Arcing on Space Solar Arrays

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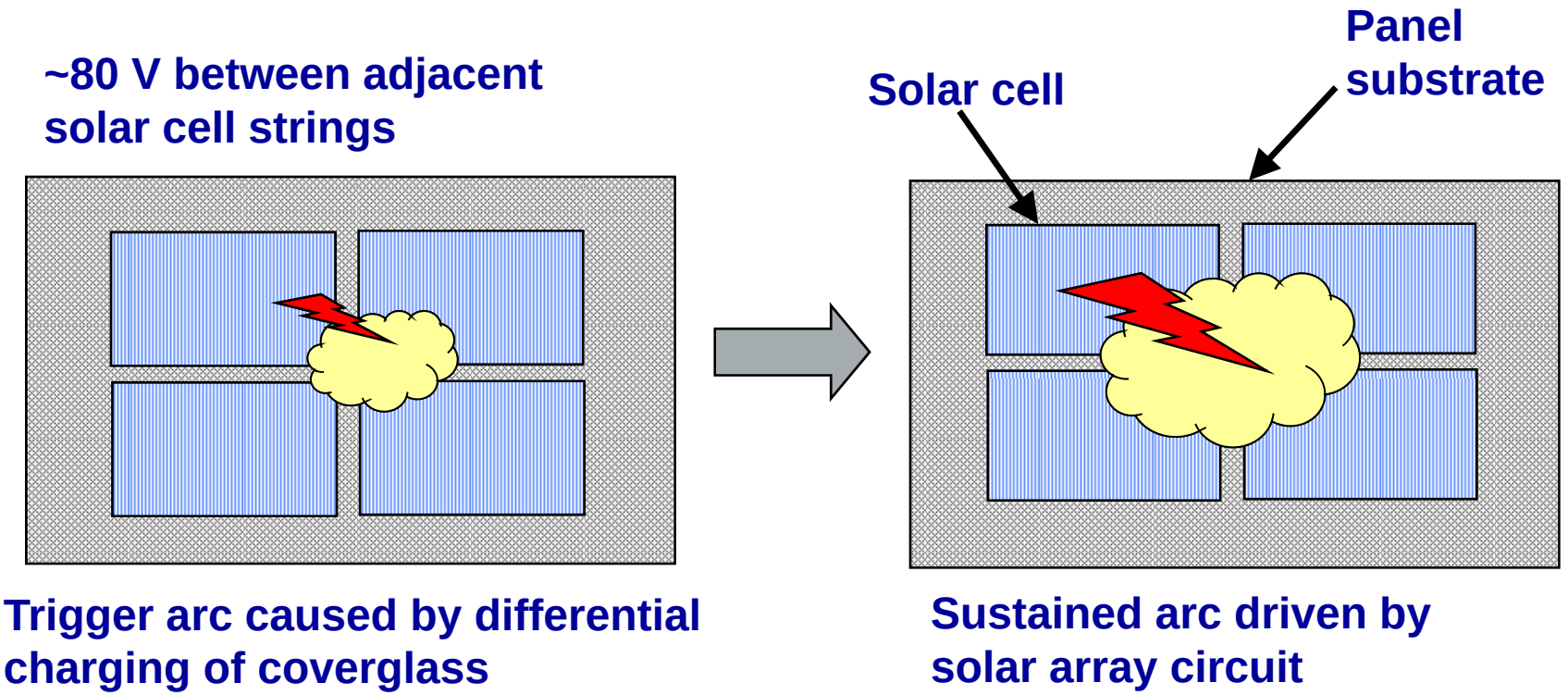
Introduction

- **Arcing on space solar arrays**
  - **Key consideration in design and test of space solar arrays**
  - **Shown to produce power anomalies in orbit**
  - **Can result from multiple causes**
  - **Exposure of solar arrays directly to space environment increases susceptibility**
- **Current trends make arrays more susceptible**
  - **Higher voltages desirable for higher power systems**
  - **Reported anomalies in literature increase at higher operating voltages**
  - **Trend towards systems >200 V increases risk**
- **Experiments undertaken to investigate potential causes and effects of arcing on arrays**
  - **Experiment #1: Arcing between wires**
  - **Experiment #2: Arcing between wire and panel substrate**
  - **Experiment #3: Arcing between wire and metallic bracket**
  - **Note: Experiments were not performed on spacecraft hardware and do not represent performance of actual spacecraft**

Key Previous Results (page 1 of 2)

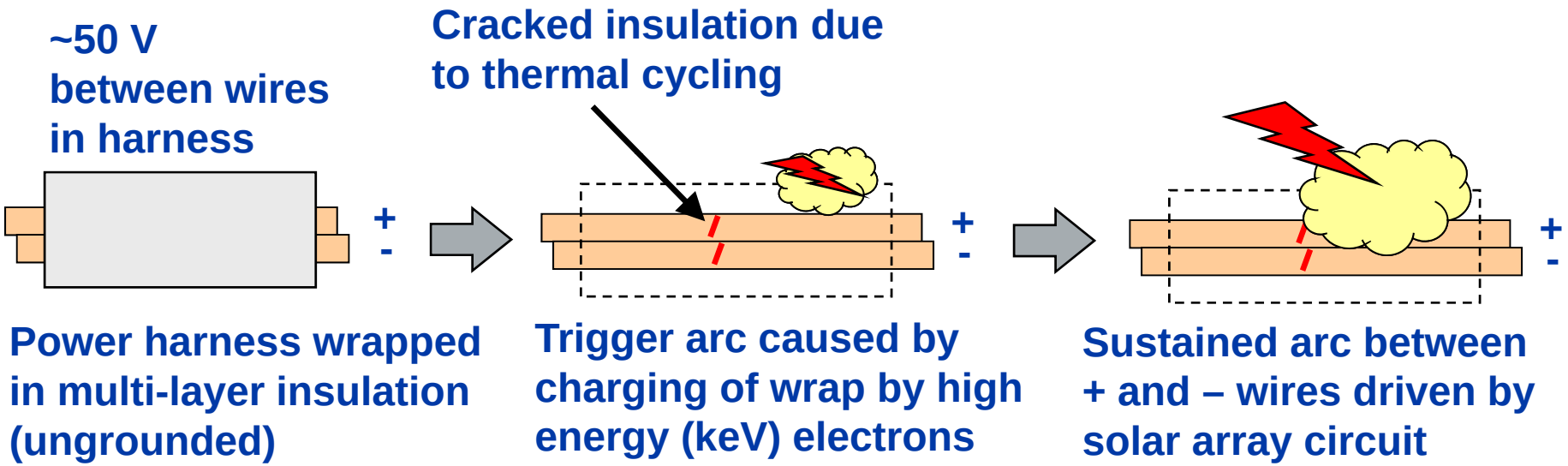
- **Hoeber et al, "Solar Array Augmented Electrostatic Discharge in GEO", AIAA 98-1401 (1998)**



- **Arcing resulted in pyrolized insulation and permanent shorting of solar array circuits on satellites in orbit**

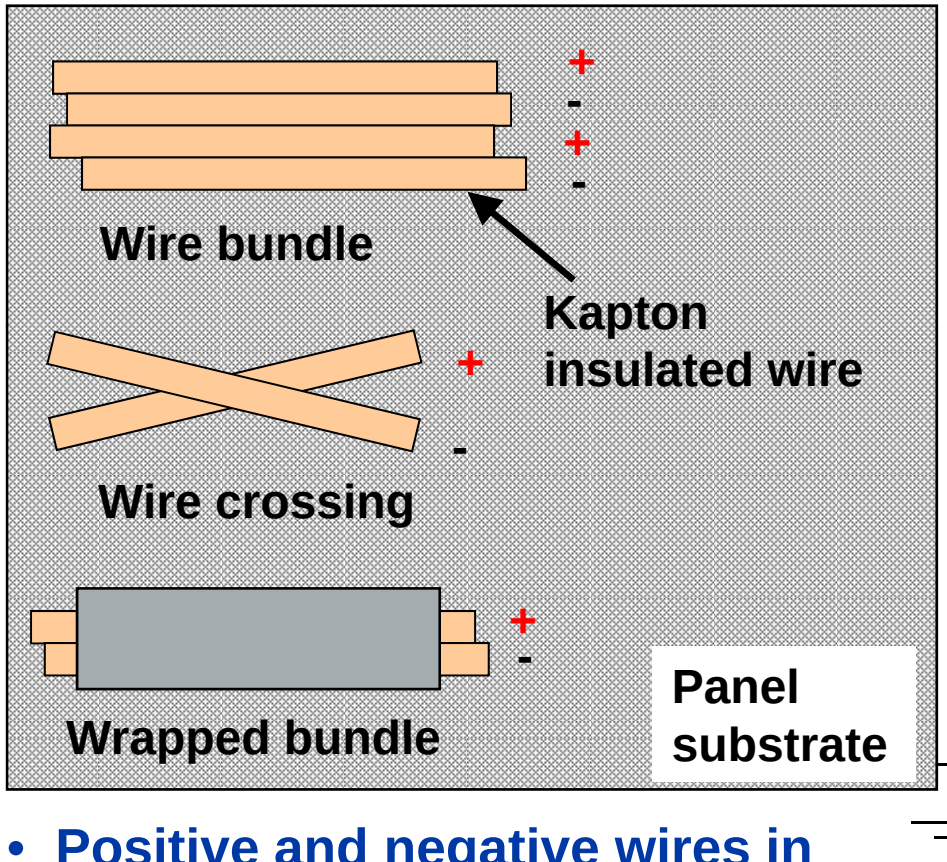
Key Previous Results (page 2 of 2)

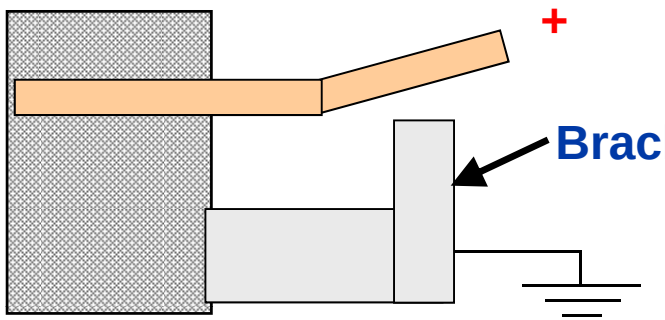
- Kawakita et al, "Investigation of an Operational Anomaly of the ADEOS II Satellite", AIAA 2004-5658 (2004)



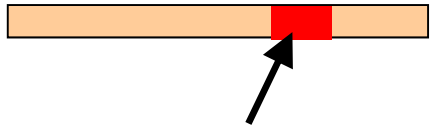
- Satellite passed through auroral region when high energy (keV) flux was 2 orders of magnitude higher than normal resulting in significant charging of multi-layer insulation
- Arcing resulted in pyrolized wires, destruction of wire harness and significant loss of power

Features of Interest on Planar Space Solar Arrays





Positive wire close to a metallic bracket or structure



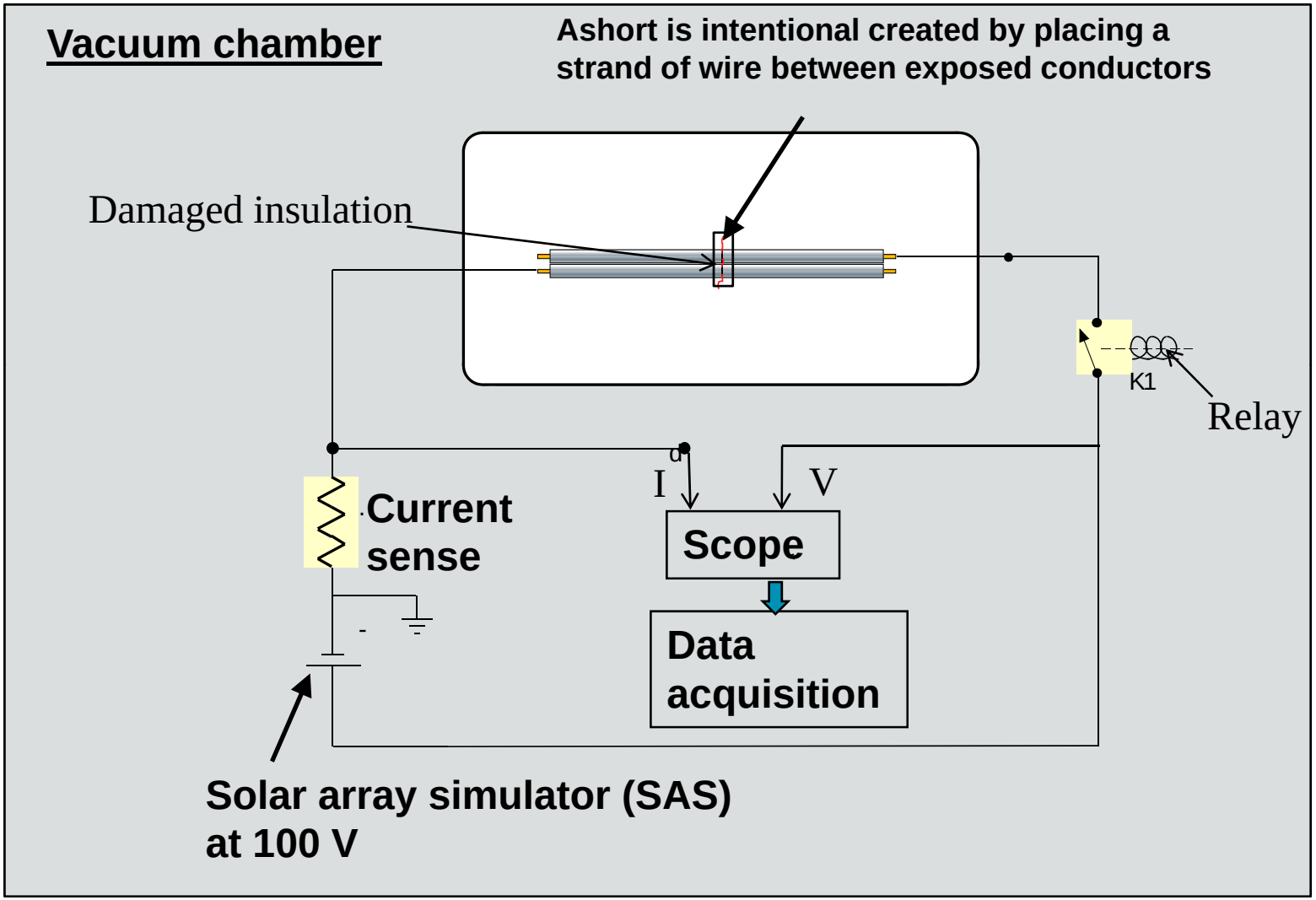
Insulation damaged during manufacturing or due to space environmental effects

- Positive and negative wires in close proximity
- Potential difference between wires and panel substrate

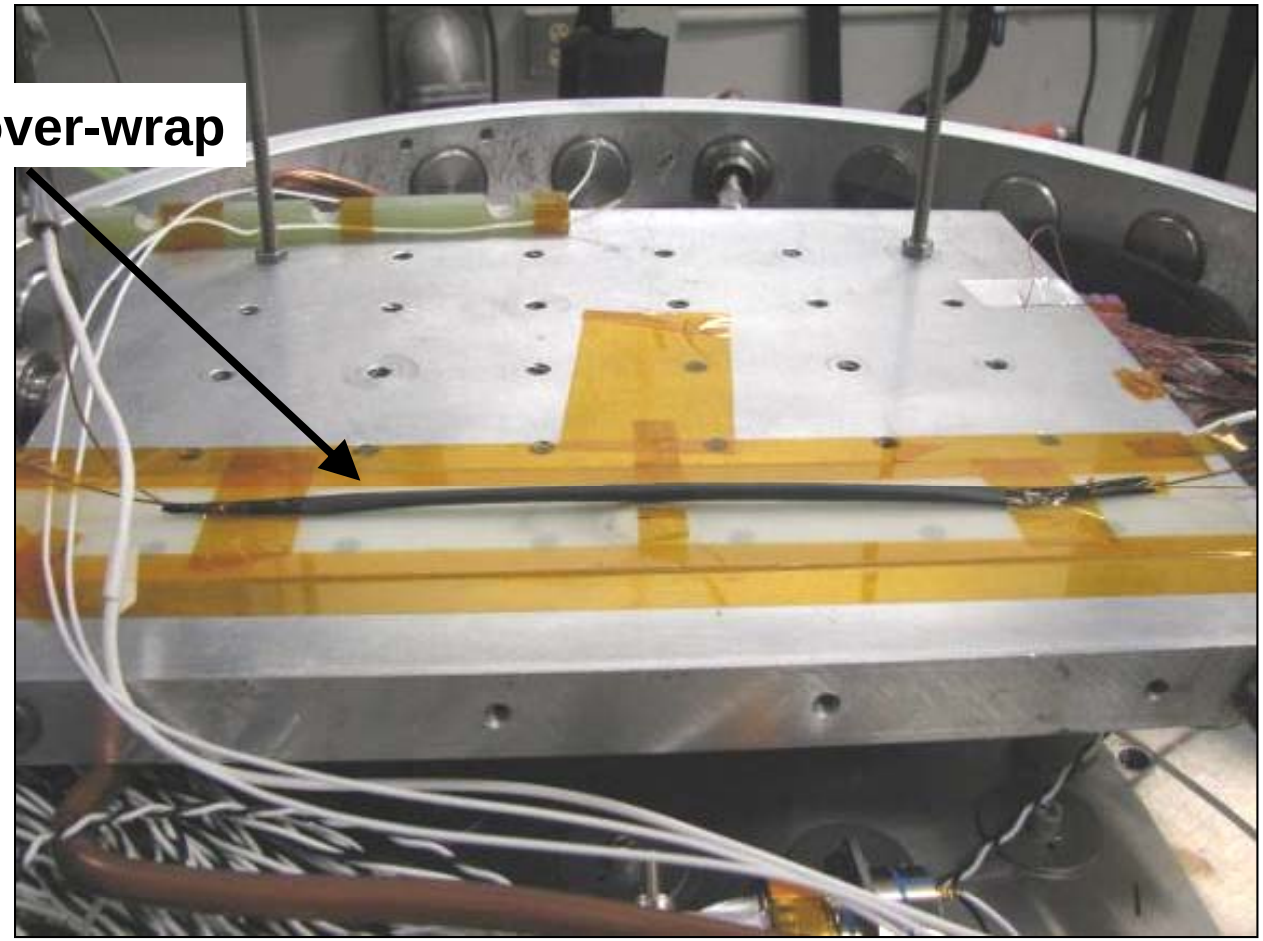
Experiment #1: Arcing Between Wires

- **Purpose**
  - Determine conditions under which exposed conductors on adjacent wires will result in arcing.
  - Determine whether arcing can propagate along the length of adjacent wires (i.e. “arc tracking”).
  - Assess the damage due to arcing (if applicable).
- **Experimental methods**
  - Route two wires adjacent to each other on a plate in vacuum
  - Provide potential difference of 100 V using power supply or solar array simulator (SAS)
  - Provide initial short by one of several methods:
    - Broken insulation
    - Broken insulation + strand of wire bridging gap between conductors
    - Wrapped pair of wires with broken insulation + strand of wire
    - Broken insulation + pyrolized insulation in location of defect

Experiment #1 Set-Up

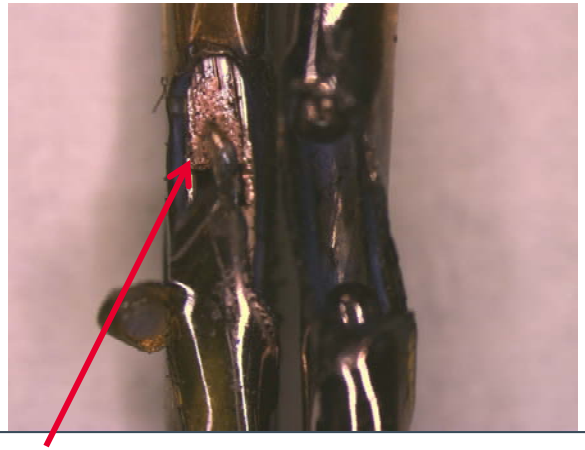


Experiment #1: Set-Up using Wrapped Wires

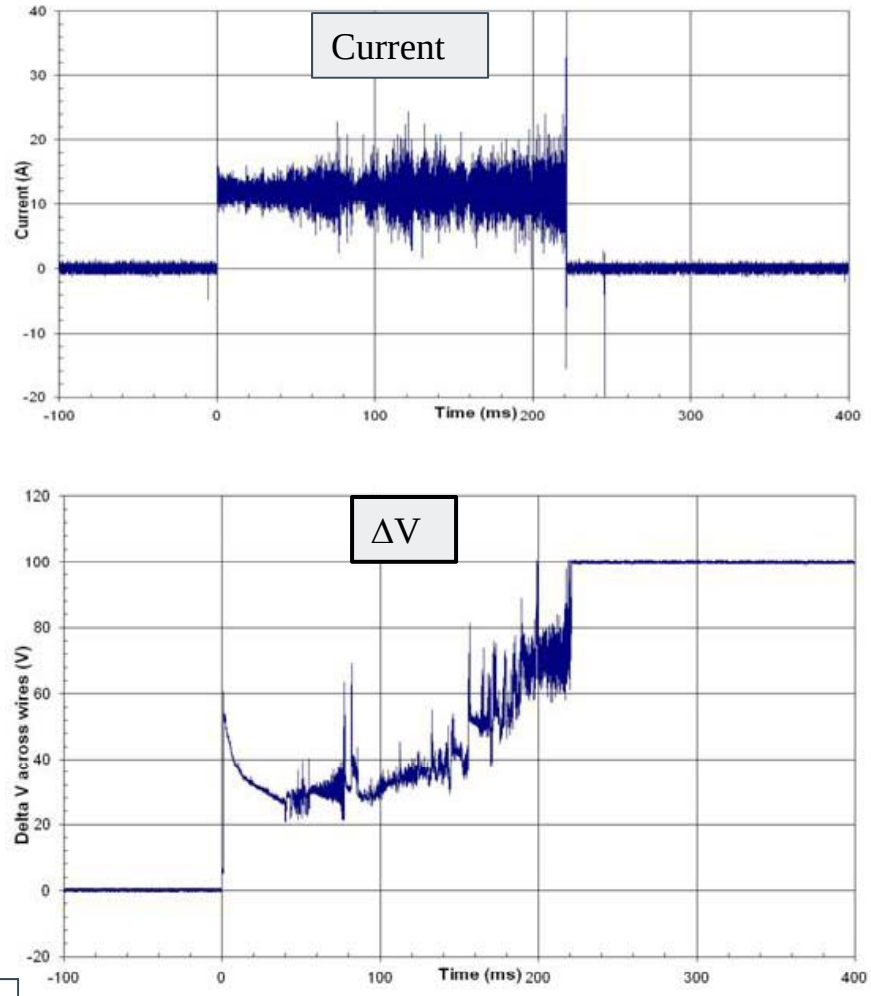


Experiment #1: Results

- **First arcing event observed in experiment #1**
  - **Arcing initiated with intentionally damaged insulation and strand of wire bridging gap between conductors**
  - **Significant damage, mass ejection and arc tracking along wires observed**



Insulation was damaged and copper material was ejected during the arcing event



Current and Voltage waveforms

Experiment #1: Arcing with Wrapped Wires

Time: 0.000

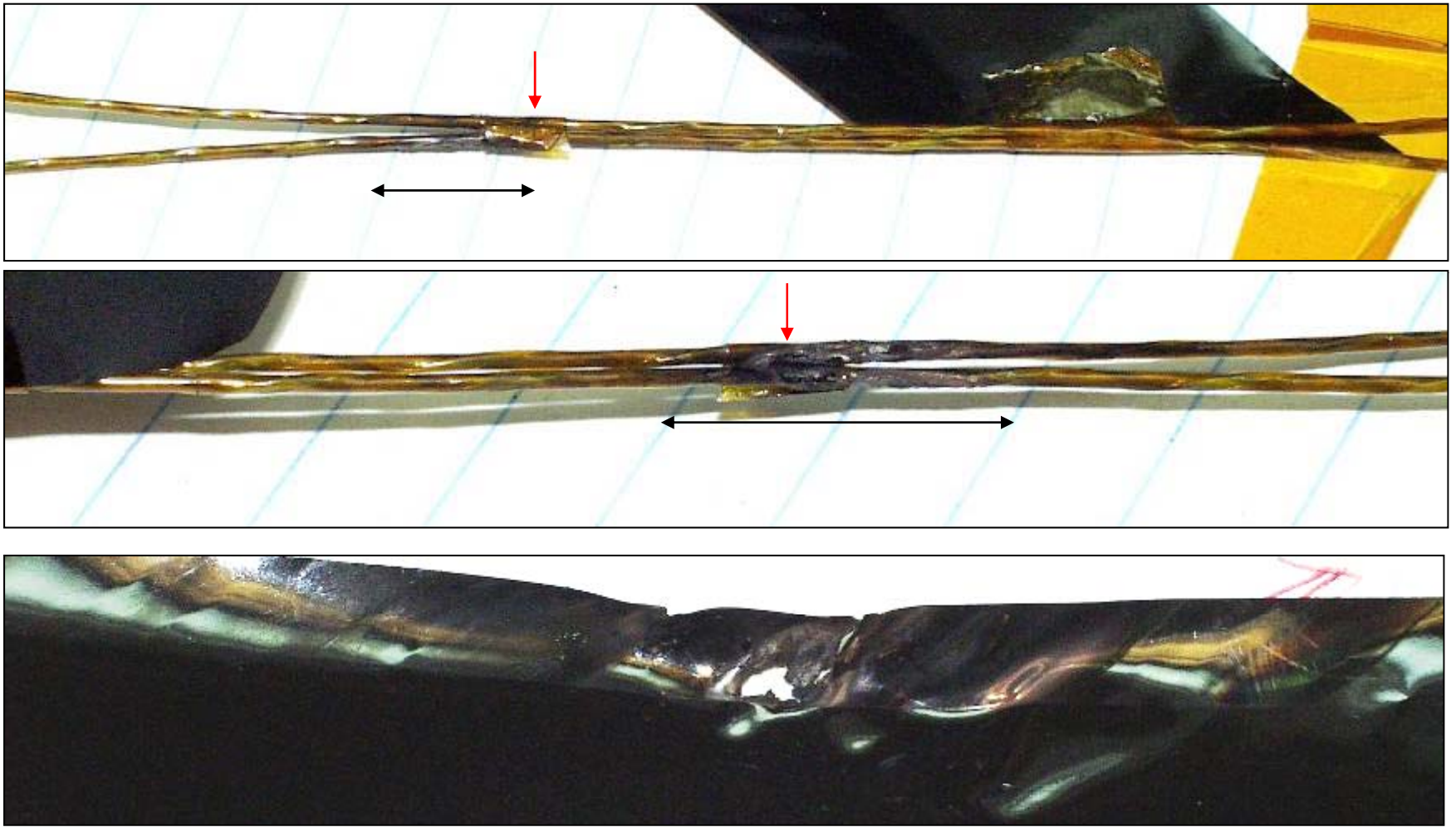
Time: 0.0167

Time: 0.0333

Time: 0.0500

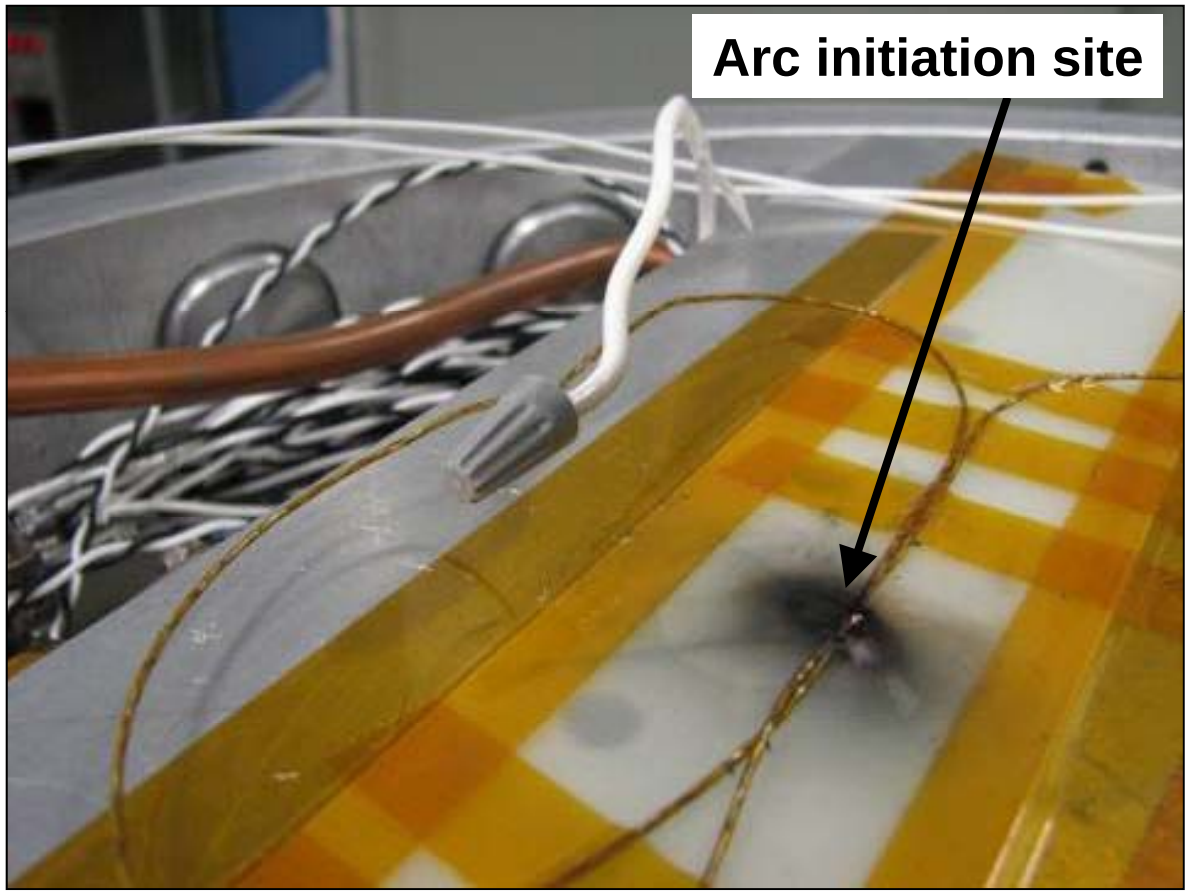
Arcing resulted in highly directional mass ejection.

Experiment #1: Damage to Wrapped Wires due to Arcing



Insulation was pyrolized during the arcing event.

Experiment #1: Set-Up using Twisted Wires and Pyrolized Insulation Defect



The longest and most powerful arcing events were observed when a portion of the insulation was already pyrolized.

Experiment #1: Results using Twisted Wires and Pyrolized Insulation Defect (page 1 of 6)

Time: 0.000

Time: 0.0167

Time: 0.0333

Time: 0.0500

Experiment #1: Results using Twisted Wires and Pyrolized Insulation Defect (page 2 of 6)

Time: 0.0667

Time: 0.0833

Time: 0.100

Time: 0.1167

Experiment #1: Results using Twisted Wires and Pyrolized Insulation Defect (page 3 of 6)

Time: 0.1333

Time: 0.1500

Time: 0.1667

Time: 0.1833

Experiment #1: Results using Twisted Wires and Pyrolized Insulation Defect (page 4 of 6)

Time: 0.2000

Time: 0.2167

Time: 0.2333

Time: 0.2500

Experiment #1: Results using Twisted Wires and Pyrolized Insulation Defect (page 5 of 6)

Time: 0.2667

Time: 0.2833

Time: 0.3000

Time: 0.3167

Experiment #1: Results using Twisted Wires and Pyrolized Insulation Defect (page 6 of 6)

Time: 0.3333

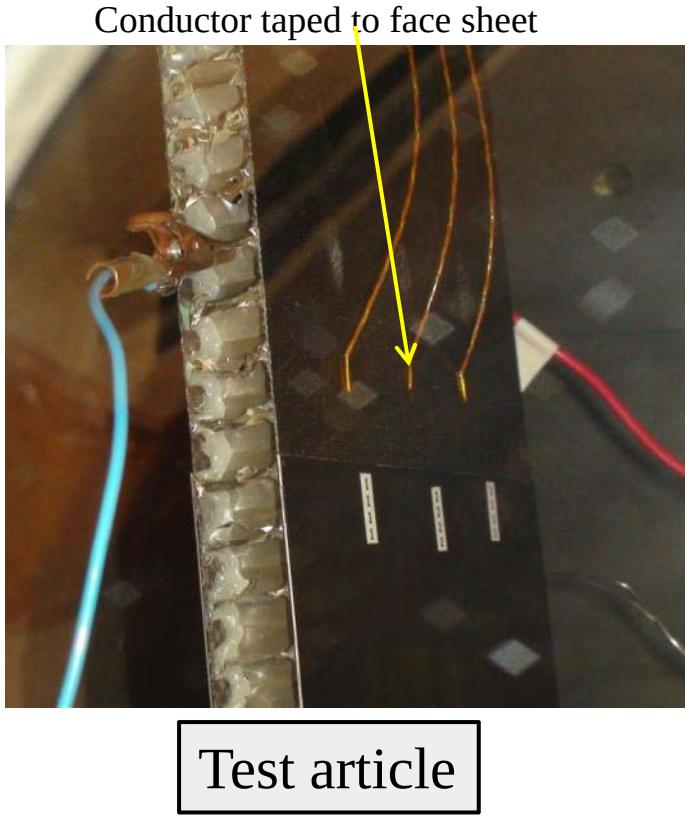
Time: 0.3500

Time: 0.3667

Time: 0.3833

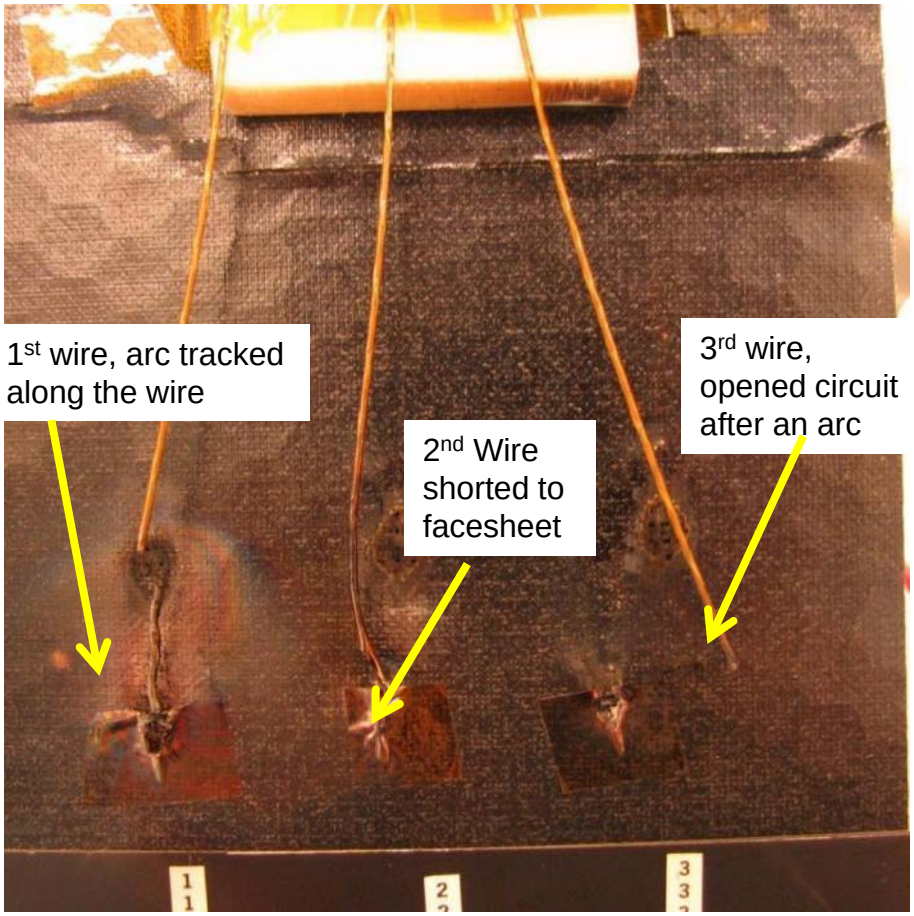
Experiment #2: Arcing Between Wires and Panel

- **Purpose**
  - **Determine whether exposed conductors will arc to solar panel face-sheet**
    - Face sheet of the panel is made of conductive composite materials
  - **Assess damage due to arcing (if applicable)**
- **Experiment approach**
  - **Exposed wire conductor**
  - **Tape the conductor to a conductive face sheet**
  - **Apply a 100 V bias using an SAS**
  - **Monitor the current**
    - Transient and steady current (if applicable)



Experiment #2 Results

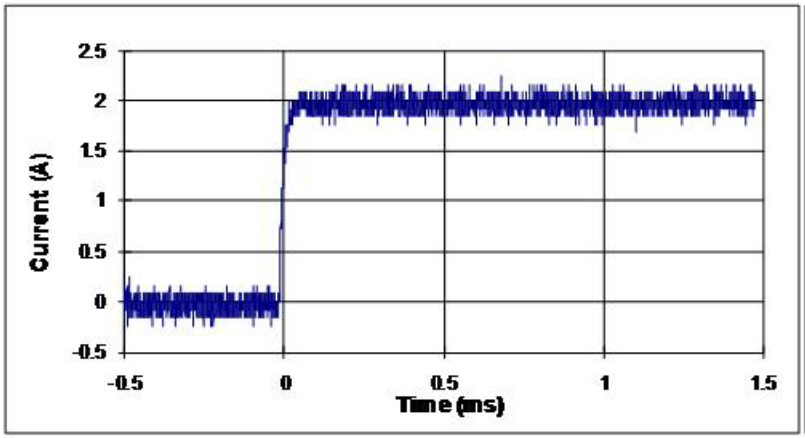
- 1st wire – arc track along the wire
  - Open circuit at end of test
- 2nd wire – wire conductor shorted to face sheet
  - Visible glow at point of contact
  - Continuously material release as witness by the increase in the chamber pressure from 10^{-6} torr to 10^{-4} torr
  - Short to face sheet at end of test
- 3rd wire – short duration arc
  - Conductor detached from face sheet
  - Open circuit at end of test

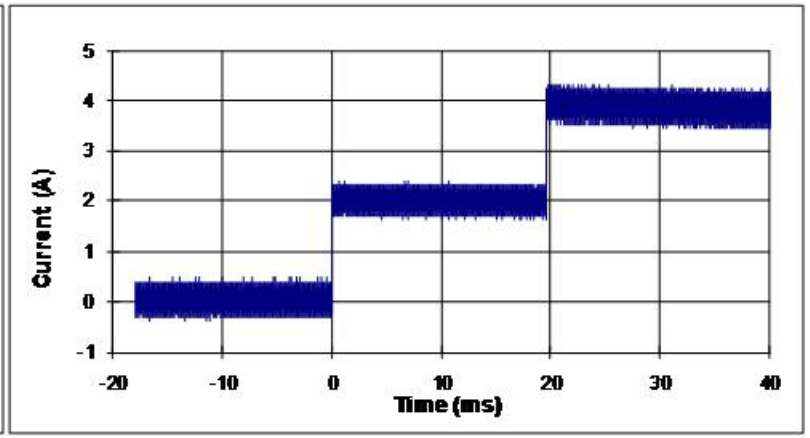


Short between wire and panel could result in different arcing scenarios

Experiment #2 Results

Waveforms of arc current for wire#2





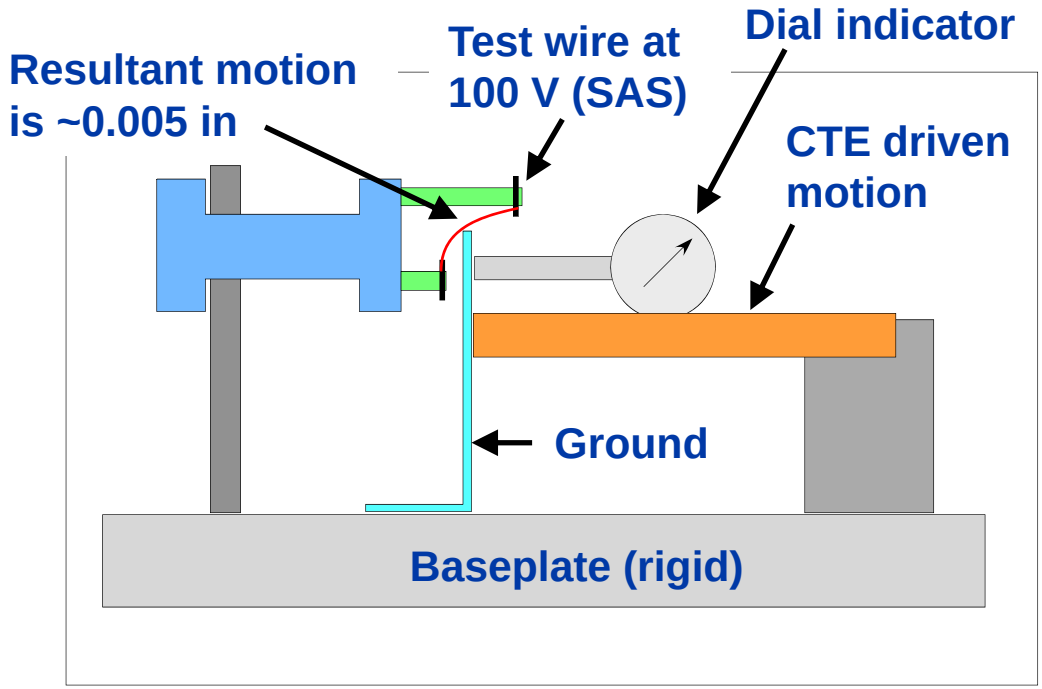
Initial current was ~ 2A

Current jumped to ~4 A after ~20 ms

Interaction of arc current with face sheet material could cause a change in arc impedance

Experiment #3: Arcing Between Wires and Brackets

- **Purpose**
  - Determine whether exposed conductors will arc to metallic bracket.
  - Include motion of wire against and away from bracket, due to thermal expansion and contraction.
  - Assess damage due to arcing (if applicable).
- **Experimental method**



Experiment #3 Results

- **Typical result**
  - Arcing occurred when motion breaks contact between conductor and bracket.
  - Wire was vaporized
  - Resulted in open-circuit condition

- **Singular result (observed once)**
  - Conductor welded to bracket
  - Resulted in short between wire and bracket
  - Weld broke after subsequent handling

Experiment #3 Results
Inspection after shorting event

Metallic transfer of copper on to aluminum plate is noted. Weld was intact at end of test. Broke during disassembly.

Observations

- **Arcing was observed when an initial defect led to contact between**
  - **Conductors in adjacent wires**
  - **Positive conductor and panel**
  - **Positive conductor and bracket**
- **Arcing resulted in**
  - **Damage to insulation and conductors**
  - **Ejection of material**
  - **Arc tracking between adjacent wires and between wire and panel**
  - **Open circuit condition in most experiments**
  - **Shorted condition between wire and panel and short between wire and bracket were observed**

Conclusions

- Arcing on space solar panels can significantly damage wire harnesses.
- Arcing can result in open circuits and possibly short circuits, depending on details of the electrical circuit design.
- Defects in the wire insulation and contact between conductors were necessary in these experiments to produce arcing phenomena.
- Solar array design and manufacturing processes that that prevent both damage to insulation and ensuing contact between conductors are needed to provide the greatest reliability in orbit.