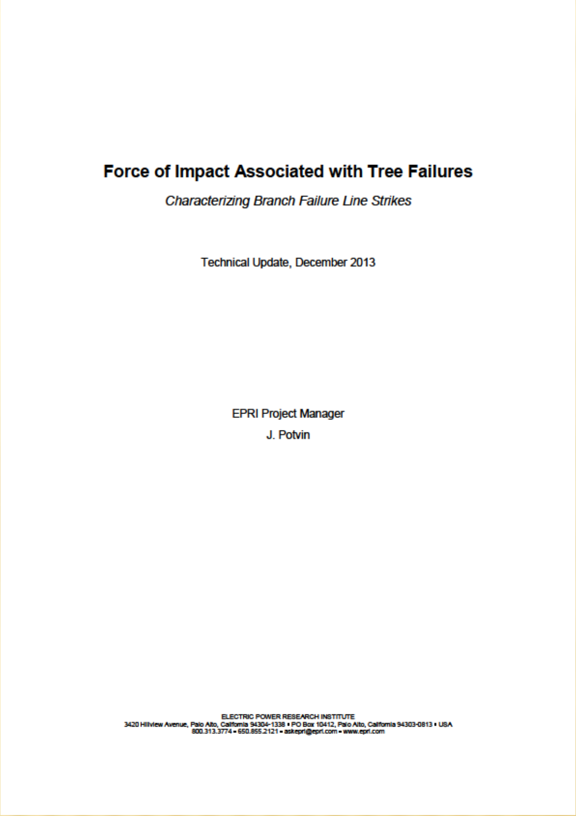
BRANCH REDUCTION PRUNING STUDY 2012



Final Report:
Assessing the Potential of Reduction Pruning in Mitigating the Risk of Branch Failure
Report of findings and recommendations

BioCompliance Consulting, Inc.
10/30/2012

BRANCH STRIKE STUDY 2013



Force of Impact Associated with Tree Failures
Characterizing Branch Failure Line Strikes

Technical Update, December 2013

EPRI Project Manager
J. Potvin

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PROGRESSION OF BRANCH RELATED R&D

OBJECTIVES OF THE PROJECT

To describe the destructive potential of a branch strike on a target.

Three metrics were used to quantify a strike:

1. Energy (potential and kinetic) available at the target location.
2. Change in momentum of branch (deceleration) and target (acceleration) on impact.
3. Force of Impact on branch and target on impact.

To identify intuitive means of assessing consequences of branch failures for use in risk assessment field surveys of risks.

THE RISK EQUATION

Risk = Hazard X Consequence

Where:

Hazard is the probability (likelihood):

- of structural failure of the tree
- that the failed part strikes the target

Consequence is defined in terms of potential damage to the target (line or other) and is a function of the force of impact on the target.

Any assessment of the risk of tree-caused damage due to a target strike must consider both the likelihood that a tree fails and strikes the line, and the consequences of that impact.

CONSEQUENCES OF STRIKES DEPENDS ON THE TARGET

Overhead utility line target:

- Loss of reliability: an interruption and subsequent outage.
- Damage of energy delivery infrastructure, wires down, broken poles
- Adverse public exposures to high voltages and fault currents.
- Power line initiated wildfire/bushfire.

Human target;

- Injury
- Death

Structures as targets (e.g. building, cars, etc):

- Structural damage
- Total loss of the structure

… and also on how hard the target is struck!

REVIEW OF THE LITERATURE

Seven broad subject areas were considered:

1. Allometric studies of tree structure and form.
2. Structural stability studies that considered failures in the main stem/trunk and soil/root plate.
3. Carbon sequestration and biomass of trees.
4. Arboricultural practices of rigging and dismantling operations.
5. Forestry operation and harvesting efficiency.
6. Engineering properties of wood.
7. Utility consequences of line strikes.

- Whole tree failures generate enough force to damage overhead infrastructure.
- Line strikes by smaller branches may be survivable.
- The project goal was to provide data that support assessment of “storm hardening” of the distribution system.

STRUCTURAL FAILURES OF INTEREST: *SMALL TO MEDIUM BRANCHES*

BRANCH SPECIMENS TESTED

Two species were used in the testing:

1. The silver maple species were representative of failure of upright branches within the crown, and ranged between 3-7” butt diameter, 14-32’ in length, and weighed 30-340lbs

2. The London plane tree specimens were representative of failure of a main stem (tops) within the crown and ranged 5-7” butt diameter, 14-19’ in length, weighed 250-540lbs.

Species	Number	Mass (kg)	Dia. (cm)	Length (m)
Silver maple (*Acer saccharinum*)	15	14 - 155	8-18	4.5 - 10.5
London planetree (*Platanus x acerfolia*)	3	112 – 245	14 -19	4.5 - 5.7

SOURCE OF SPECIMENS

The specimens were harvested from mid crown positions.

Specimens were predominantly upright in orientation.

A case of synergy at TBW 2013:

- Collaboration with Jake Miesbauer Ph.D. (Morton Arboretum), providing source of specimens.
- Consultation with Ken James Ph.D. in refining test protocol and data interpretation.

SPECIMENS & REPLICATIONS

Each specimen was dropped several times. *…unless it fractured on impact!*

Condition	# Replications
@ Harvest (in leaf)	1
Full leaf, to simulate growing season strikes	3
Leafless, to simulate dormant season strikes	3

SEQUENCE OF A STRIKE

- Branch at rest (***potential energy***)
- Branch failure, detaches, and begins to fall (***acceleration***)
- Maximum velocity of fall just before impact (**kinetic energy**)
- Upon impact momentum is transferred:
  - Branch ***decelerates*** and looses ***momentum*** as it deflects
  - Target **accelerated** and gains **momentum** as it deflects and deforms
- The amount of energy transferred over time describes the ***force*** of impact.

Dynamic behavior of a target influences peak force.

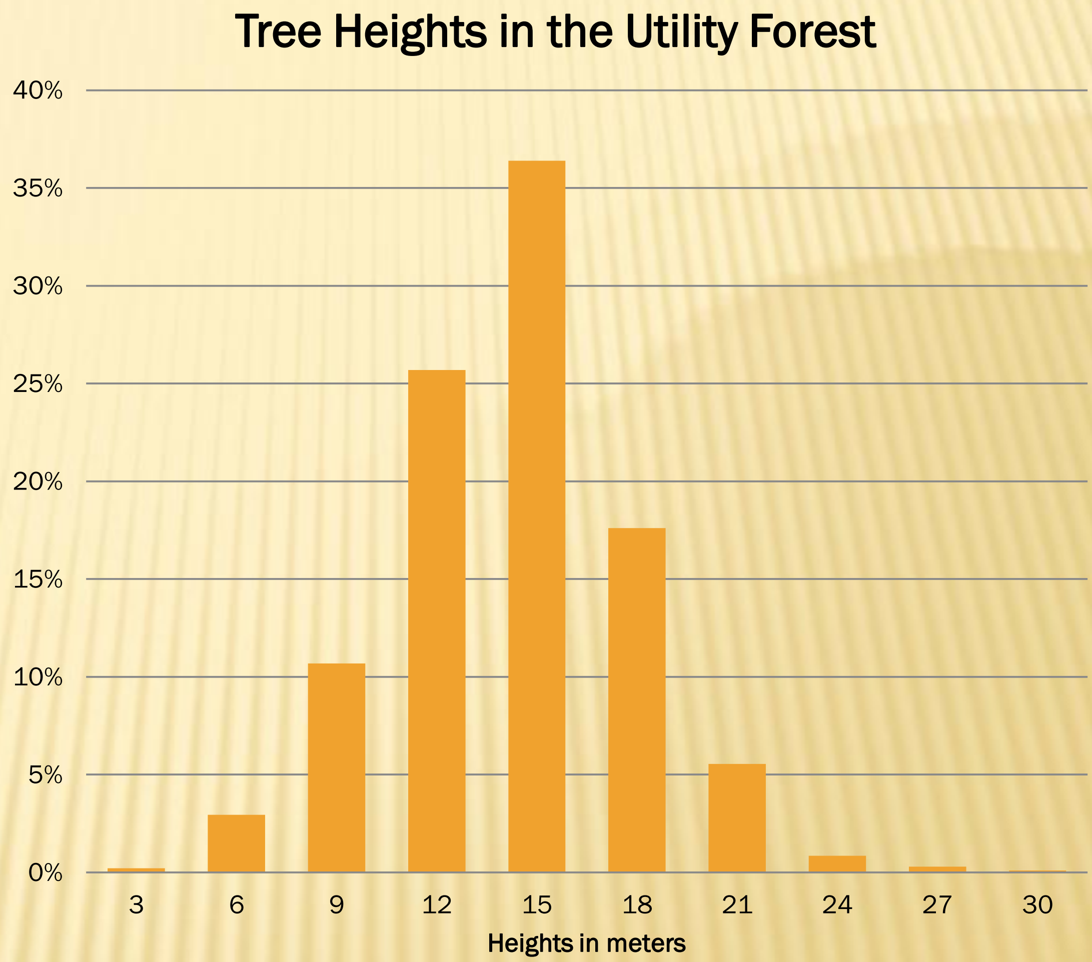
A rigid target was selected for this investigation because it would provide a basis for characterizing the worst-case impact.

TARGET RESPONSE IS THE KEY

PLACEMENT OF ACCELEROMETERS & VISUAL REFERENCE MARKERS

FALL DISTANCE

The drop height was selected based on the difference between the average height of typical distribution lines (~8-10 m) above the ground and the expected height of the canopy of trees in the utility forest.



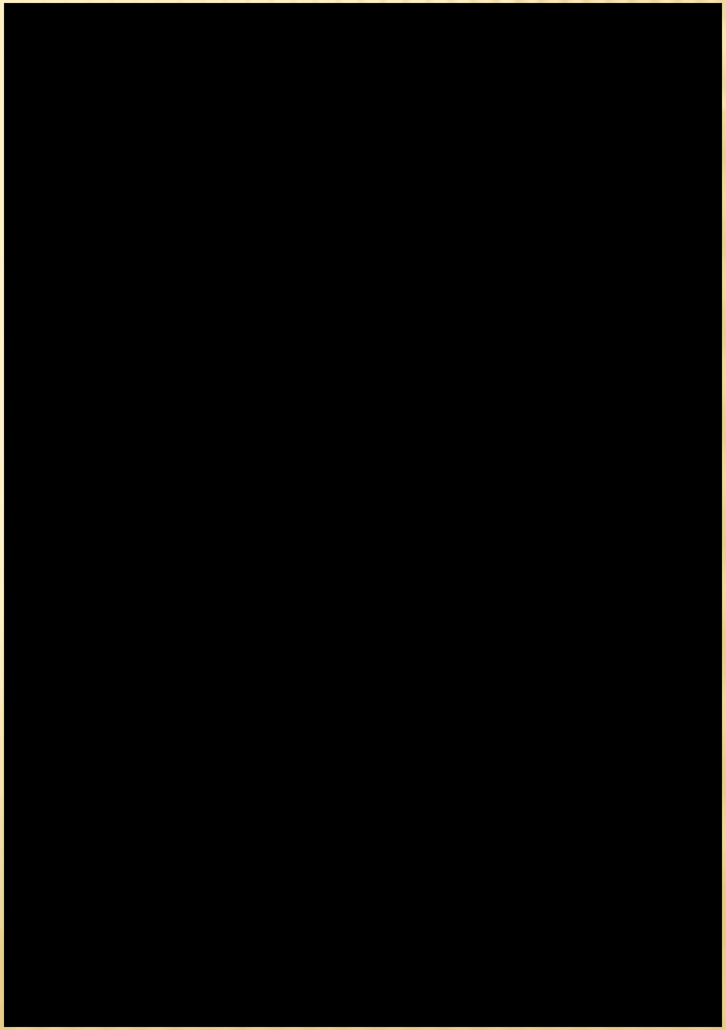
The test simulated a detached branch in free fall making direct hits on a target.

A total of 86 branch drops were completed with 18 branches.

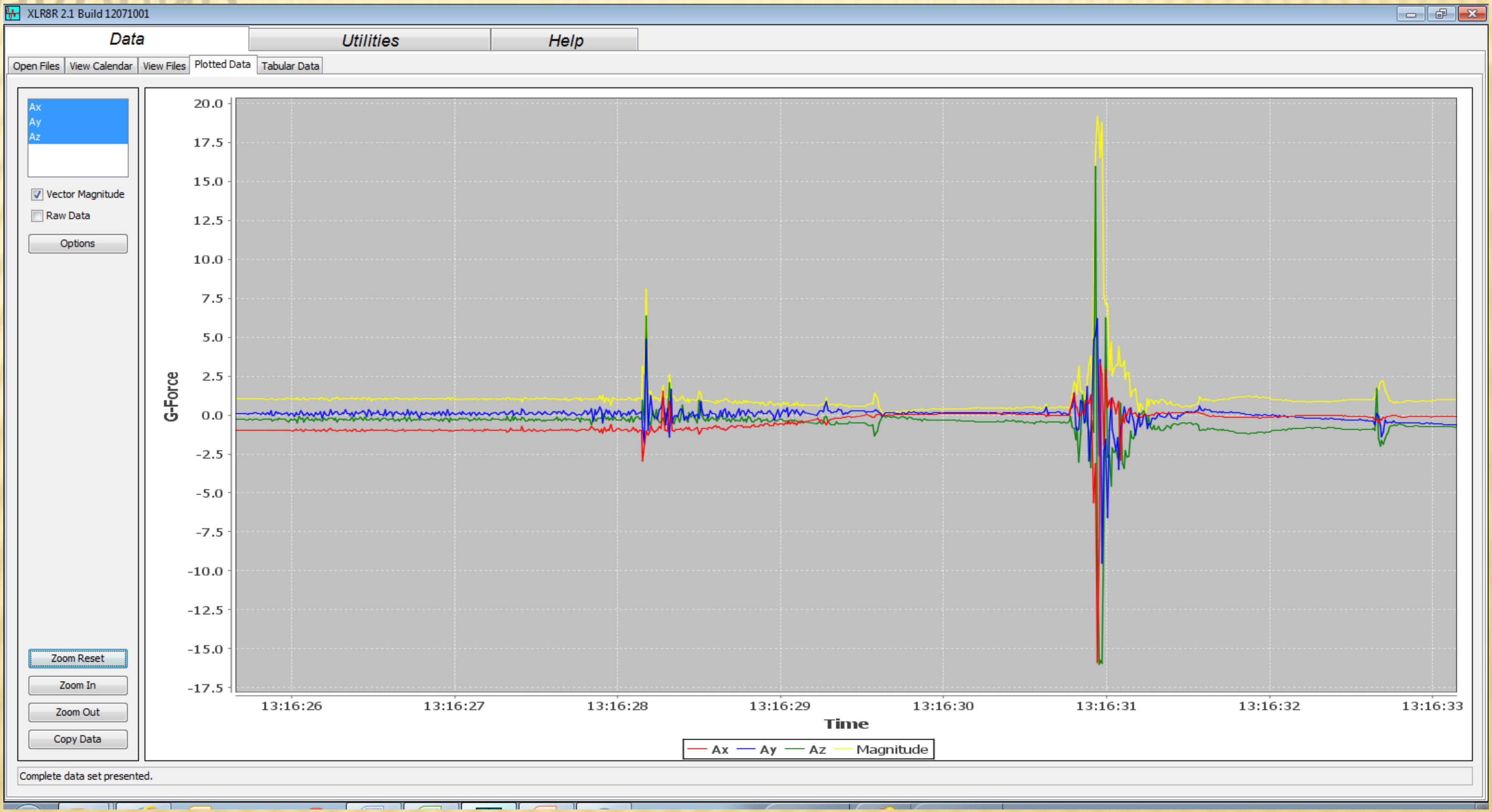
BRANCH DROP TEST

THE STORY OF ONE TEST RUN, SPECIMEN 15D

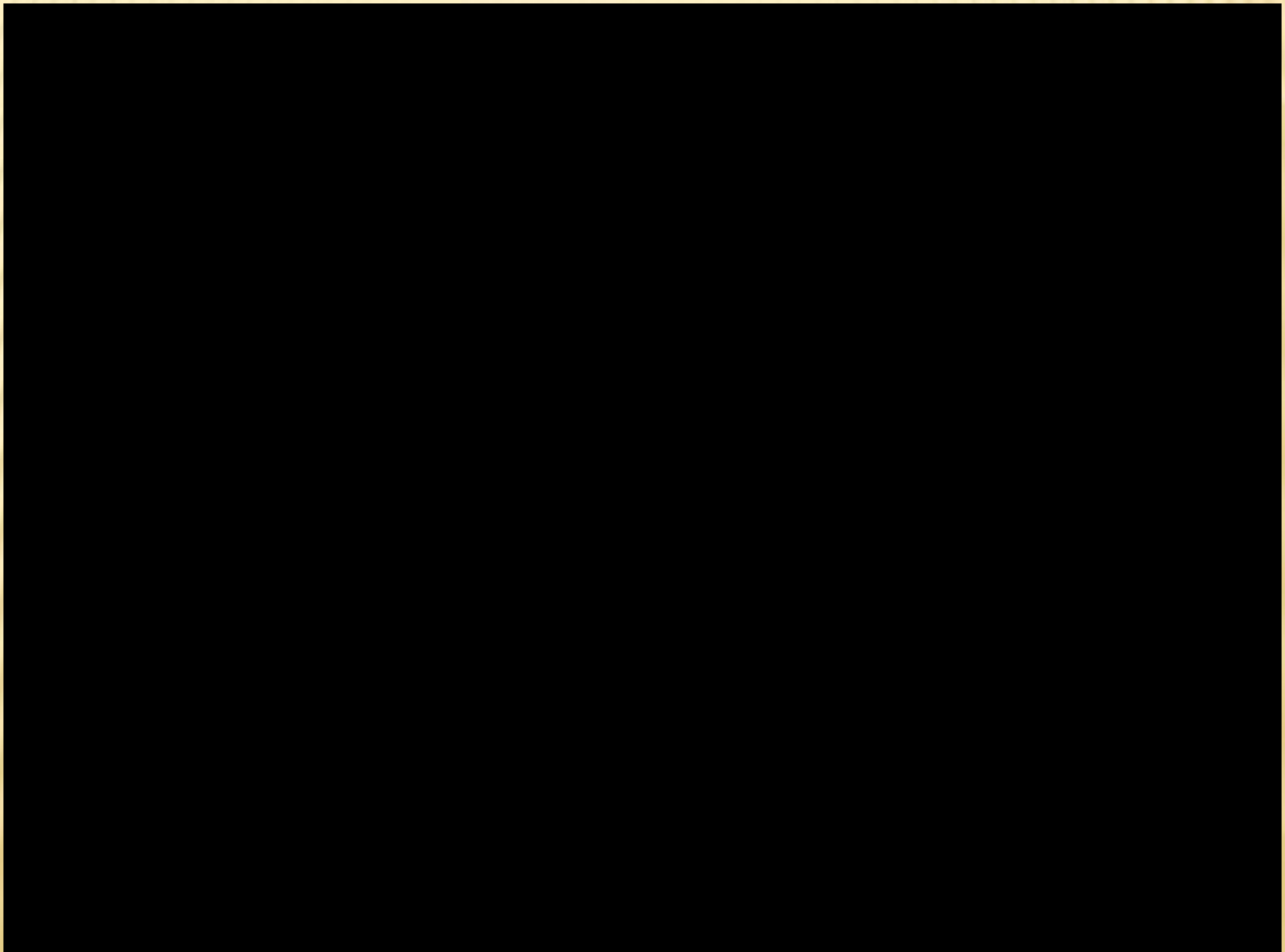
- A silver maple limb was cut from a tree at a height of approximately 25-30ft
- The fall was recorded using a high definition/high speed camera
- an accelerometer was attached to the branch



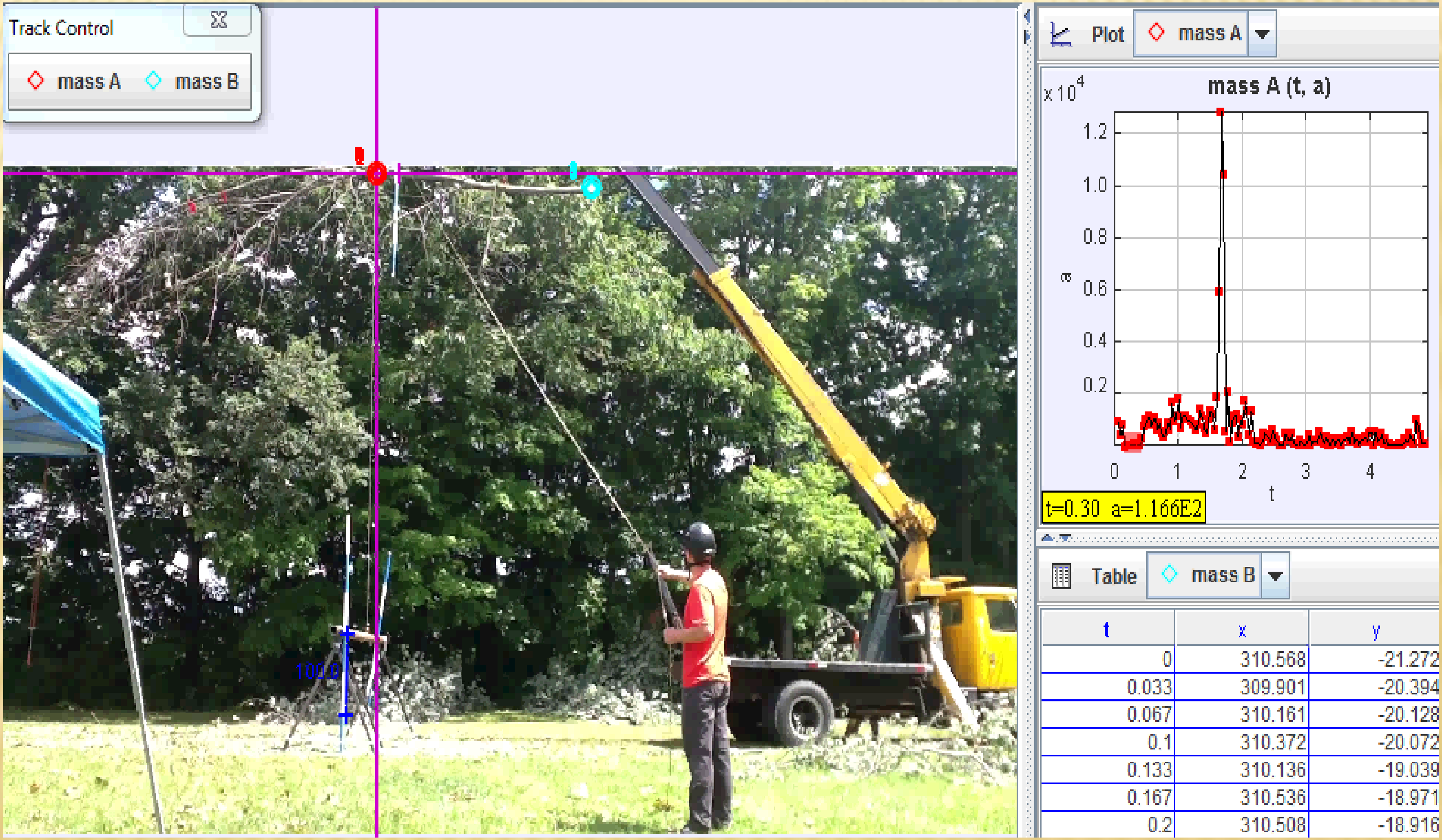
ACCELEROMETER DATA FROM A BRANCH AS IT IS HARVESTED FROM A TREE AND FALLS TO THE GROUND



REPLICATING DROP TEST, *specimen 15D*



DETERMINING VELOCITY BY VIDEO ANALYSIS



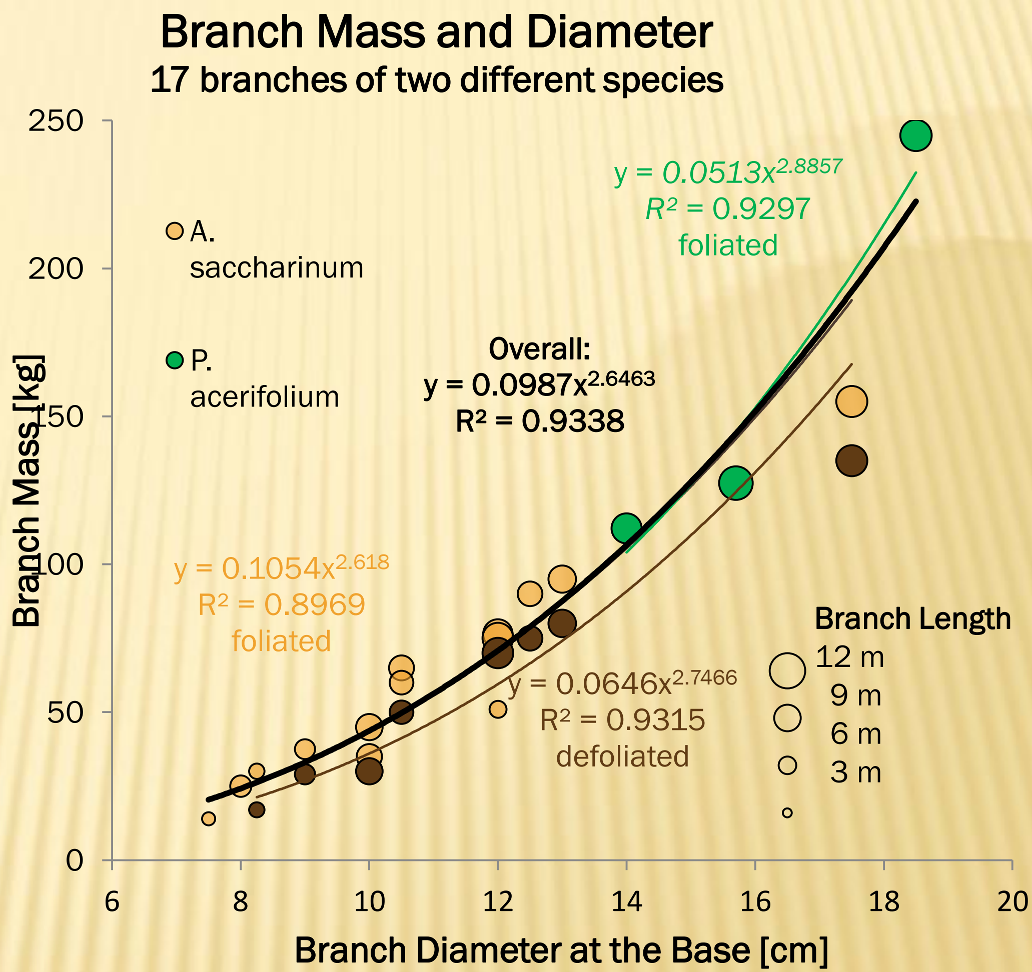
THINGS DIDN'T ALWAYS WORK OUT SO NICELY!

The first task was to identify a an intuitive indicator of potential force.

The mass of each branch was required for each calculation.

The total mass of a branch correlates well with diameter, which is easily observed.

As expected, branches lacking foliage weigh less than those in full leaf.



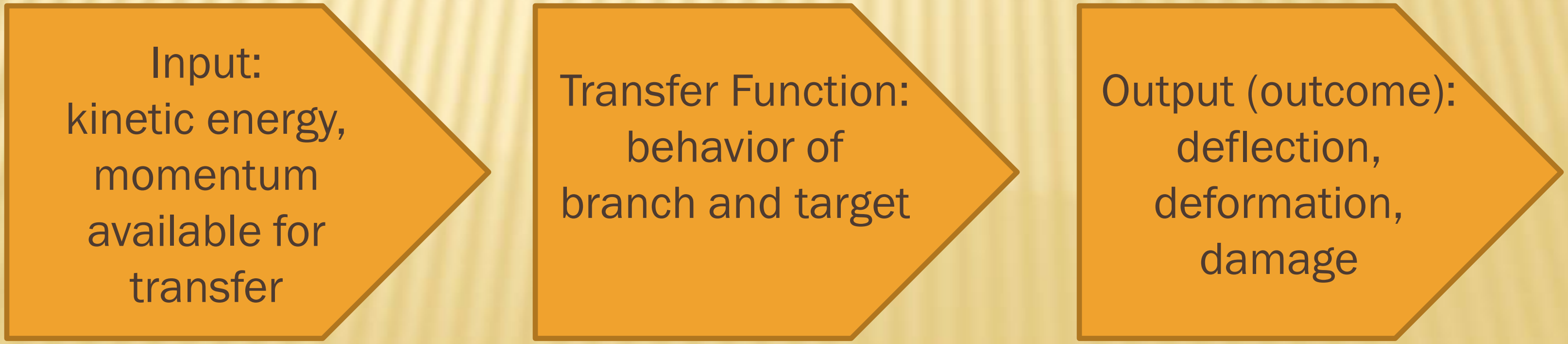
DIAMETER VS. MASS

MODELING IMPACT ON A SYSTEM

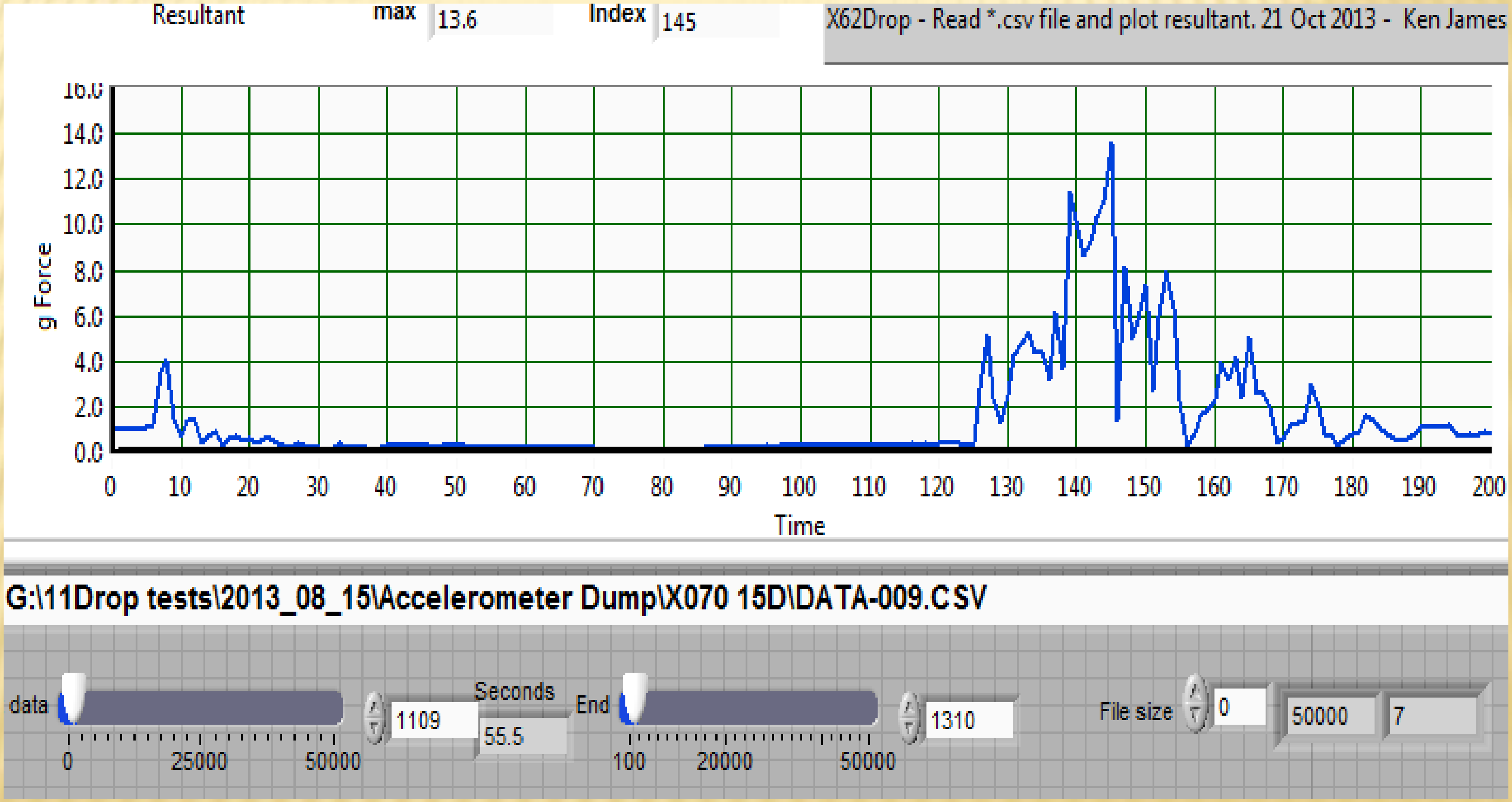
Force of impact is dependent on branch and target characteristics and response.

- During any impact there is a transfer of energy from one object to another.
- Peak force is dependant on input energy, impact time, and target displacement (deflection, deformation, damage).

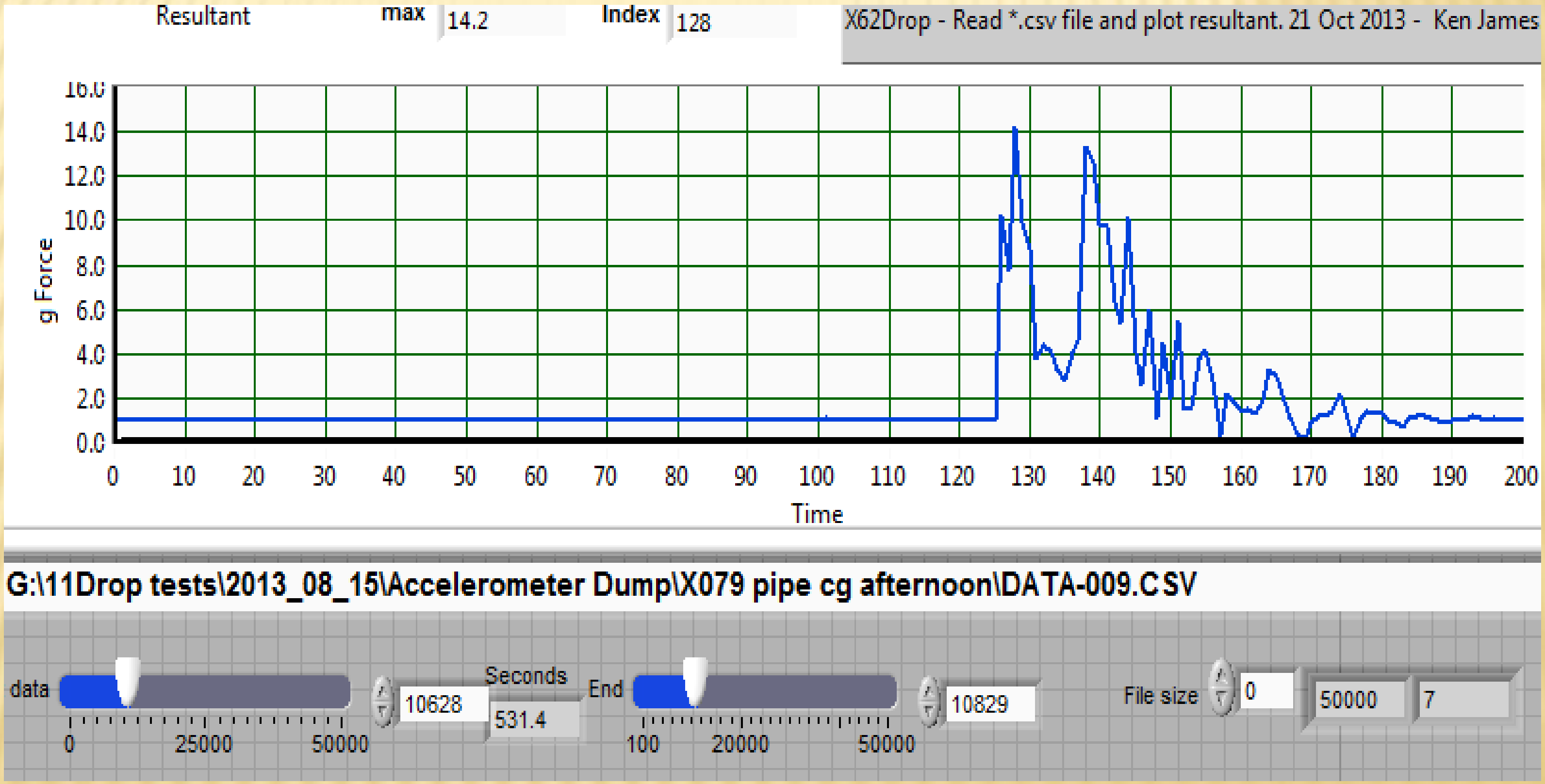
The response of an overhead distribution line is much more dynamic than a rigid pipe (worst case).



PEAK ACCELERATION EXPERIENCED BY A BRANCH SPECIMEN DURING DROP TEST

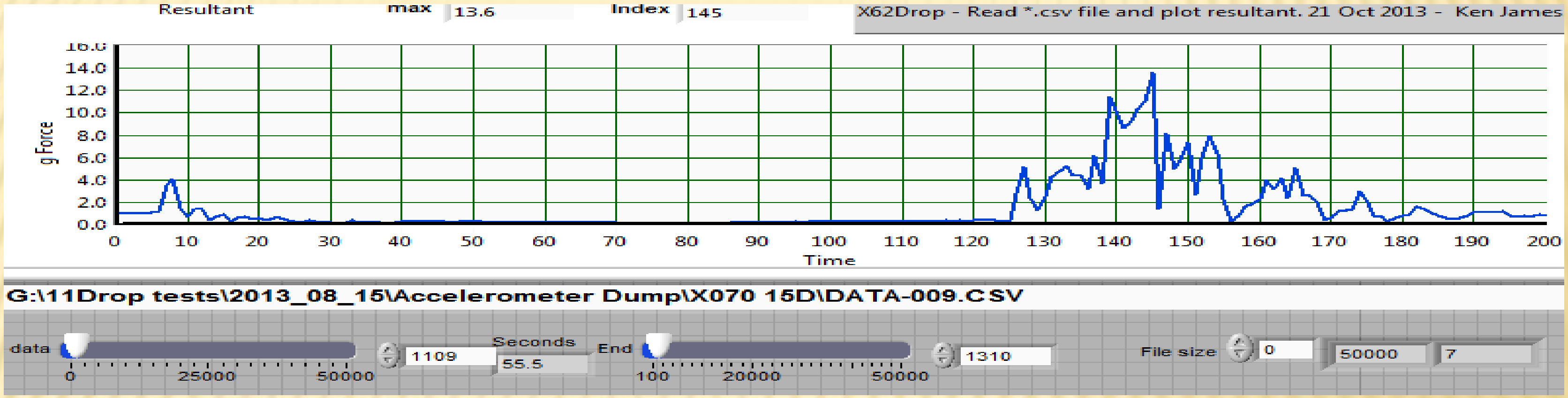


PEAK ACCELERATION EXPERIENCED BY THE RIGID TARGET DURING DROP TEST

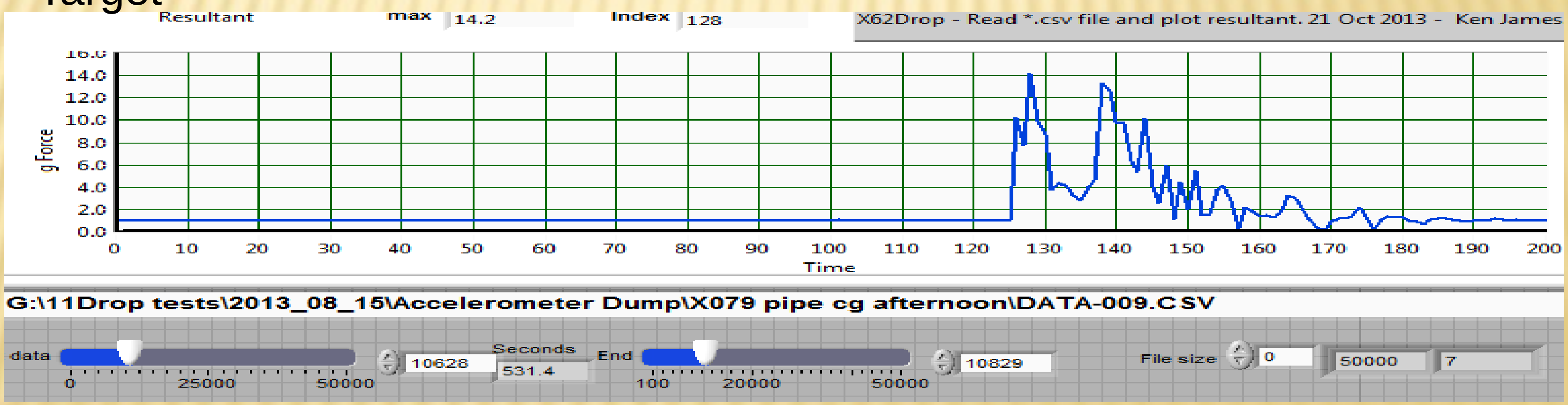


∆ ACCELERATION OF BRANCH & TARGET

Branch



Target

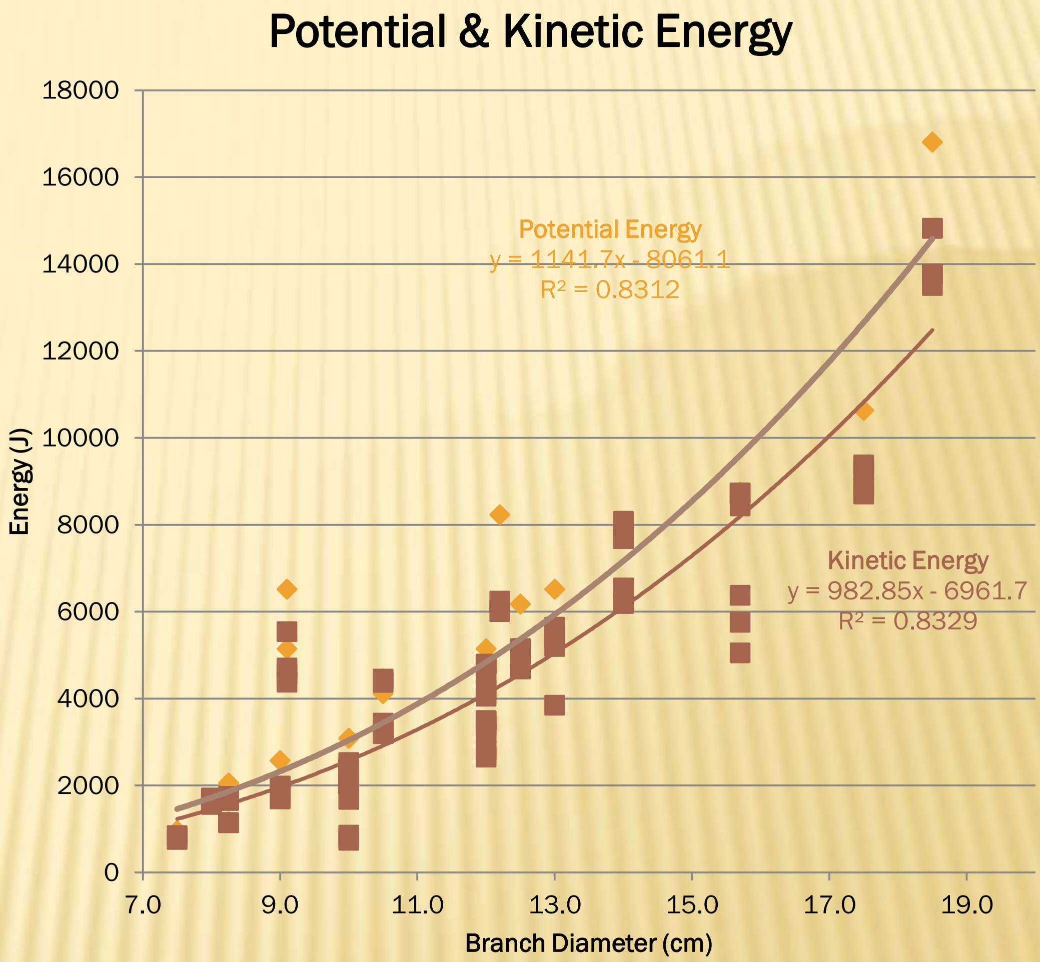


Potential Energy (J) =
mass * height *acceleration

Potential energy is a function of the mass of the branch, vertical distance above the target, and the rate of acceleration of the branch.

Kinetic Energy (J) =
1/2 mass * velocity²

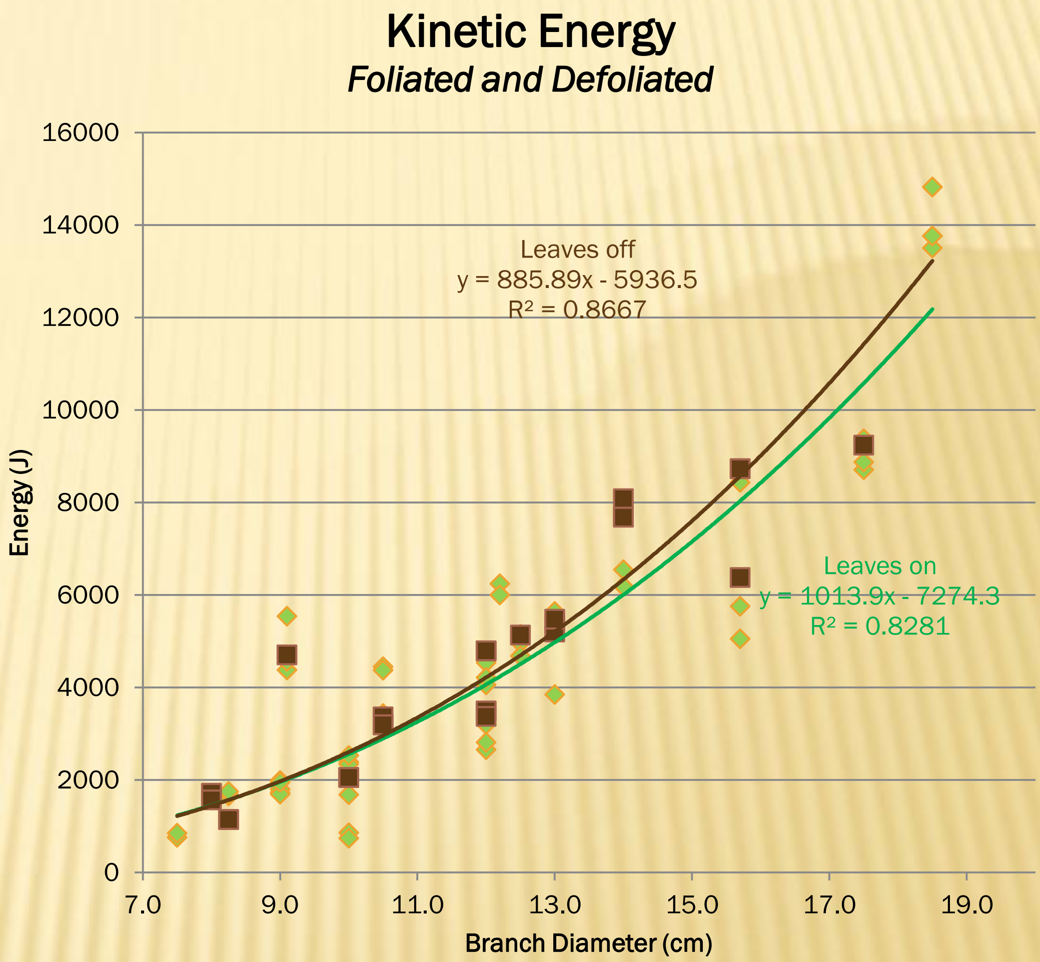
Kinetic energy is a function of the mass of the branch and velocity.



ENERGY OF BRANCH AT REST & IN FREE FALL PRIOR TO IMPACT

As expected, some of the energy represented in the branch at rest is lost to aerodynamic drag as the branch falls toward the target.

Kinetic energy increases with diameter, which in turn is an expression of mass.

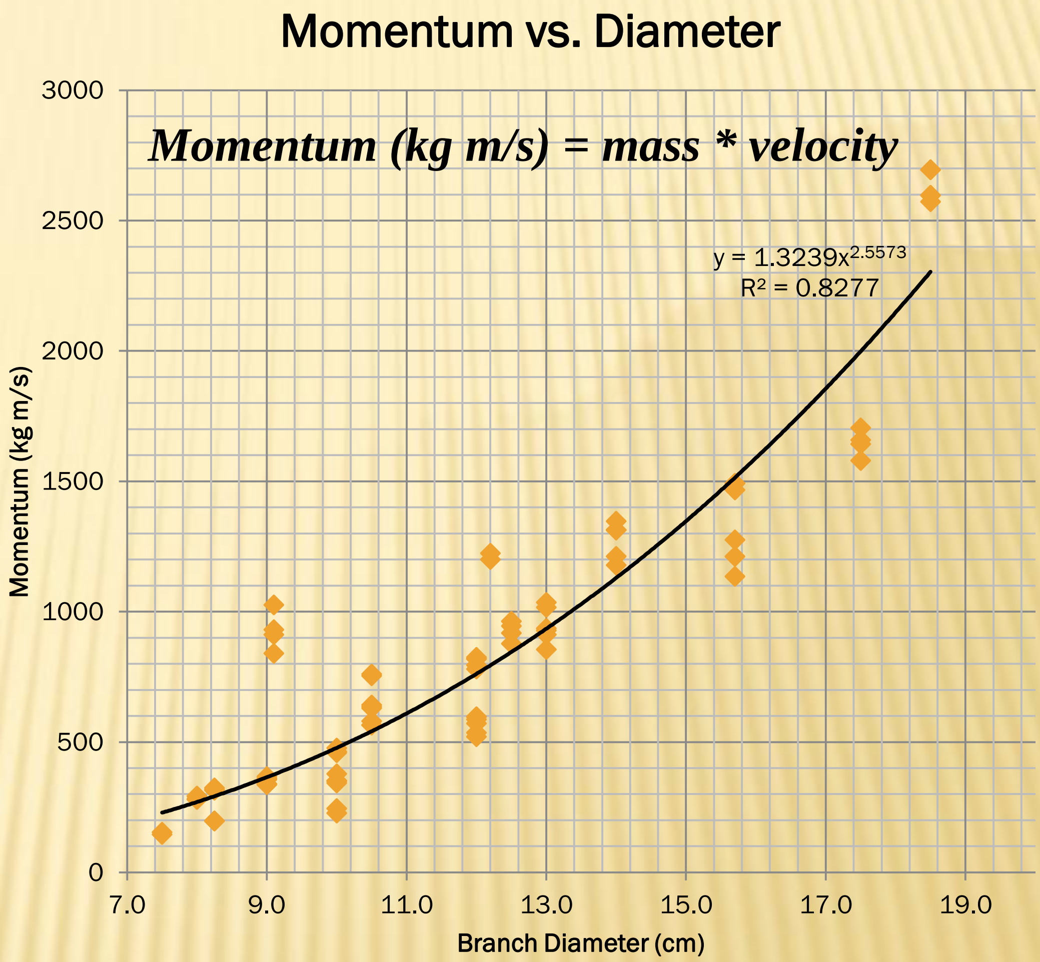


LEAVES AND AERODYNAMIC DRAG

Momentum (kg m/s) =
*mass * velocity*

- The momentum available for transfer from branch to target is a function of the mass of the branch and its velocity immediately prior to impact.

- Momentum increases with diameter, which in turn is an expression of mass

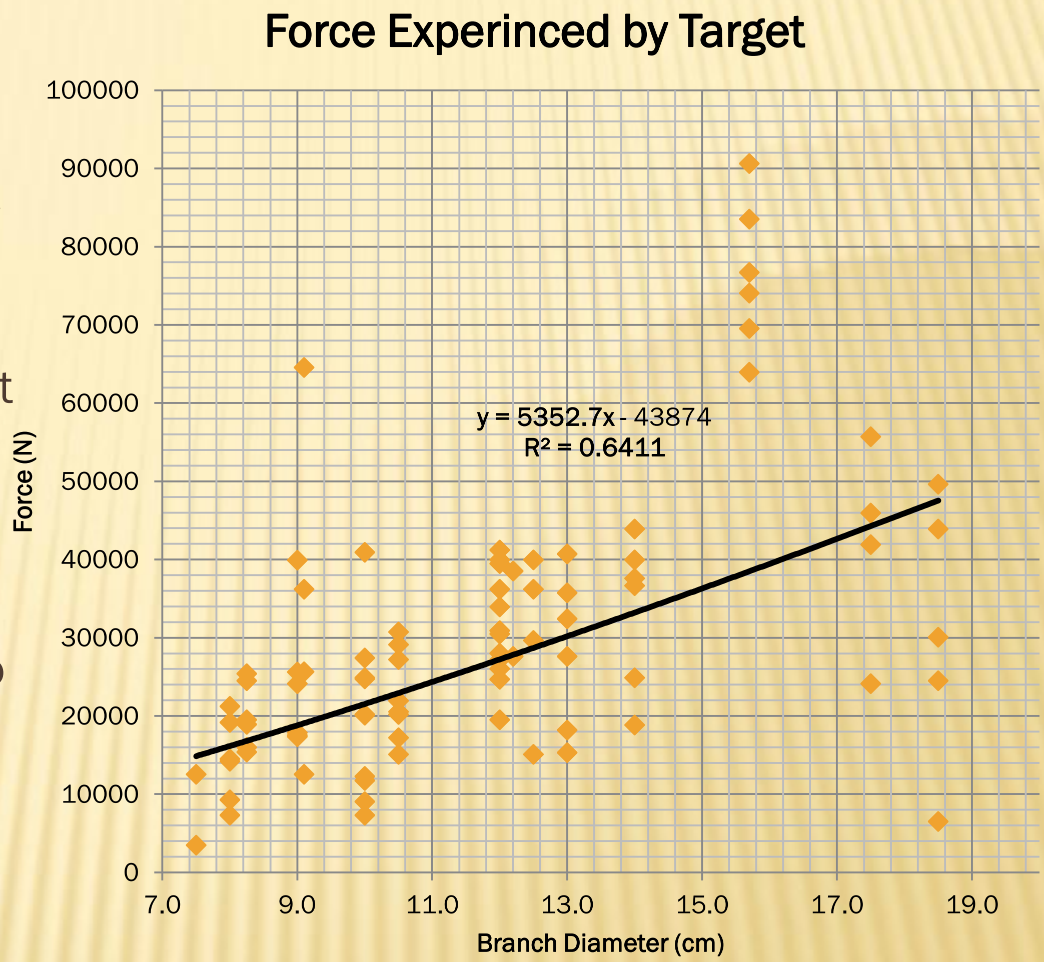


MOMENTUM OF BRANCH AVAILABLE FOR TRANSFER TO TARGET

$Force_{target}\ (N) =$
$mass_{target} * acceleration_{target}$

The force of impact on the target is a function of the mass and acceleration of the target.

The rate of acceleration experienced by the target due to the impact of the branch is the most relevant data set for this investigation.



FORCE OF BRANCH IMPACT ON TARGET

LIMITATIONS

The study did not simulate:

- A strike by a branch that fell in other than horizontal orientation
- a glancing blow by a failed branch
- arc of sweep strikes by branches that remain attached (hinge break)
- Whole tree failures

POTENTIAL ENERGY IS A GOOD CRITERION FOR ASSESSING CONSEQUENCE

- Diameter is a good proxy for mass
- There was only a small difference between potential and kinetic energy
- Branch diameter and height above a target are easily estimated by direct observation from the ground.

RECOMMENDATIONS – EXISTING LINES

- Develop a ranking system (most-least likely to survive a branch strike) for use in an assessment of vegetative conditions (tree risks) to in-service overhead lines and base VM Rx on consequences.

- Evaluate existing in-service OH line designs to determine those least likely to survive a branch impact strike of the magnitude characterized in this study. This information can then be used to inform VM Rx's.

- Refine branch strike consequence rankings based on kinetic energy (diameter & height) and target type, per ANSI A300 Part 9 and ISA BMP Tree Risk Assessment.

RECOMMENDATIONS – NEW LINES

- Conduct an engineering study of potential for new designs that "harden" the overhead system to branch strikes.
- Evaluate the potential for "break away" hardware, reducing restoration and repair times.