Integrated Vehicle Health Management Lightning & HIRF Research Activities

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December 9, 2008

Outline

- **Project Milestone Overview**
- **Lightning Hazards**
- **Diagnosis Research Activities**
- **Detection Research Activities**
- **Conclusions**

Project Milestone Overview

- Level 2 Diagnosis Research
  - Milestone 2.1.2.2 Tools & techniques to conduct experiments to establish baseline parameters & assess user requirements for lightning direct & indirect effects.
    - Lightning direct effects- Primary effects from lighting strike
      - Structural damage caused by heating and shock wave
    - Lightning indirect effects- Secondary effects from induced currents
      - Avionic upset due to magnetic field coupling into wiring
  - Metrics
    - (iii) Characterize at least 3 conditions under which a composite structure sustains each of the following types of damage: immediate, short-term, and long-term damage.
    - (iv) Quantify the mean-time to failure of a composite structure as a function of surface current for immediate, short-term, and long-term damage within 10% of the true value.
  - Planned Research Activities
    - Understand lightning interactions with composite materials to support safer aircraft designs & guide future research

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Project Milestone Overview

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- Level 1 Diagnosis Research
  - Milestone 1.1.2.1 Characterize the effects of lightning and high intensity radiated fields to avionics systems on composite-based aircraft for 100% of the HIRF test requirements documented in DO160 Section 20.6 & 22.
    - DO160 Section 20.6
      - Radiated susceptibility test alternate procedure (reverberation chamber)
    - DO160 Section 22
      - Lightning induced transient susceptibility
  - Metric Rationale
    - Up-to-date laboratory capability is needed for credible verification and validation of diagnostic and prognostic algorithms used in new fault-tolerant avionics architectures and for measurement of lightning/HIRF effects.
  - Planned Research Activities
    - Enhance HIRF Lab capabilities for IVHM research

Project Milestone Overview

- Level 1 Detection Research
  - Milestone 1.1.1.9 Demonstrate lightning current detection sensor capable of sensing lightning strikes which could potentially present hazards to avionics on composite-based aircraft.
    - On-board sensor measurements to support IVHM diagnosis and prognosis reasoning
      - Measure lightning parameters to assess potential damage & predict useful life
      - Determine path and intensity of induced currents
    - Collect Positive lightning strike data to support refined lightning test standards
      - Lightning damage is often worse than existing standards would predict
  - Planned Research Activities
    - Develop lightning detection sensor using Faraday effect devices
    - Potential flight test opportunity on icing research flights
    - Detection research aligns well with and leverages diagnosis research

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Lightning Hazards

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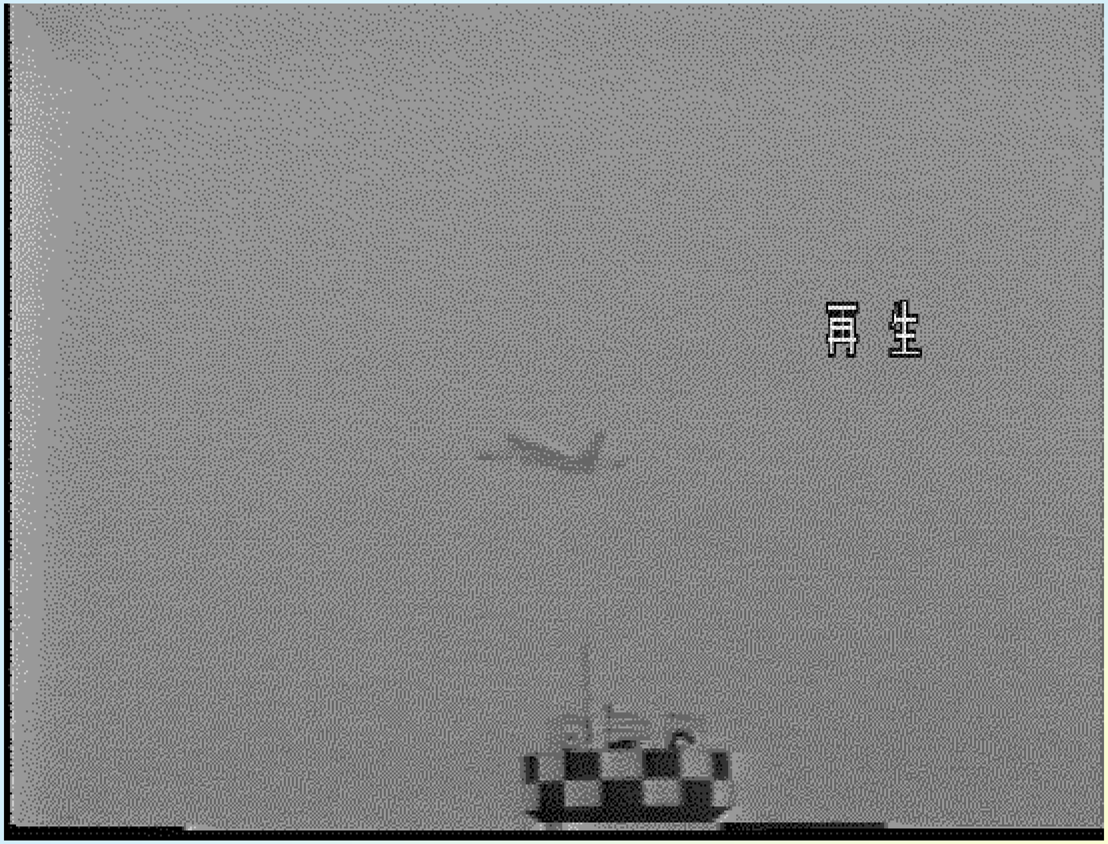

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Lightning Hazards

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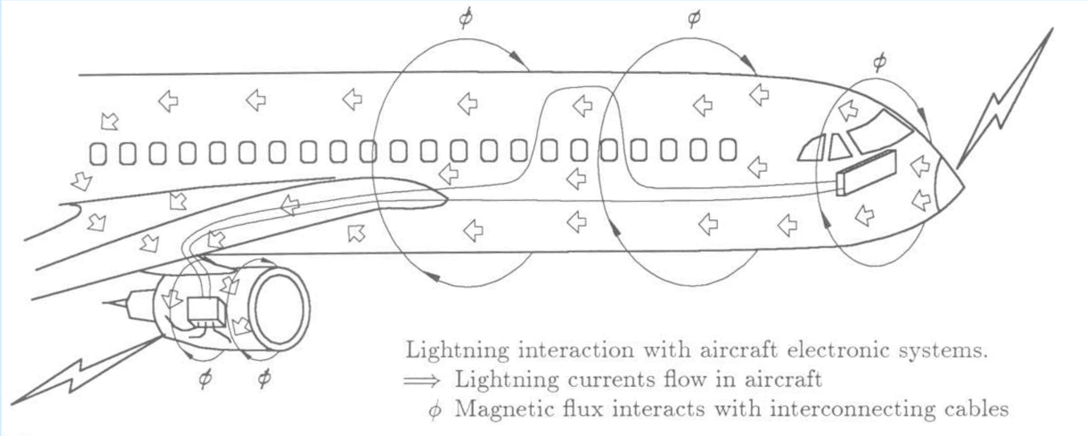

- **Lightning Hazards to Composite Aircraft**
  - Magnetic flux penetrates deeper into avionics wiring (Less shielding)
  - Structural IR voltages increase by thousands of volts (Higher skin resistance)
  - Unshielded panels are physically damaged (All composites must have shielding)
  - Increasing complexity of avionics may lead to unforeseen failures (lower voltage, smaller size, tighter packaging)
  - Lightning damage inflicted on aircraft is often more severe than test standards would predict. (Positive lightning strike energy is not fully quantified)

Diagnosis Research

- Characterize immediate, short-term and long-term damage on composite structures due to lightning.
  - ➢ Requires cross discipline knowledge in electrical, mechanical & material science
- Foster collaborations & leverage research to study lightning hazards on existing and emerging lightning strike protection techniques in composite materials
  - ➢ Common research interests exist between IVHM, AAD & Air Force Research Lab
    - Phase III SBIR to construct composite panels
      - ➢ **IVHM procurement with IPP matching funds**
    - IVHM FTE & HIRF facilities
    - AAD FTE & NDE facilities
    - Matching funding from Air Force FY09 procurement and use of NDE facilities

Composite panel damage due to direct lightning strike.

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Diagnosis Research

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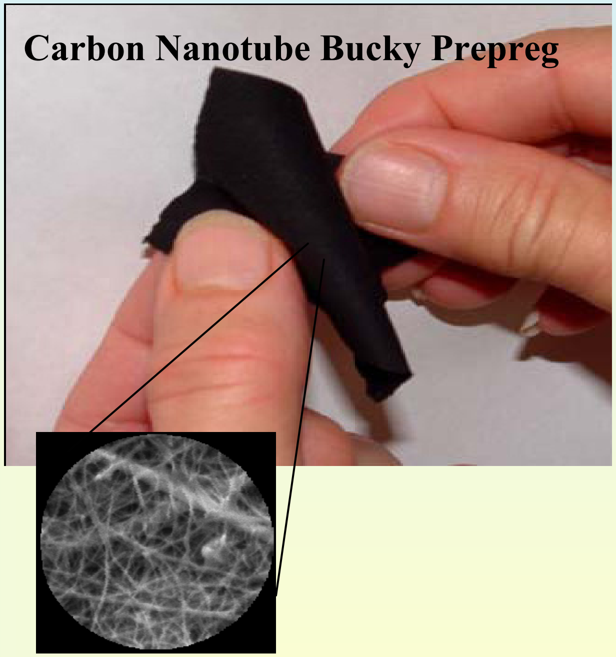
- "Lightning Strike Protection Methods for Composite Structures“ Phase 3 SBIR, FY08
  - 64 total panels will be fabricated and delivered by early March 2009
  - 16 panels each of 4 different lightning strike protection techniques
    - **Copper Mesh (existing technology)**
    - **Carbon Nanotube bucky prepreg (emerging)**
    - **Carbon nano-graphene platelets (emerging)**
    - **Multi-walled carbon nanotubes decorated with silver particles (newly emerging)**
  - 2 different composite weaves & resins
    - **Woven and unidirectional**
  - 2 different paint materials
    - **DOD and commercial grade**
  - 4 duplicate panels of each configuration
    - **same conductor, composite weave and paint**
  - Panels are 14” square, ¼” thick utilizing existing materials and fabrication methods to simulate realistic fabrication of lightning hardened strike areas



- Panels will be characterized for lightning resilience in the NASA HIRF Lab, NDE test facilities. Direct effect testing will be conducted at Lightning Technologies Inc

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Diagnosis Research

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Transfer Function Characterizations

- Induce Indirect effects using simulated lightning waveforms in both time and frequency domains to measure surface currents at various locations on the panel. 16 panels will be characterized pre and post direct effect testing.

Transfer Function Setup

- Test Objectives
  - Correlate Time & Frequency domain techniques
  - Provide well quantified results to modeling community to support lightning computational activities
  - Results will provide insight into electrical current propagation on composite structures and baseline measurements for future lightning detection sensor evaluations.

Shielding Effectiveness Characterizations

- Electrically seal composite panel in aperture between HIRF chambers and measure radiated emissions between chambers. 16 panels will be characterized pre and post direct effect testing.

- Test Objectives
  - Develop 4 port network analyzer measurements for full matrix characterization
  - Gain understanding into post strike shielding susceptibilities
  - Provide well quantified results to modeling community for lightning computations
  - Validate technique to build follow on research studying bonded joints/structures

Eddy Current Characterizations

- Monitor voltage as a function of position from an electromagnetic coil moved along the surface of a composite panel to calculate surface impedance parameters to identify irregularities in the lightning protection conductor or composite structure beneath. 9 panels will be evaluated pre and post direct effect testing. Research lead by Buzz Wincheski in AAD with support from John Mielnik (HIRF WYE)

- Test Objectives
  - Evaluate efficacy of eddy current technique and correlate results to other NDE techniques
  - Gain knowledge to support development of enhanced eddy current techniques
  - Out year planning will explore merging of eddy current or similar functioning sensors with lightning detection sensors to integrate an all in one sensor solution for both detection and diagnosis to achieve airframe manufacture buy in.

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Diagnosis Research

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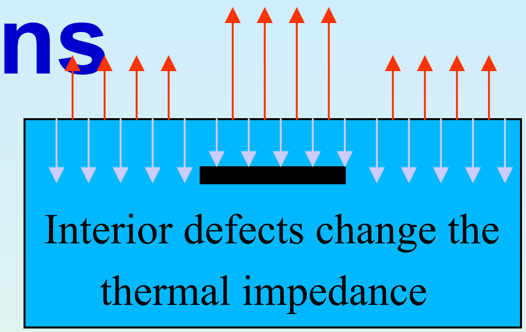
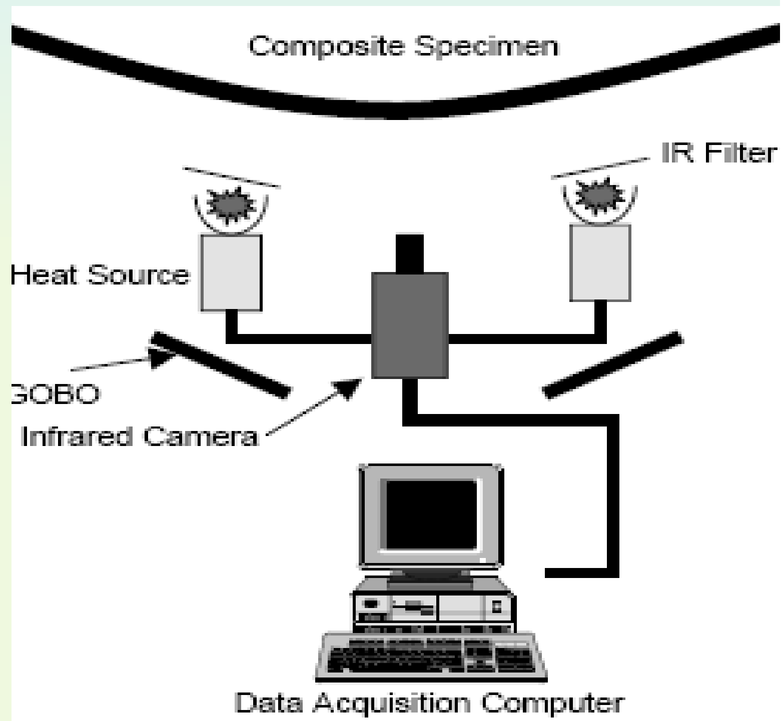
NDE Characterizations

- Flash theromography imaging will be performed to detect delimitations and gross defects that lie in a plane parallel to the surface which block thermal conduction through the composite. 4 panels will be pre and post strike tested by Cheryl Rose of AAD.
- AFRL may perform X-Ray analysis at the cost of $750 per panel.
- No other NDE evaluations are being considered, however a technique to measure moisture content in a composite would be of significant interest. Moisture ageing may be performed at the NASA Ames ageing chamber.
- No vibration, temperature or ultraviolet ageing are planned.
- No fatigue or compression testing will be conducted.
- Analysis will be performed on a cross sectional cut of damaged area to determine failure mechanisms (heat transfer or shockwave)





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Diagnosis Research

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Direct Effect Characterizations

- Lightning direct effect testing will be conducted on 16 different composite panel configurations at the Lighting Technologies Inc facility under the Phase III SBIR.
- Sensor evaluations will be performed on faraday effect current and fiber optic thermal sensors for peak detection of current and temperature.

- In-flight lightning strike would occur on cold, wet composite airframe.
  - Conduct test on composite panel chilled to -40 degrees Fahrenheit.
  - Conduct test on moisture aged composite using environmental ageing chamber at Ames.
- Data results will be reported under the Phase III SBIR and will evaluate effectiveness of the 4 lightning protection techniques.
  - Data will be used to support diagnosis, detection, prognosis and computational predictions.

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Diagnosis Research

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Composite Testing Schedule

Activity Name	Start Date	Finish Date	Duration (weeks)	Facility	2009 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Composite Testing	1/1/09	9/30/09	38.91										
Panel Fabrication	1/1/09	2/28/09	8.24	Nanotech									
Surface Current Mapping	3/1/09	4/30/09	8.67	HIRF Lab									
Test development & setup				HIRF Lab									
Conduct test				HIRF Lab									
Analysis				HIRF Lab									
Shielding Effectiveness Test	5/1/09	6/30/09	8.67	HIRF Lab									
Test development & setup				HIRF Lab									
Conduct Test				HIRF Lab									
Analysis				HIRF Lab									
Thermography Test	7/1/09	7/30/09	4.20	NDE									
X-Ray Test	7/1/09	7/30/09	4.20	NDE									
Direct Strike Test	8/1/09	8/30/09	4.14	LTI									
Moisture Aging	8/1/09	8/30/09	4.14	Ames									
Eddy Current Test	5/1/09	6/30/09	8.63	NDE									
Analysis & follow on tests	7/1/09	9/30/09	13.05										
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept

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Diagnosis Research

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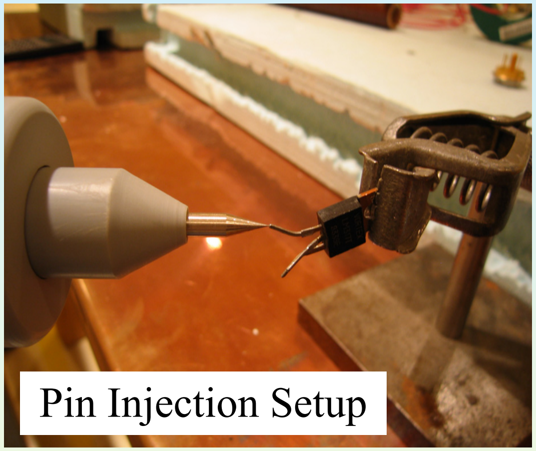
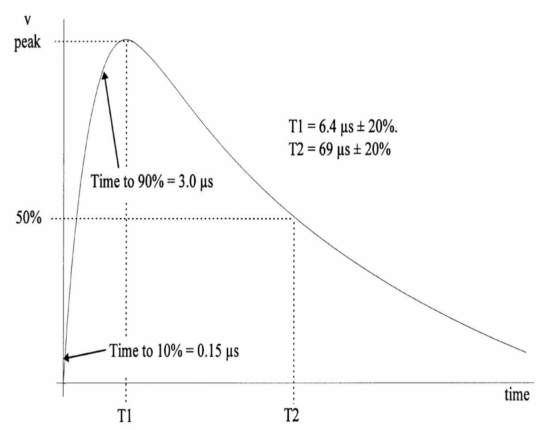
Component Characterizations

- Induce pin injection lightning waveform 4 onto the terminals of silicon power distribution IGBTs & MOSFET devices (Ames research) and high temperature silicon carbide JFET (Glenn Research) to characterize failure modes and to support prognosis of impending faults. Baseline parameters will be measured after each pin injection measurement to record breakdown and threshold voltage, leakage current and I/V curves to quantify the onset of component failure.
- IVHM collaboration will leverage project laboratory resources and NRA activities to enhance research activities. Auburn and Arizona State NRA professors have weighed in on the test procedures to ensure targeted data collection will benefit prognosis research.
- Test Objectives
  - Understand failure modes to support prognosis and enhance SiC designs.
  - Begin study at 20 Volt peak. Increase peak voltage iteration by 50% each cycle. Matrix cycle TBD.
  - Initial look at component characterizations will support future research activities.



Pin Injection Setup



DO-160 Section 22: Double Exponential Voltage Waveform 4

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Diagnosis Research

ESB-HIRF Lab

Component Testing Schedule

Activity Name	Start Date	Finish Date	Duration (weeks)	Facility	2009								
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Component Testing													
IGBT & MOSFET Test	1/1/09	1/30/09	4.20	HIRF Lab/Ames									
Test development & setup				HIRF Lab									
Conduct test				HIRF Lab									
Analysis				HIRF Lab/Ames									
SiC JFET Test	2/1/09	2/28/09	3.86	HIRF Lab/Glenn									
Test development & setup				HIRF Lab									
Conduct test				HIRF Lab									
Analysis				HIRF Lab/Glenn									

Detection Research

- Develop sensors for lightning current detection.
  - Determine lightning current path and intensity. (multi node sensor)
    - Measure lightning parameters to support IVHM diagnosis and prognosis research to assess potential damage & predict remaining useful life.
    - Compliments diagnosis research by determining critical detection requirements.
      - Electrical propagation characterization in composite materials will support proper sensor placement.
  - Measure the total energy transferred during a strike. (single sensor)
    - Lightning community requires better statistical sample of positive lightning strike data to develop refined lightning test standards because damage is sometimes worse than existing standards would predict.
    - NASA F106 flight test data was used in today's lightning test standards. Test results were inconclusive in determining the upper bound of lighting intensity.

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Detection Research

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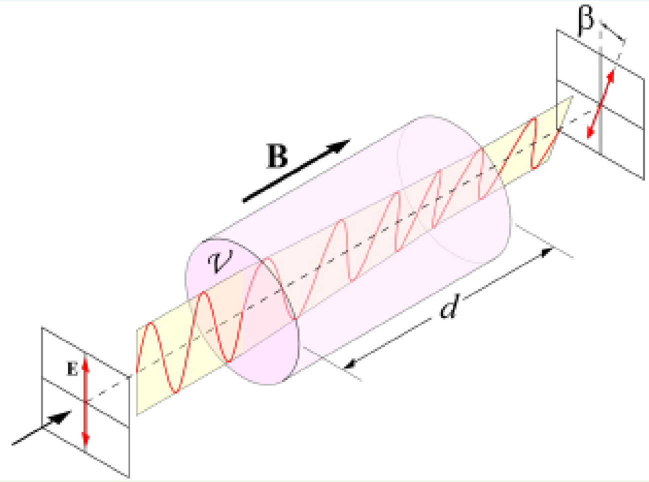
- **Optical Lightning Sensors based on Faraday Effect use the rotation of the plane of polarization of the light in the dielectric to determine the intensity of the magnetic field. This technology offers flexible designs with wide bandwidth and large dynamic range in small, light weight packages. They are immune to lightning and will not saturate like ferrites.**



- Large dynamic range, up to 72 dB
  - Measurement Range: (+/-) 100A to 400,000A in one design.
  - 10A range possible with change in diamagnetic material.
- Wide bandwidth: 0.2 Hz to 10 MHz in the current design.
  - Can increase to >20 MHz with amplifier design change.
- Two sensors
  - Point sensing.
  - Distributed sensing.
    - Effects integrated over length of sensor.
- Commercial product
  - Developed by Phi Invention.
  - Marketed by North Sensors A/S.

Detection Research

- **Research Objectives**
  - Determine appropriate lightning strike parameters to diagnosis damage on composites; peak current, dwell time, temperature, shock
    - Identify precursor signatures of an imminent lightning strike to arm sensors.
  - Select appropriate sensor locations to monitor lightning propagation.
    - Support lightning computational modeling activities.
  - Explore potential dual use technologies to support detection and diagnosis.
    - Eddy current or similar technologies.
  - Validate sensor concepts using direct effect and flight test opportunities.
    - NASA S3 Icing research, NSF sponsored A10 Storm Penetrating Aircraft
  - Evaluate lightning data sets from the National Lightning Detection Network to support IVHM lightning detection user requirements.
    - Use ground truth data to reduce IVHM lightning sensor requirements.

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Conclusions

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- A cross disciplined collaboration has been established to study the effects of lightning damage on composite materials

- 4 lightning protection techniques, 2 composite weaves, 2 different types of paint will be compared.

- Electrical and Mechanical characterizations will be conducted pre & post strike.

- Test results will support IVHM detection goals and lead to better IVHM diagnosis and prognosis systems.