Section 3

ENERGY LIMITS AND NEW RATING SYSTEM FOR FRANGIBILITY

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TRIDYNAMIC SOLUTIONS

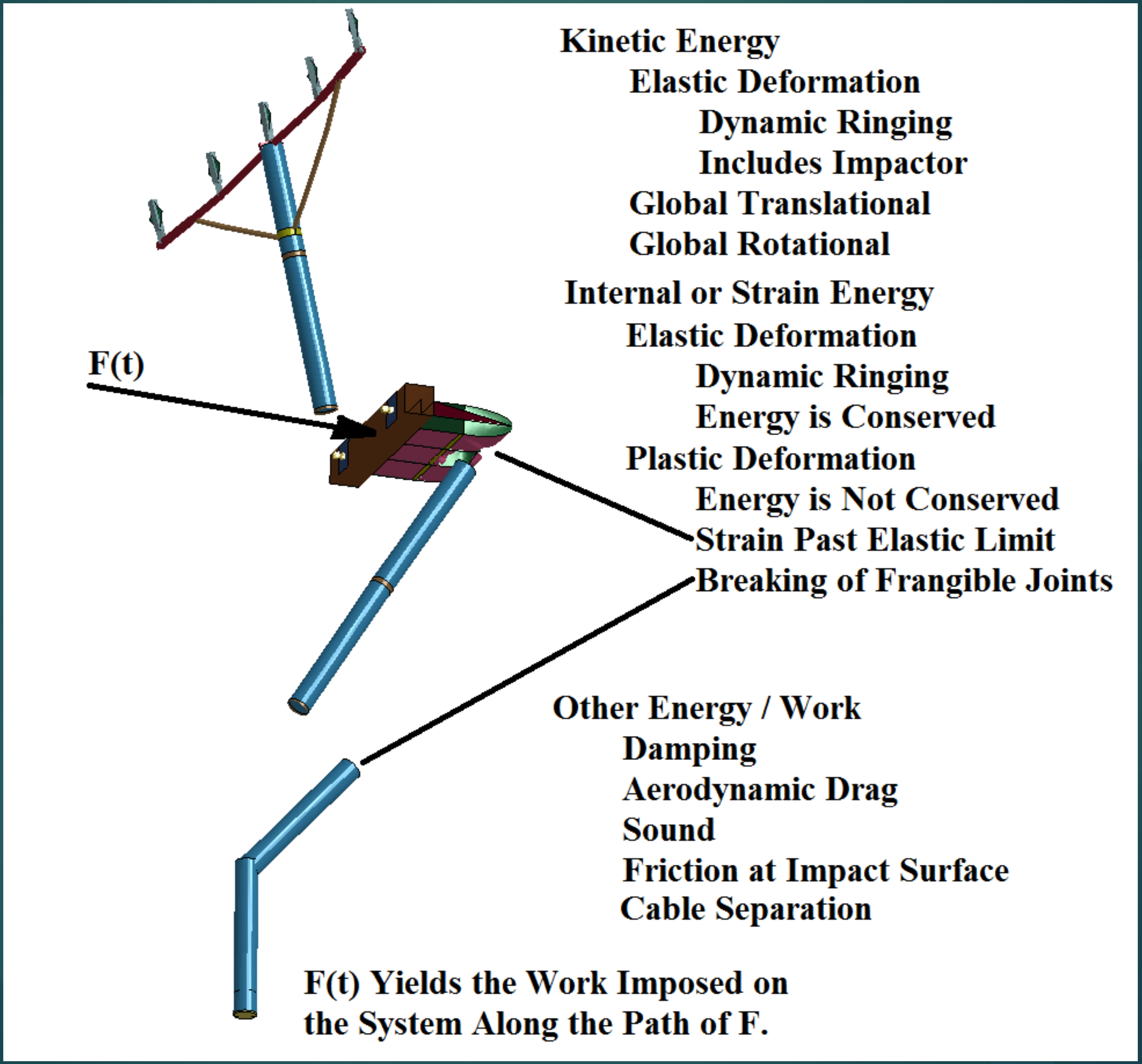
Recommendations

- Re-evaluate current energy limit
  - Current Thought: 20 kN-m Limit
- Re-evaluate current failure mode limitations
  - Clarify wrap-around
  - Define segmentation parameters
- Quantify acceptable wing damage
- Consider alternative to current energy calculation
- Introduce rating system for energy criteria

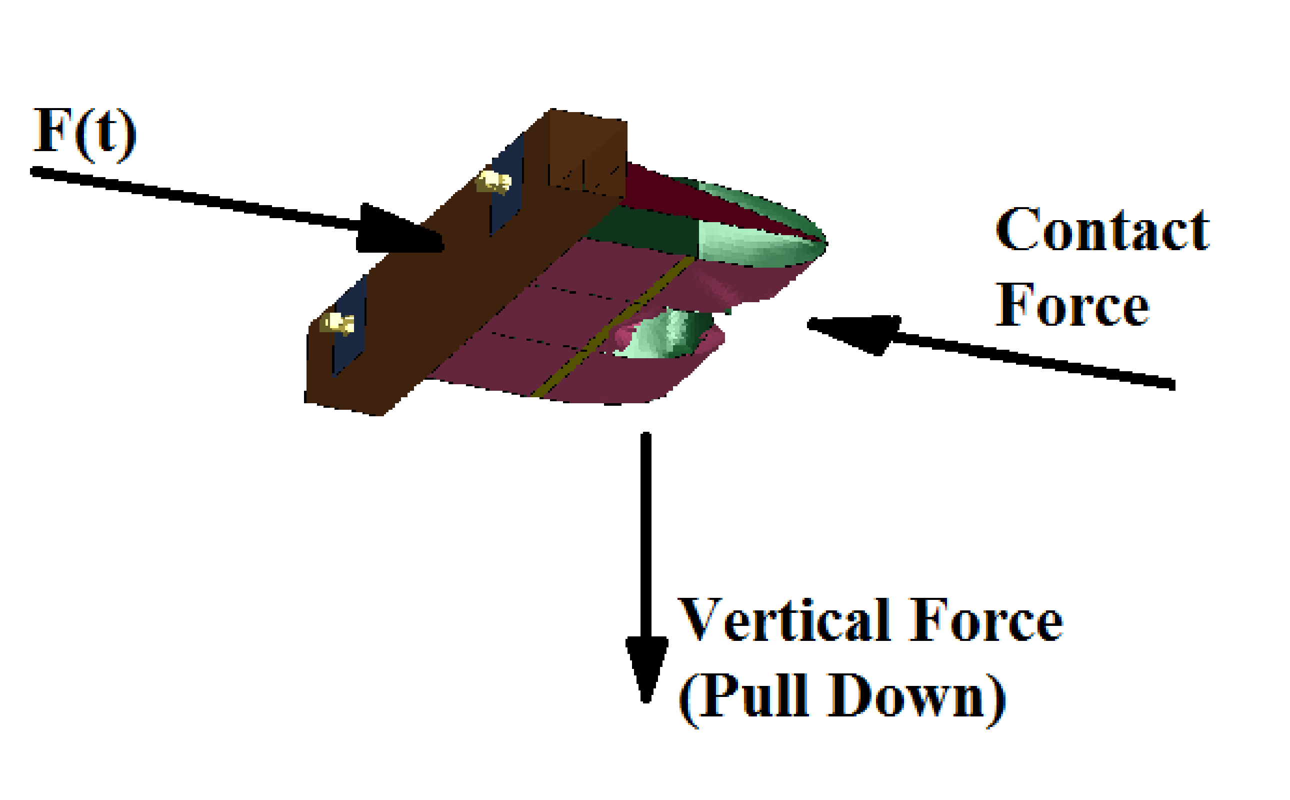
Energy Limit and Windowing

- ICAO:
  - "The structural damage to the aircraft is related to the amount of energy it requires to move the obstacle, or part of it, out of the way and should therefore be limited. This energy can be broken down into the following components:
    - energy to activate break-away or failure mechanisms;
    - energy required for plastic and/or elastic deformation of the obstacle, or part of it; and
    - energy required to accelerate the obstacle, or part of it, up to at least the aircraft velocity."

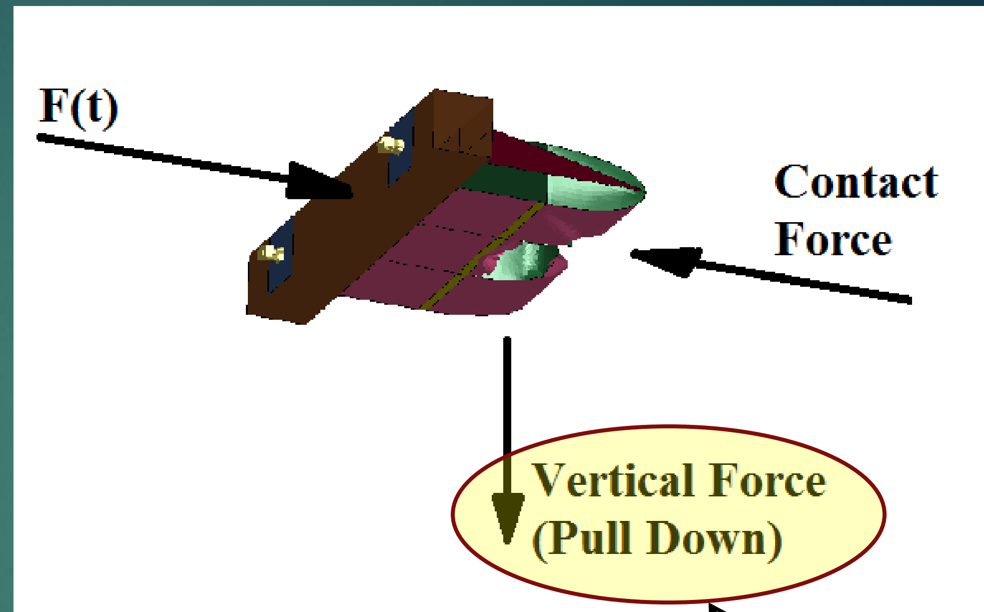
Work and Energy



Free Body Diagram of Impactor Head



Impact Energy



Not Included

$E_{lc} = v \int F(t)\, dt$

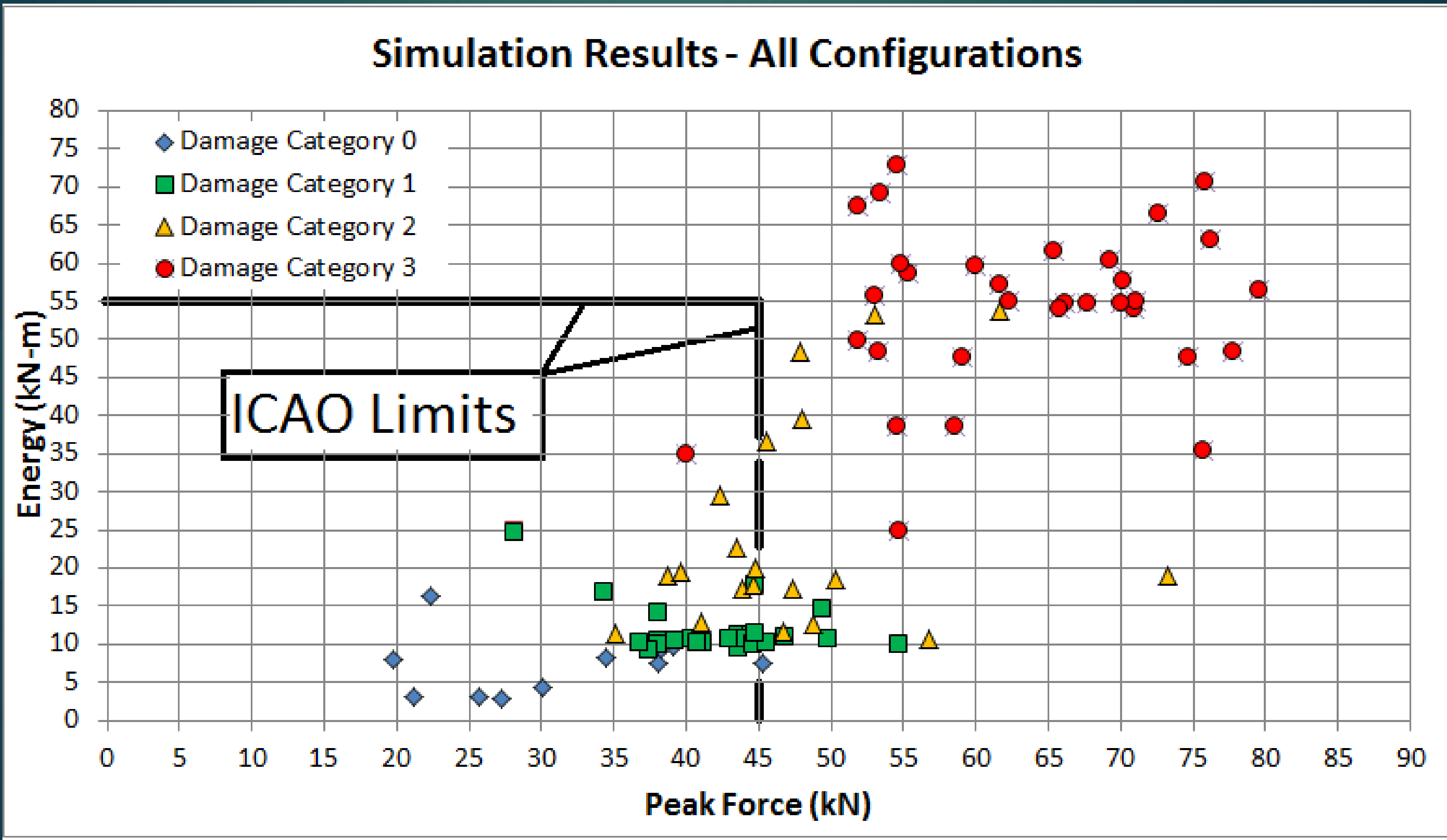
= Impact Energy

(technically Load Cell Work).

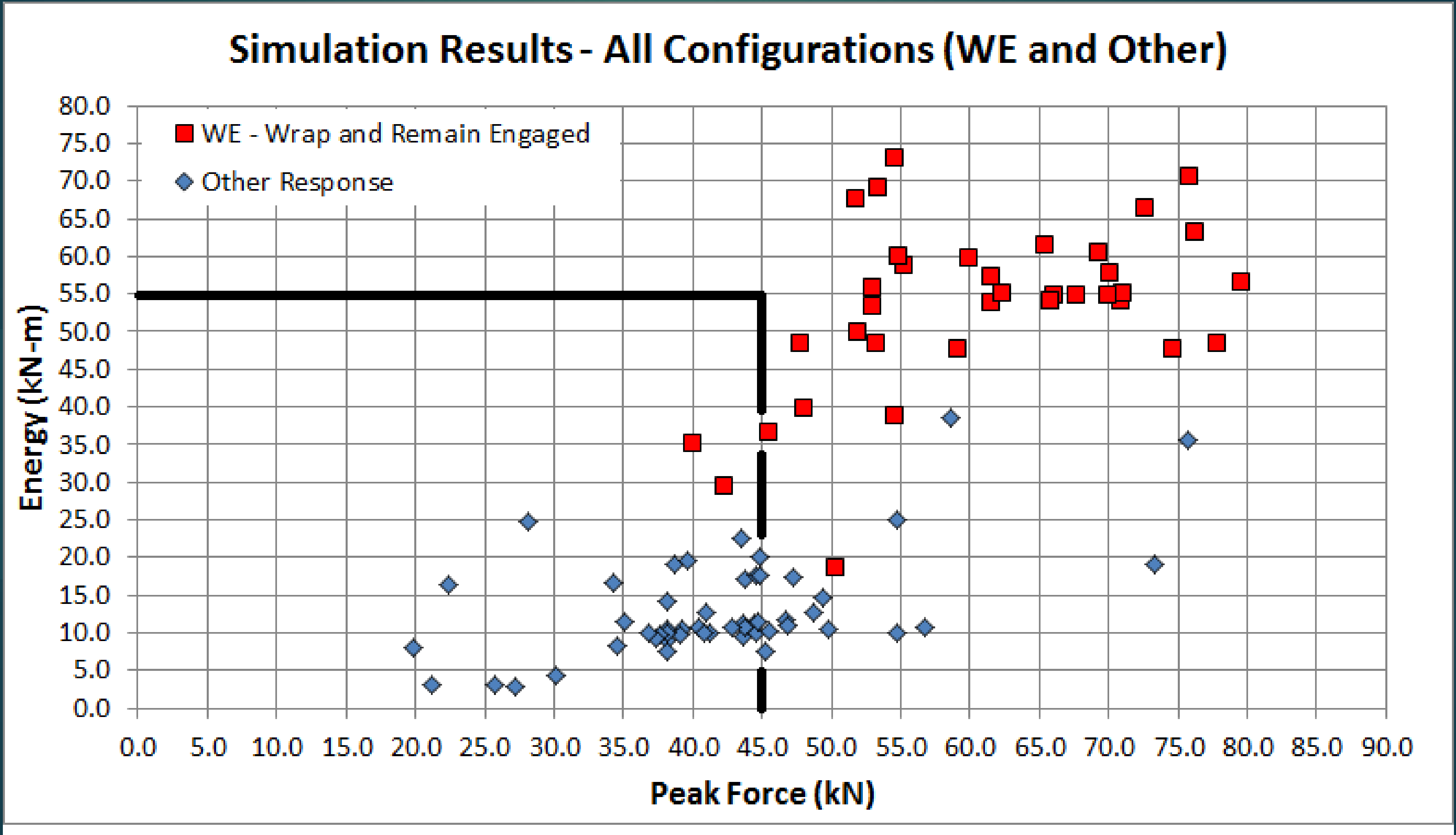
v = speed (assumed constant)

$E_{lc} = v \cdot (Linear\ Impulse)$

Parameter Studies: Damage



Parameter Studies: Damage



ICAO

Prohibits “wrap-around”

3.3 Frangible requirements

3.3.1 The design materials selected should preclude any tendency for the components, including the electrical conductors, etc., to "wrap around" the colliding aircraft or any part of it.

ICAO

Recommends

Minimum energy for break-away
Minimize mass for segmentation and
Efforts to minimize “wrap-around”

4.2 Failure Mode

4.2.2

In the case of a modular design, the structure should contain break-away or failure mechanisms which, apart and together, require only a minimum amount of energy for their activation. This concept permits moving the least amount of mass out of the way of a colliding aircraft. The sequence of events is easier to predict as the structure behaves in a brittle way, disintegrating preferably at small deflections. It also reduces to a minimum the possibility of a "wrap-around" effect.

ICAO

Limit mass
"Wrap-around" an additional hazard

4.2 Failure Mode

4.2.3
In the case of a one-piece design, the frangibility must be guaranteed by a complete failure of the structure, which is achieved by the random failure of structure members, instead of by failure of predetermined break-away or failure mechanisms. This implies that eventually the entire structure will be involved in the impact, resulting in a relatively high value of the kinetic energy required to move the structure out of the way. Therefore, this type of failure mechanism seems to be suitable only for lightly loaded structures, i.e. those meant to carry low-mass equipment. Moreover, due to the continuous nature of the structure, the sequence of events is difficult to predict and the tendency to "wrap around" the aircraft should be considered an additional hazard.

ICAO

Member failure should be segmented

4.5 Frangibility Concepts

Frangible Members

4.5.3 In this design, the structural member is required to fail and not the end connection. The member should achieve a segmented-type separation along its length, thereby minimizing the amount of mass acceleration and reducing the potential of a wrap-around effect. Brittle materials such as plastic, fibreglass or other non-metals are more likely to be used than metals. The main advantage with frangible members is that impact forces do not have to be carried back to the connection in order to fail the section. This means that energy is not absorbed by bending the member as in a frangible connection design. The disadvantage is that special, non-metallic materials require extensive testing to establish properties to be used for deflection analysis of the structure. The analysis should also be confirmed by doing full-scale load tests on the structure. Non-metals must also contain ultra-violet inhibitors for protection against the environment.

ICAO

Clarification needed

5.2 Testing Procedures

Approach Lighting Towers and Similar Structures

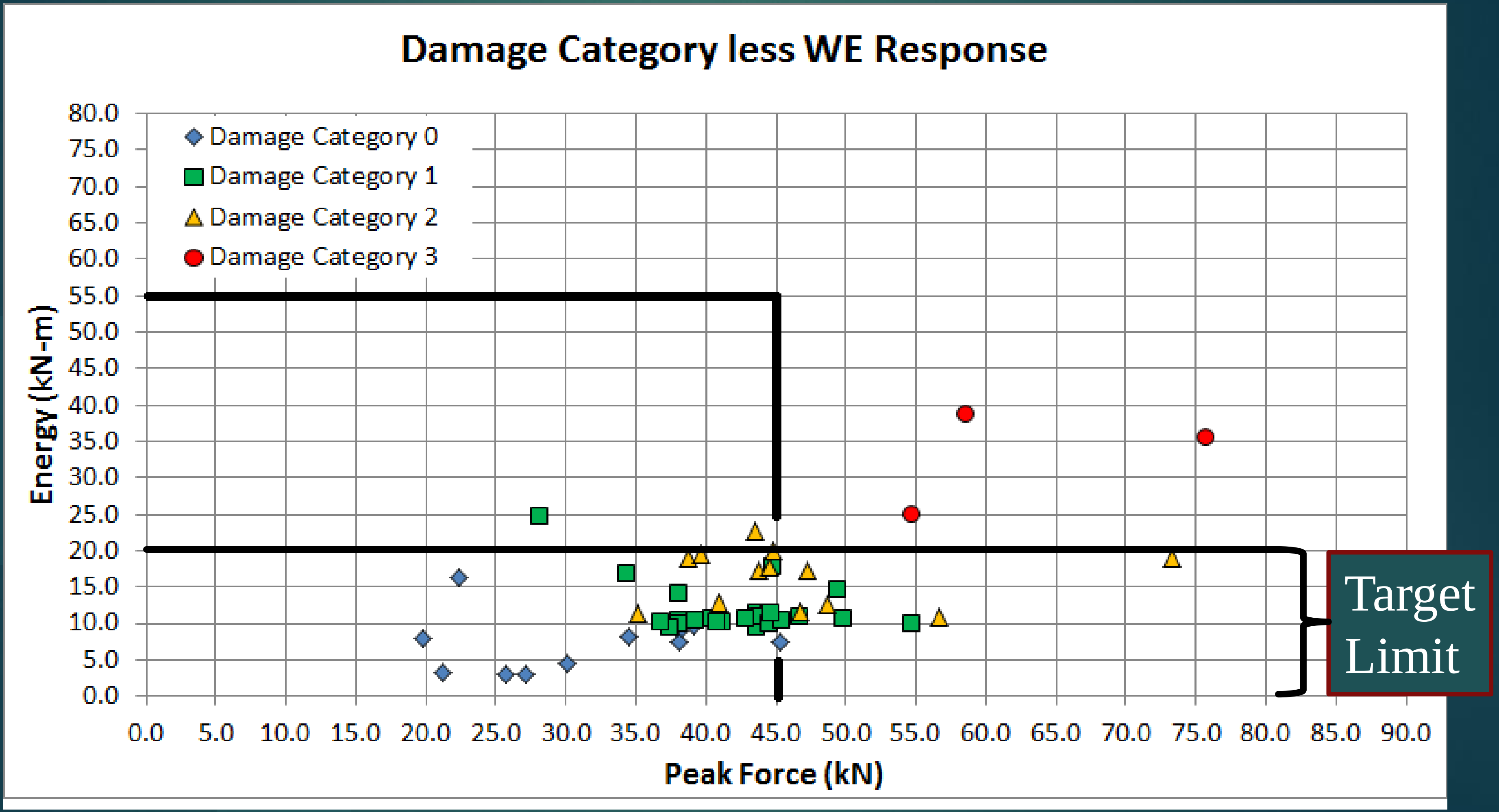
5.2.19 a)

Towers that "wrap-around" the aircraft's wing do not necessarily present a hazard if there is segmentation, or its bottom portion releases from the foundation and is carried by the aircraft.

Segmentation – should be defined

“Bottom portion releases” – current research indicates otherwise

Parameter Studies: Damage



Parameter Studies: Summary

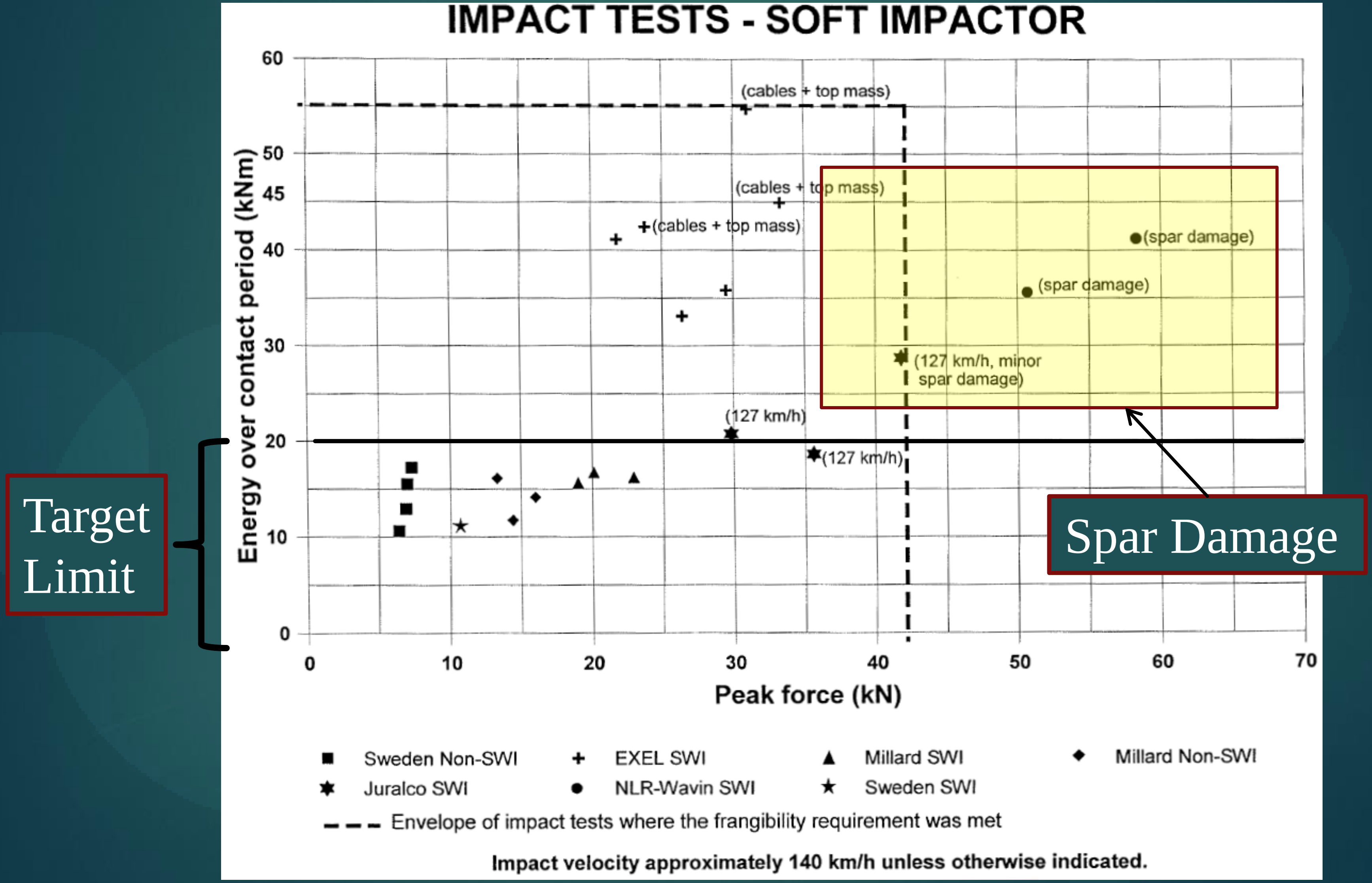
- Reduce energy limit to 20 kN-m (impulse = 514 N-s at 140 kph).
- 3.0 kN-m kinetic energy change for windowing segment
  - Up to 4.0 kg mass
  - Up to 1.6 m length

Device Type	Mass = 4 kg Segment Length (m)
Aluminum Lattice	1.61
Aluminum Pipe	1.08
Composite Lattice	1.25
Composite Pipe	1.37

“Scale” KE for Windowing Segment

Piper PA-28 Warrior
Bird impact on
KE ~ 2.0 kN-m

ICAO Development



Energy (Impulse) and Windowing

Potential Criteria Recommendation

- Reduce energy limit to 20 kN-m (impulse = 514 N-s at 140 kph).
- 3.0 kN-m kinetic energy change for windowing segment
  - Reject all devices that have a propensity to wrap and remain engaged except with limited segmentation
  - Limit segmentation to 4.0 kg max mass and 1.6 m max length

Impact Test Pass / Fail Summary

Potential Criteria Recommendation

- Pass / Fail Criteria
  - Abandon ICAO force limit.
  - Reduce energy limit to 20 kN-m (impulse = 514 N-s at 140 kph).
  - Reject all devices that have a propensity to wrap and remain engaged (limit segmentation to 4.0 kg and 1.6 m max length).
  - Reject all devices causing wing damage having Damaging Severity Category = 3.

Ben Griffiths

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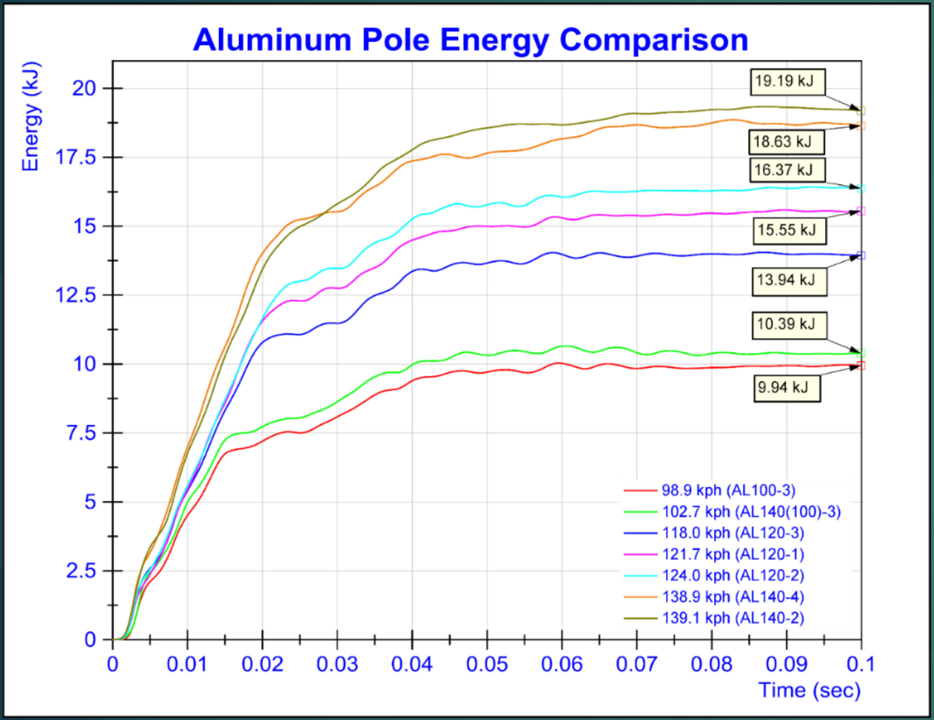
Energy (Work)

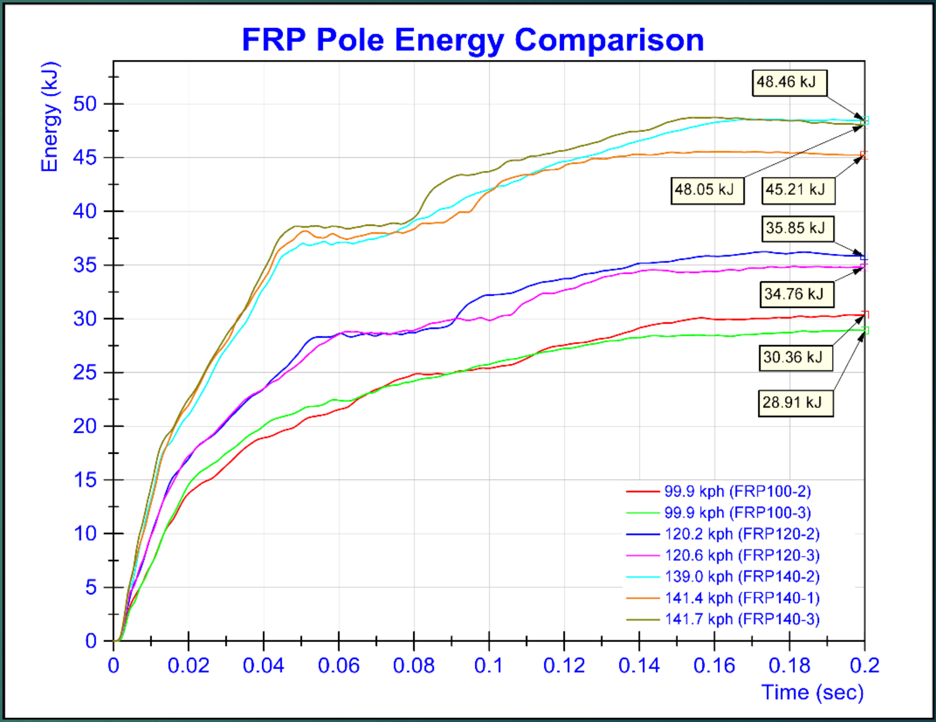
- ICAO
  - “5.2.13 Energy over the contact period is calculated by integration of the impact force with respect to distance.”
  - “5.2.16 Impact speed should remain constant during impact and should be accurately and directly recorded from the moving vehicle at the time of impact.”

Energy (Work)

- Calculation methods (implied by ICAO)
  - $\text{Speed at Impact} \times \int (F_x)dt$
    - Conservative to assume constant speed
  - Force × displacement
    - Second integral of accelerometer at trolley CG scaled to speed at impact to get displacements

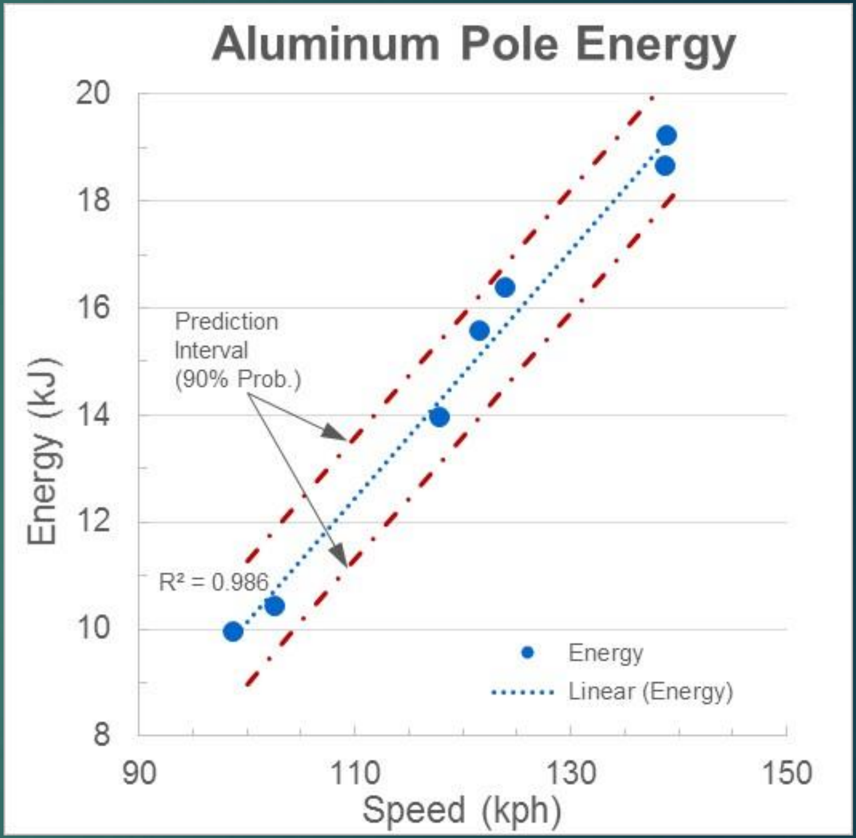
Data Overview





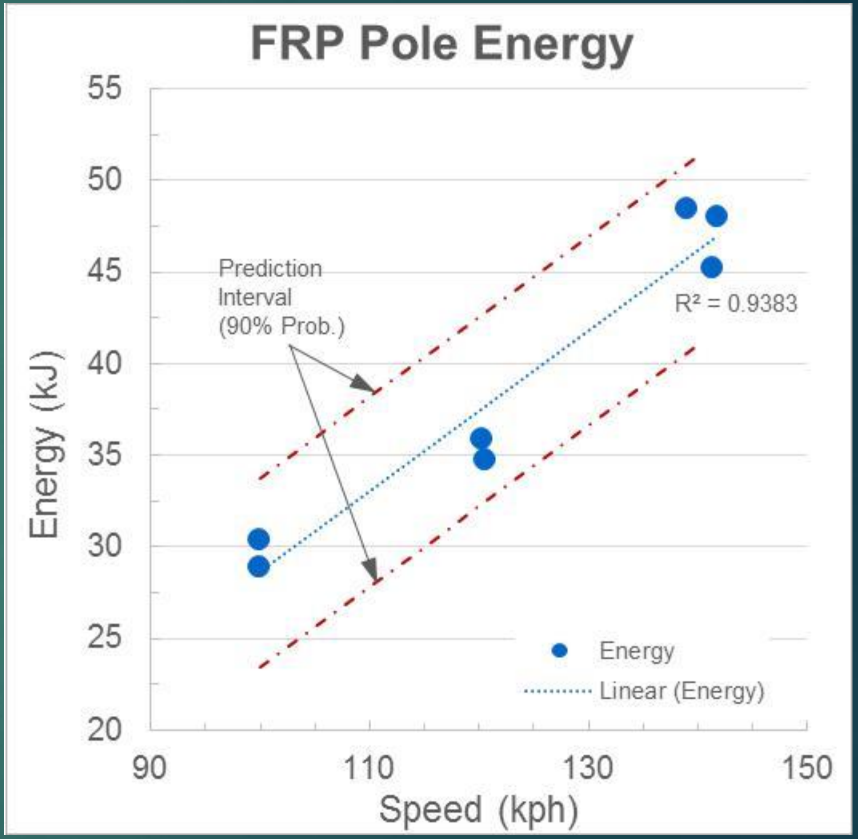
Energy (Work)

- Aluminum poles
  - Relatively small variation
  - Clear correlation to speed
    - Partially due to speed being used in the Energy (work) calculation
  - Prediction interval @ 140 kph: 19.4 kJ ± 5.9%



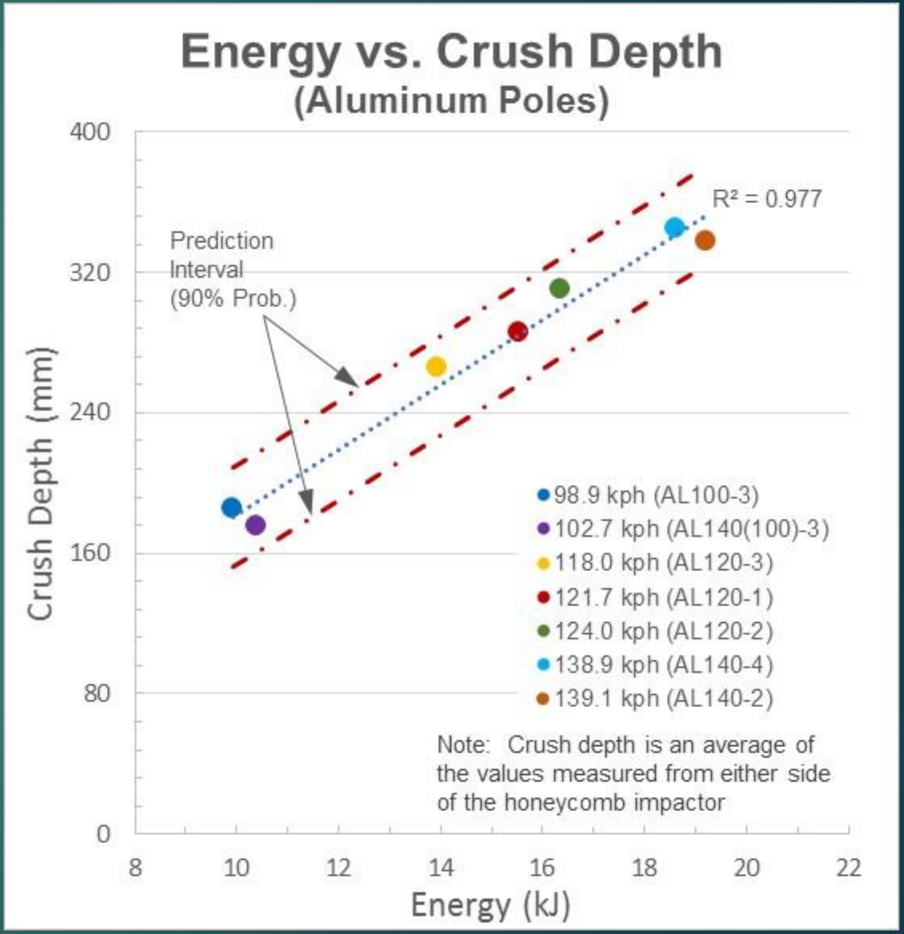
Energy (Work)

- FRP poles
  - Relatively small variation
  - Clear correlation to speed
    - Partially due to speed being used in the Energy (work) calculation
  - Prediction interval @ 140 kph: 46.1 kJ ± 11.2%



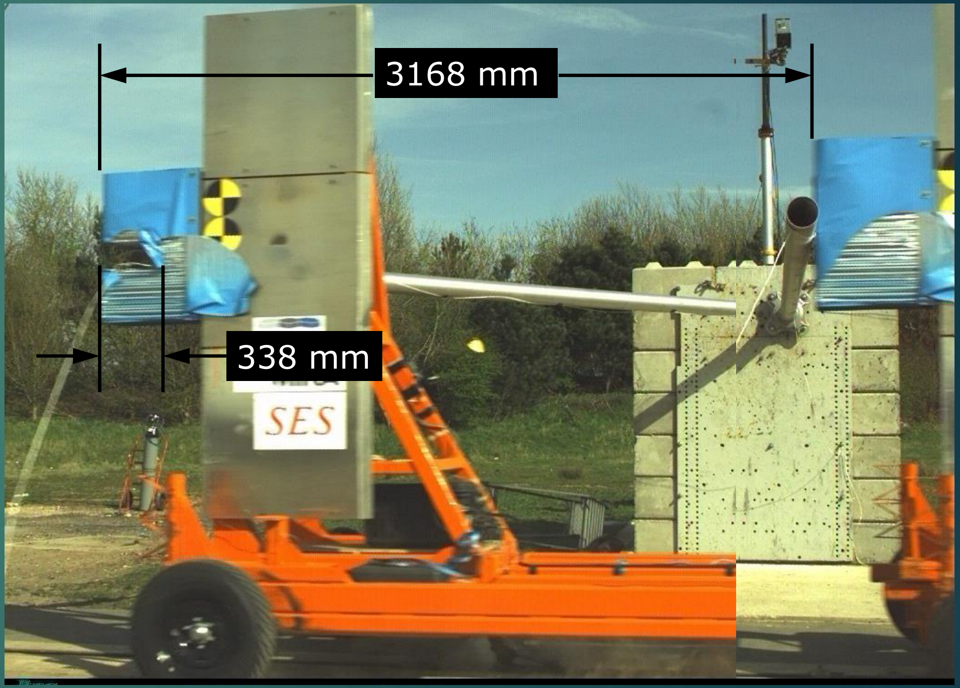
Energy (Work)

- Aluminum poles
  - Relatively small variation
  - Clear correlation to Crush Depth
    - Partially due to speed being used in the Energy (work) calculation
  - Prediction interval @ 19.4 kJ: 355 mm ± 7.6%



Energy (Work)

- Calculation issues
  - Relative displacement
    - Crush depth = 10.7% of overall impactor displacement for Aluminum pole
    - Different products crush to different depths causing different effects on the Energy (work) calculation
  - Only applies to X-direction
  - Possible alternative



Shane Shurtliff, P.E.

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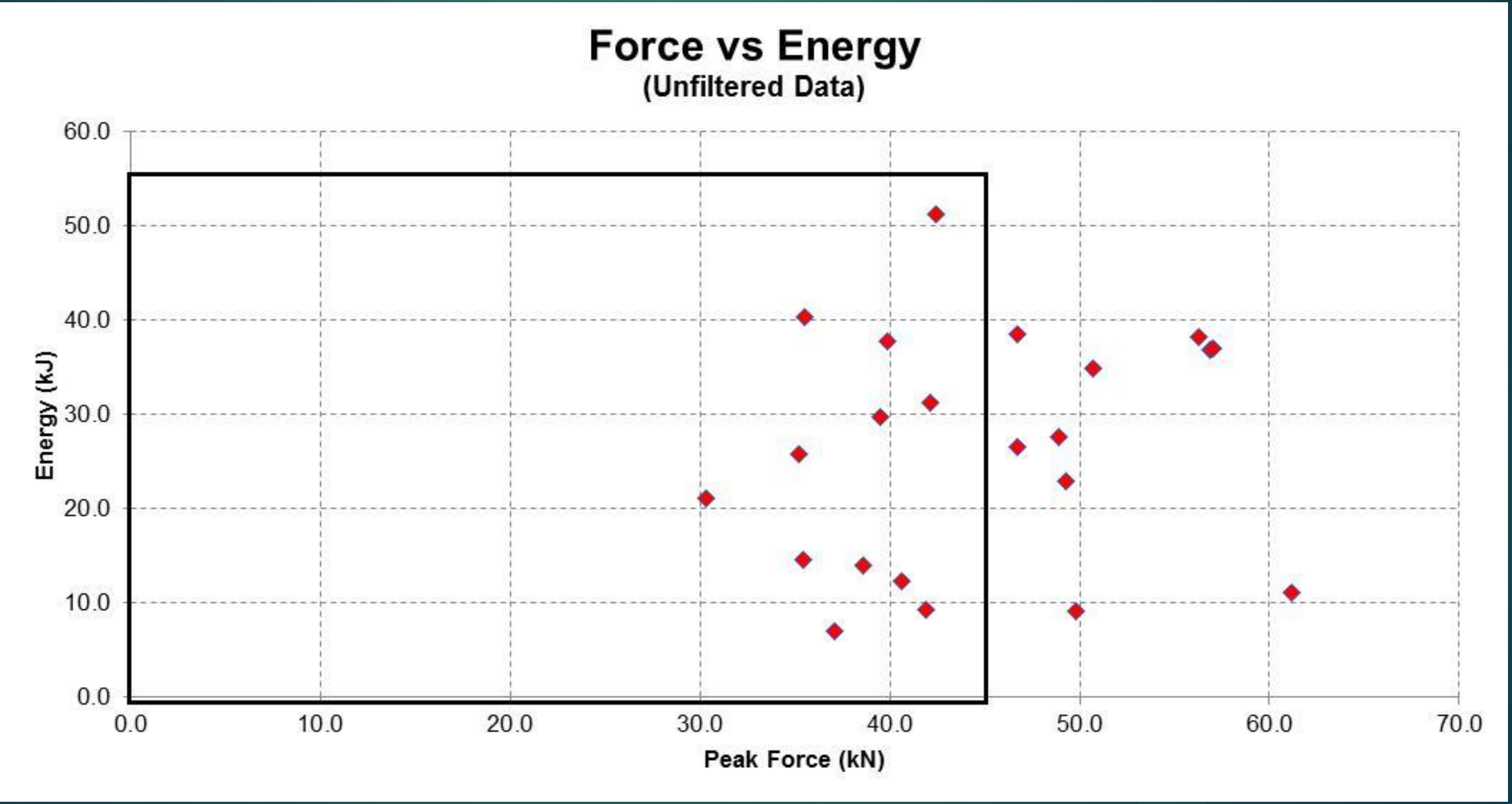
FAA Frangibility Study

- Approval Criteria
  - Energy
    - Energy will be calculated by integrating the force curve with respect to time which gives impulse.
    - Assume a constant velocity through the impact and therefore multiply the impulse by the velocity at impact.

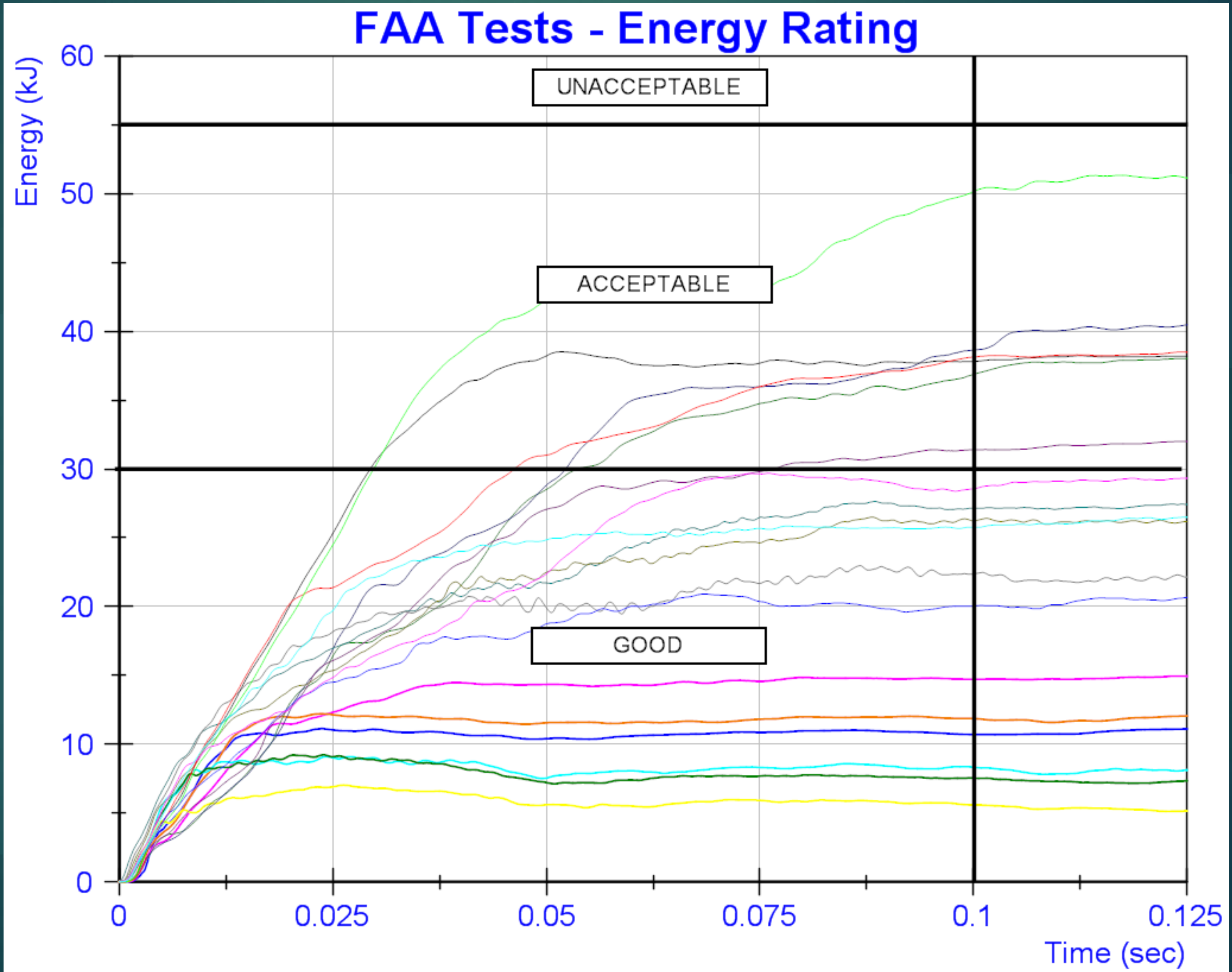
FAA Frangibility Study

- Test Results
  - Shown in traditional pass/fail format



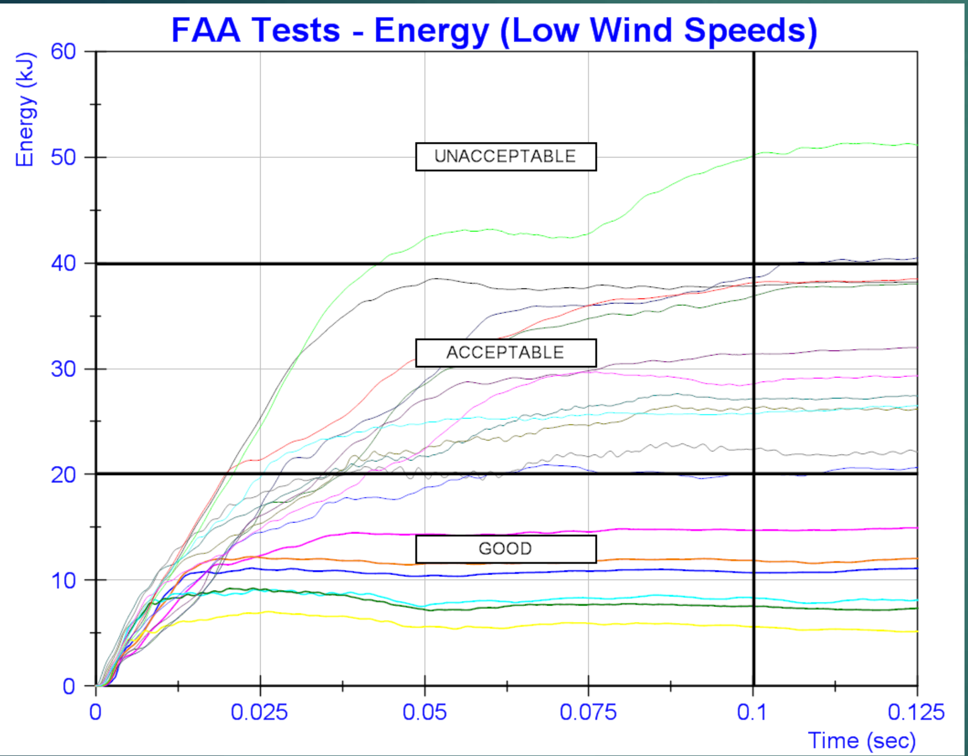
FAA Frangibility Study

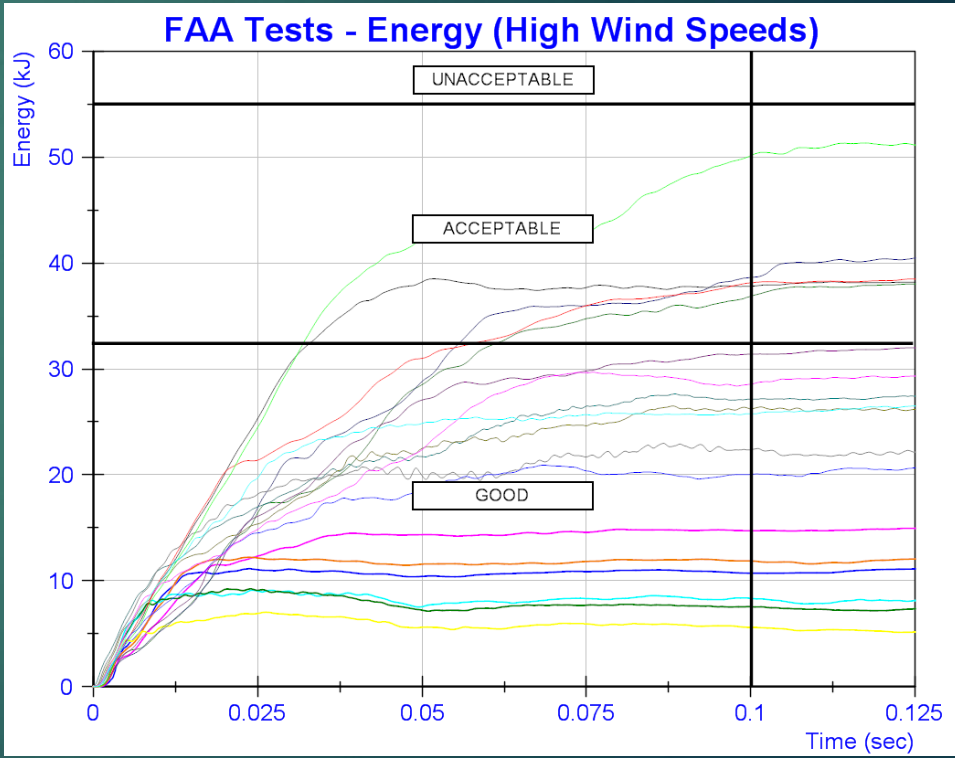
- Approval Criteria
  - New Rating Criteria



FAA Frangibility Study

- Approval Criteria
  - New Rating Criteria based on Wind Speed requirement





Summary

- Current energy limits potentially allow excessive wing damage
- Some currently accepted failure modes produce excessive wing damage
- Current energy calculation has uncertainties and limitations
- Energy limits can be implemented as a rating system

Recommendations

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