Nondestructive Evaluation
Aerospace Composites

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Outline

• National Aeronautics and Space Administration (NASA)
• NESB Overview
• Need for NDE of Composites
• NESB NDE Composites Research
• Conclusion
NASA Locations

14 Major Centers/Facilities
~18,000 Civil Service Employees
~40,000 Contract Employees

Centers:
- Ames Research Center
- Armstrong Flight Research Center
- Glenn Research Center
- Goddard Space Flight Center
- Jet Propulsion Laboratory
- Johnson Space Center
- Kennedy Space Center
- Langley Research Center
- Marshall Space Flight Center
- NASA Headquarters
- Stennis Space Center
- Wallops Flight Facility

- NASA
- NESB
- Need for composites NDE
- NESB Research
- Conclusion
A picture from 1934 that includes Charles Lindbergh, Howard Hughes, Glenn Curtiss and Orville Wright is an indicator of the history of LaRC.

A picture from 1970 of Alan Shepard (1st American in space) at LaRC lunar landing facility.
Aeronautics Research

- Supersonic vehicles
- More efficient vehicles
- Autonomous vehicles
- Safer vehicles
- Personal Air Vehicles
- Air traffic
Human Exploration

Shuttle: 30 years, 1981-2011

Space Launch System (SLS)
Beyond LEO
Asteroid, Mars

If you wonder how NASA's Space Launch System, or SLS, compares to earlier generations of NASA launch vehicles...

- Space Shuttle: 365 ft
- Statue of Liberty: 333 ft
- SLS: 395 ft
- Saturn V: 365 ft
- SLS will produce 8.4 times more thrust at launch than the space shuttle and 3.6 times the thrust of Saturn V.

Shuttle: 3.5 million pounds
Saturn V: 5.5 million pounds
SLS will launch more than three times as much weight into space as the space shuttle.

www.nasa.gov/sls  #SLSinspires
Science

Earth Science: Orbiting Carbon Observatory

Mars Science Laboratory: Curiosity

Heliophysics: SDO

Astrophysics: Spitzer Space Telescope Image

Planetary: Cassini Image of Saturn
Space Technology

Asteroid Retrieval

3D Printing

E-beam FFF

Inflatable Re-entry
• Only branch level NDE at NASA

• 1 of 2 NDE research level organizations in the US government

• ~24 Full-Time Personnel
  • 18 Civil Servants
  • 9 Support Contractors

• Extensive Skill Mix
  • 10 PhD’s
  • 65% Physicist
  • 15% Electrical Engineers
  • 15% Mechanical Engineers
  • 5% Aerospace Engineers

• NDE Research Laboratory
  • Thermal Imaging
  • Ultrasonic Scanning
  • Phased-Array Ultrasound
  • Electromagnetics
  • Computed X-Ray Tomography
  • Photo & Thermal Elasticity
  • Scanning Electron Microscopy
  • Terahertz Imaging
  • Fiber Optic Sensors Fab.
  • Nano & Mem's Sensor Fab
  • Raman Spectroscopy
Ultrasound

Nonlinear Acoustics

Wireless Sensor Units

Ultrasonic Noise source

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Thermography

Human spaceflight

ISS Radiator

Real time inspection during loading

STS-125
M=14.3

STS-128
M=14.7

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Terahertz

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Pulsed THz
Many other areas

Carbon nanotube sensor

Microfocus X-ray CT

SAW Sensor

Size of pore
0.51 mm x 0.12 mm

400 Conventional Sensors

3000 F/O Sensors
Composites in Aerospace

- NASA
- NESB
- Need for composites NDE
- NESB Research
- Conclusion

Composite Cryotank
Orion Composite Crew Module
Commercial Aircraft from www.airbus.com
Commercial Aircraft from www.boeing.com
• 5 Year Project:
  – Reduce timeline for certification of composite structures
    • Currently takes ~20 years from material development to market use
  – Infuse advanced tools to accelerate regulatory acceptance of advanced composites
• Partnership: NASA, FAA, DoD, Industry, University
• NDE of composites will play a key role in all three technical challenge areas:
  1. Predictive capabilities (e.g., damage progression)
  2. Rapid Inspection
  3. Enhanced Manufacturing
Unique Damage Types

X-ray CT data of delamination damage

UT data of delamination damage

X-ray CT data of microcrack damage

X-ray CT data of delamination damage

Voids

Delams

X-ray CT of PRSEUS Joint, From NASA TM-2013-217799 by Patrick Johnston
NESB Composite NDE Research

- Focus areas: Inspection of complex geometry components and rapid large area inspection
- Development of new techniques
  - Goal: quantitative damage/material characterization
  - Microcracking, fiber waviness, delamination, porosity
- Validation of detectability
  - Inspectability of complex components
  - Model based validation tools
- Experiment:
  - Thermography, ultrasound, nonlinear ultrasound
- Simulation:
  - Custom code, 3D simulation

ISAAC Automated fiber placement machine
Large Area Inspection

• Flash Thermography
  • Delaminations, disbonding, porosity, skin-to-core disbonding
  • Good for solid laminates and for honeycomb
  • Fast – 0.09 m² (140 in.²) in 10-15 sec.
  • Can handle complex geometries

• Non-Immersion Single Element UT
  • Delaminations, disbonding, porosity, matrix cracking, core crushing, skin-to-core disbonding
  • Good for solid laminates and for honeycomb
  • Very high spatial resolution ~.01in. (0.25 mm)
  • Very high speed – 10-12 in. / sec.
Composite Crew Module

- Vessel dimensions
  - 3.8m dia. and 3.1m tall
- Full Scale Load testing to failure
- 100% Thermography
- Critical Locations UT
- AE During Loading
- ~ 140 GB of Thermal Data Acquired During Load Testing Cycle (Multiple Inspections)

LaRC PCA-processed IR image
SLS Composite Payload Fairing

1/16 Circumference

SLS system trade studies show that an all composite structure would decrease the mass by 40% and increase the payload to LEO by 25 metric tons.

Payload Shroud 8.4 m Dia.

~3m

Membrane and wear layer was changed here

~2m

*Up to 190 GB of ultrasonic data per panel
Guided Wave Ultrasound Research

- GW created in plate-like specimens due to boundaries
  - Interaction of coupled L and SV with boundaries leads to various modes
- Promise for covering large areas via long distance travel
- Noncontact measurement with Laser Doppler Vibrometry

Out of plane velocity
Wavefield Analysis

- NASA/Georgia Institute of Technology NRA starting 01/2013
  - Hybrid SHM/NDE topic: SGWA and AWI to locate *and characterize* damage
- Simulation work led to understanding of energy trapping effect on SGWA
- Moving on to test methods in complex composite components

**Simulation work**
- MV-Env, 80 kHz, 5.00 Cyc, B-1/F2

**Experimental wavefield data**
- GIT Experimental wavefield data

**Simulated Damage**
- MV-Env, 80 kHz, 5.00 Cyc, B-1/F43

**NASA local wavenumber**
- GIT Instantaneous wavenumber

**Energy trapping**
- MV-Env, 80 kHz, 5.00 Cyc, B-1/F43

**Damage depth wave IW**
- GIT Instantaneous wavenumber
Wavenumber Analysis

Immersion Ultrasound

Immersion Ultrasound

Noncontact LDV Wavenumber Analysis

1 Juarez, P. and Leckey, C. “Multi-frequency Local Wavenumber Analysis and Ply Correlation of Delamination Damage”. Submitted to Ultrasonics
NDE/SHM Simulation

• Simulation of energy interaction with material/structure and damage
  • Composite focus

• Realistic NDE simulation tools for aerospace materials enables inspection prediction
  • Establish confidence in ability to inspect: complex components, ‘hard to reach’ locations, cover large areas, advanced materials (composites)

• Creates cost-effective tools for developing and optimizing damage characterization techniques

• Aid in understanding of experimental results

• Simulations enable cost-effective SHM validation
• Custom code simulates 3D wave interaction with *realistic* damage
• Custom EFIT code has many benefits:
  • Speed, memory efficiency, control, adaptability
  • Currently runs on multi-core and cluster computers
  • Validated against experiment and theory

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Guided Wave Example

- 3D EFIT: 1.8 billion grid cells
  - 110 mm x 65 mm x 3.2 mm
- Run on 80 core 1TB shared memory machine
- Step size=23.4μm, $\lambda_{\text{min}}/64$
- Images show shorter wavelength scattering from damage
Local Wavenumber Analysis Technique:
1) 3D FT of Hann windowed wavefield, local window
2) Select 3D FT slice at excitation center frequency
3) Calculate dominant wavenumber of local window

Model Based Detectability Studies

- NASA/University of South Carolina*
- Started with simple isotropic (aluminum) case
- Results\(^1\) demonstrated use of 3D simulation data in place of experimental data for investigating sensor location w.r.t. damage

\[\text{Damage orbit} \quad Z_o \quad Z_i \quad \text{Focusing Array} \]

Conclusion

• NASA needs quantitative NDE for aerospace components, including:
  • Rapid inspection for large scale parts
  • Techniques for complex geometry composites
  • Validation methodologies for determining inspectability

• Experiment and simulation are needed to develop optimized, validated inspection/monitoring techniques

• NESB is performing ongoing research in these areas
A list of related publications can be found at:
http://nde.larc.nasa.gov/physicsbased.shtml

Thanks to:
• Peter Juarez
• Jeffrey Seebo

QUESTIONS?

*NASA/USC work under SAA1181
**NASA/GaTech work under NRA NNX12AL13A
Simulation SOA and Gaps

- SOA of NDE and SHM modeling/simulation not adequate for future needs, including:
  - Larger scale simulations
  - Composites
  - Advanced designs
  - Realistic damage scenarios


3D FE, Single circular delamination (investigated ‘clapping’ behavior)


3D FE, Single rectangular delamination (investigated mode conversion)


2D FE, Single ‘strip’ delamination


2D FE (ANSYS) Turning modes

Computational Trends

• Computational power per unit space increasing, cost decreasing

• iPad2 has as much processing power as Cray 2 (world’s fastest computer in mid 1980s)

• Cost per GFLOP (adj for inflation)
  • 1984: $42M
  • 1997: $42k
  • 2007: $52
  • 2013: $0.12

• Simulations will play an increasing role in the future science and engineering (including NDE)

http://www.tuaw.com/2011/05/09/ipad-2-would-have-bested-1990s-era-supercomputers/
Guided Wave Simulation

Case 1

Case 2

Case 3