Spacecraft Pre-launch/Turnaround NDE needs at the Kennedy Space Center

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NDE included in NASA Roadmaps

Figure 1
Space Technology Roadmaps STR • TABS
TECHNOLOGY AREA BREAKDOWN STRUCTURE

TA12 • MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

CROSS-CUTTING
- Nondestructive Evaluation & Sensors
- Model-Based Certification & Sustainment Methods
- Loads and Environments

Table 22. WBS # 2.5.1 NDE

<table>
<thead>
<tr>
<th>TECHNOLOGY PRODUCT</th>
<th>What it Enables</th>
<th>Current TRL/Status</th>
<th>Steps to TRL 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. NDE Complex Built-Up Structures</td>
<td>Assurance of the integrity of complex built-up structures.</td>
<td>TRL 2: Viable techniques for inspection of exposed surfaces and inspection following disassembly.</td>
<td>Sensors for prognostics and reconstruction techniques for data acquired from limited views of penetrating radiation 2023.</td>
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<tr>
<td>d. Autonomous Inspection</td>
<td>Performance of inspections in areas where a human interaction is either not possible, challenging, or too time consuming.</td>
<td>TRL 1-2: Development of systems with simplified human operations.</td>
<td>Sensors and AI systems for large area inspection 2023.</td>
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</table>
NDE expertise in high demand across all NASA missions
- Challenge to provide sufficient expertise
- Multi-Center cooperation key
  - e.g. NESC NDE TDT, NASA NDE Working Group (NNWG), Orbiter NDE Working Group (ONWG)
- Reduced research capabilities and output lead to risk in meeting future mission requirements

Many mature NDE technologies – challenge applying them to complex aerospace materials and structures
- Composites, ceramics, TPS, multilayer, multi-functional structures, etc.

Interaction with other disciplines (materials, structures, etc.) present challenges
- NDE requirements, expectations, and need to consider NDE in the initial design

Structural Health Monitoring (SHM) is new frontier with great potential returns
- Critical for longer duration manned space missions
KSC NDE Vital to Overall NASA NDE Mission

- KSC NDE required to maintain KSC/CCAFS institutional facility
- KSC NDE required to support current customers (customers defined later slide)
- KSC NDE will be required for future customers
  - Beginning with Shuttle Program KSC has historical worked with operations centers (JSC, MSFC) and Research Centers (LaRC, GRC) to develop and implement advanced NDE procedures.
  - Current and future and NASA programs are dependant of KSC to maintain its current core and advanced capabilities
Where we are now: KSC NDE Laboratories

- Institutional (ISC) NDE Primary Services
  - Provide Non-Destructive Testing and Evaluation for the Kennedy Space Center/Air Force Operational Programs and Facilities
    - Examples include
      - Crane hooks
      - Lifting fixtures
      - Pressure vessels
    - Includes operational ground support equipment and flight vehicle hardware.
    - Provides 24/7 support launch site operations customers processing and launching rockets and payloads.
    - The Lab also develops new NDE techniques and equipment to improve evaluation capabilities.

- USA/Hangar N NDE Primary Services
  - Provide Non-Destructive Testing and Evaluation for the Space Shuttle and other KSC Operational Programs
    - Performs inspections in support of space operations and maintenance of multi-purpose space systems
    - Provides NDE Project Engineering for New Technology Development
    - Includes advanced NDE capabilities
      - Flash Infrared Thermography (Orbiter Wing Leading Edge)
      - Terahertz (External Tank)
      - Backscatter x-ray (External Tank)
    - Provide R&D collaboration with the NASA Engineering Safety Center (NESC) NDE Technical Development Team

Some cross linking exists amongst the 2 laboratories – Consolidation plans are currently being discussed
Institutional (ISC) Non-Destructive Examination Laboratory

- **Skills and Capabilities**
  - Eddy Current Testing
  - Infrared imaging
  - Leak Testing
  - Micro-Focus X-Ray
  - Magnetic Particle
  - Fluorescent Dye Penetrant
  - Radiography
    - High Energy X-Ray – 420 kV
    - Portable X-Ray and Gamma Sources
    - Computed Tomography (CT)
  - Ultrasonic Testing
  - Visual
    - Certified Weld Inspection (CWI)
  - ASNT-certified Level III engineering consulting
USA/Hangar N Non-Destructive Examination Laboratory

- **Skills and Capabilities**
  - Radiography
    - CT
    - Film and Digital
    - Laminography
  - Ultrasonic
    - A-Scan, B-Scan, P-Scan
    - 3D CAD UT Modeling
  - Flash Thermography imaging
  - Shearography - Vacuum/Acoustic
  - Magnetic Particle
  - Fluorescent Dye Penetrant
  - Visual
    - CWI, Dimensional, UV Borescope
  - Eddy Current
    - MWM, Single/Multi Channel
    - Bolt Hole/Surface
    - Custom Coil
  - Terahertz
  - Large scale X-Ray Chamber
    - 11-Axis Robot and gantry
  - Structural Health Monitoring (IVHM)
Materials Science Division Support

- Materials & Processes Engineering
  - Program support (engineering/project management)
  - ESD Composites for Exploration
  - OCT Composites Cryotank
  - R&D

- Applied Physics Lab
  - Program support (applied R&D)
  - R&D

- NASA NDE Working Group (NNWG)
- NESC NDE TDT
Example of Past Projects

Device for making detailed maps of orbiter window defects

Ultrasonic leak locator

Prototype device to indicate H2 leakage or fire at a flanged joint.
Current/Future NDE Customers

- KSC/CCAFS Institution
  - e.g. Pad modifications, cyrotanks, crawler transporter, pressure vessels
- Launch Services Program (LSP)
- 21st Century Launch Program
  - Orion MPCV
  - SLS
- Commercial Cargo
- Commercial Crew
21st Century Launch Complex

- Modernizing the KSC and CCFAS
  - Launch architecture
  - Environmental
  - Payload Processing
  - Range Capabilities
  - Partnering with Air Force, State of Florida and the FAA
Orion MPCV and SLS
Commercial Crew - Blue Origin

- Developing a Crew Transportation System comprised of a Space Vehicle (SV) which will be launched first on an Atlas V and then on Blue Origin’s own Reusable Booster System (RBS)
- Capable of carrying 7 astronauts and will transfer NASA crew and cargo to and from the ISS, serve as an ISS emergency escape vehicle for up to 210 days, and perform a landing to minimize the costs of recovery and reuse.
Commercial Crew - Boeing

- Developing a “full service” system for both NASA and commercial customers to LEO destinations.
- CST-100 spacecraft is configured to carry up to 7 crew members and/or cargo to LEO destinations including ISS and BA Sundancer space complex.
- Compatible with multiple launch vehicles.
- Designed for land landings and can be reused for up to 10 missions.
• Developing the Dream Chaser Space System (DCSS).
• Provides LEO access to the ISS and commercial customers needing suborbital services.
• Third generation design derived from extensive NASA Langley research providing a reusable, pressurized, lifting-body vehicle that lands on a conventional runway.
• Will most likely utilize an Atlas V launch vehicle.
**Commercial Crew - SpaceX**

- SpaceX’s Dragon crew vehicle was the first commercial spacecraft to return from orbit.
- Maturation of the Falcon9/Dragon transportation system with a particular focus on developing an integrated Launch Abort System.
- Developing prototypes of the crew cabin, crew seats and restraints, crew control panel and life support system.
So what are KSC’s needs?

- The basic infrastructure of NDE support will remain but at a reduced capacity, especially in advanced NDE development
  - Consolidation is still in work
- The new NASA programs and the new commercial customers do not have the “deep pockets” that the Shuttle Program had
  - The challenge for KSC is to maintain a world class NDE organization with less resources
- The NASA Materials Science Division will remain the POC for NDE operations and advance NDE development
  - Key challenge is to forecast future customer needs
  - Examples of a few recent development efforts are on the following charts
Multifunctional Hybrid Composite Metamaterial Systems

- Inspection of damage and subsequent repairs on composite structures which will involve:
  - Develop a Surface Wave propagating (SWP) structure consisting of arrayed sensors (piezoelectric), in conjunction with a passive single chip Radiofrequency Identification (RFID) strain/accelerometer/temp sensor configuration.
    - The goal will be to simultaneously transfer power and communicate via a wireless network, in order to detect damage and induce or monitor the cure of a repair in a fiber reinforced composite part.
    - Validation of the tools using current NDI/NDE methods
  - Repair of materials for primary structures (including newly developed out of autoclave material designed for use on primary structures).
    - Cradle-to-grave monitoring of the repair including monitoring repair cure, the initial quality of repair during installation and continuing the monitoring throughout its lifetime.
    - Provide cost-cutting measures for repair of out-of-autoclave composite structures for primary structures through the development of standard repair and monitoring kits
Eddy Current Stress Gages for COPV Health Monitoring

- Utilizes MWM® Technology
  - Goal is to provide a means of directly measuring the stresses at various depths in the overwrap

\[ \delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \]
Eddy Current Stress Gages for COPV Health Monitoring

Magnitude vs. Set (Average of all Channels)

- 17° Sensor Orientation
- 60° Sensor Orientation
- 90° Sensor Orientation

Pressurization Interval

Normalized Magnitude
Wire Detection Systems & Integration

- Diagnostic Device
- Sample Screen
- Potential Damage Sites
- Insulation
- Wire Core
- Detection Layer
- Single Wire Configuration
- Diagnostic Signal Propagation
- Damaged Wire
- Area of Damage
- Damaged Wire Bundle

(NASA logo)
Wire Construction

Materials examined during development of detection layer
- Metal foils
- Nickel coated carbon fiber
- Conductive carbon cloth
- Metallized mylar tapes
- Sputter coated metals
- Electroplated metals
- Printed-on conductive inks
- Inherently conductive polymers

Cross section of RG316 wire with Cu foil and PTFE jacket

Damage profile for TDR testing