New ASTM Standards for Nondestructive Testing of Aerospace Composites

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ASNT Fall Conference & Quality Testing Show

NASA NDE I

Houston, TX

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Statement of Problem

- Lack of consensus standards containing procedural detail for NDE of polymer matrix composite materials
  - Flat panel composites
  - Composite components with more complex geometries
    - Pressure vessels
      - composite overwrapped pressure vessels (COPVs)
      - composite pressure vessels (CPVs)
    - Sandwich core constructions
- Metal and brittle matrix composites are a possible subject of future effort

Relevant Literature (non-inclusive list)

1. **AIAA**
   - **S-080 Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components**
   - **S-081A Space Systems - Composite Overwrapped Pressure Vessels (COPVs)**
2. **ASME**
   - **STP-PT-021 Non Destructive Testing and Evaluation Methods for Composite Hydrogen Tanks**
3. **ASTM**
   - **E 1419 Test Method for Examination of Seamless, Gas-Filled, Pressure Vessels Using Acoustic Emission**
   - **E 1736 Practice for Acousto-Ultrasonic Assessment of Filament-Wound Pressure Vessels**
   - **E 2191 Test Method for Examination of Gas-Filled Filament-Wound Composite Pressure Vessels Using Acoustic Emission**
   - **E 2581 Practice for Shearography of Polymer Matrix Composites, Sandwich Core Materials and Filament-Wound Pressure Vessels in Aerospace Applications**
4. **ISO**
   - **14623 Space Systems - Pressure Vessels and Pressurized Structures - Design and Operation** (similar to AIAA S-080 and -081, and NASA-STD-5009)
5. **NASA**
   - **MSFC-RQMT-3479 Fracture Control Requirements for Composite and Bonded Vehicle and Payload Structures**
   - **NASA-STD-5007 General Fracture Control Requirements for Manned Spaceflight Systems**
   - **NASA-STD-5009 Nondestructive Evaluation Requirements For Fracture Control Programs**
     - **JSC Special Addendum Physical Crack Standard**
   - **NASA-STD-5019 Fracture Control Requirements for Spaceflight Hardware**
   - **NASA-STG-5014 Nondestructive Evaluation (NDE) Implementation Handbook for Fracture Control Programs (draft)**
6. **Miscellaneous**
   - **AFSPCMAN 91-710**
   - **CSA NGV2-2000 Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers**
   - **KHB 1710.2D**
   - **MIL-STD-1522 Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems**

NDE of Flat Panel Composite Standards

Accomplishments Since 2005

Designation: E 2580 – 07

Standard Practice for
Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications[1]

Designation: E 2581 – 07

Standard Practice for
Shearography of Polymer Matrix Composites, Sandwich Core Materials and Filament-Wound Pressure Vessels in Aerospace Applications[1]

Designation: E 2582 – 07

Standard Practice for
Infrared Flash Thermography of Composite Panels and Repair Patches Used in Aerospace Applications[1]

Accomplishments Since 2005

Designation: E 2662 – 09

Standard Practice for
Radiologic Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications[1]

Designation: E 2533 – 09

Standard Guide for
Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications[1]

Designation: E2661/E2661M – 10

Standard Practice for
Acoustic Emission Examination of Plate-like and Flat Panel Composite Structures Used in Aerospace Applications[1]

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January/February 2010
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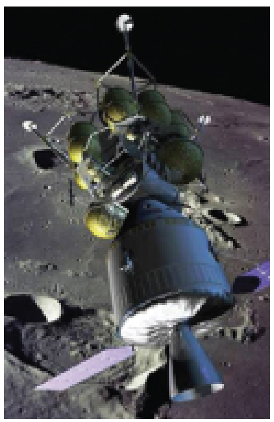

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Phased Arrays, Aerospace Applications, Digital Imaging

ASTM International Committee E07 on Nondestructive Testing has recently approved three new standards on phased arrays, polymer matrix composites for aerospace applications and digital imaging. The committee will be meeting in Plantation, Fla., Jan. 24-28, and welcomes participation in its standards developing activities.

Ultrasonic Methods

Thousands of portable phased array units, used for weld inspections, have now been sold worldwide. There are many benefits to these devices, including speed, cost, imaging, flexibility and setups, along with no radiation, licensing or contamination. Despite these advantages, there was not a universal inspection procedure for phased array inspection of welds. A new standard, E2700, Practice for Contact Ultrasonic Testing of Welds Using Phased Arrays, provides such an inspection test.

E2700 was developed by Subcommittee E07.06 on Ultrasonic Method. According to Michael Moles, senior technology manager, Olympus NDT, and an E07 member, E2700 will be most useful to inspection companies that need to write and follow procedures and to end users and regulators who need to establish practices for the inspection companies.

"E2700 will be very helpful as it covers the relevant aspects for most weld inspections, so details will not be ignored or forgotten," says Moles.

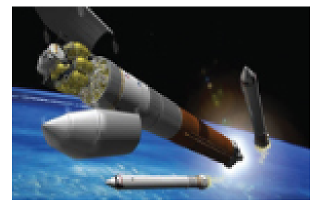
Specialized NDT Methods

A new guide gives an introductory overview that describes how mature and established nondestructive testing methods that are routinely used by industry are applied specifically to the characterization of polymer matrix aerospace composites. E2533, Guide for Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications, is under the jurisdiction of Subcommittee E07.10 on Specialized NDT Methods.

"The practical value of E2533 is that the major, accepted nondestructive testing methods are covered in a single document," says Jess Waller, a materials scientist at GeoControl Systems Inc. and a member of E07.10. "Primary users of the standard will be the aerospace industry and its primary contractors in building spacecraft and launch vehicles for present and future NASA programs." This includes all government and industrial entities involved in:

- Product and process design and optimization;
- Online process control;
- After manufacture inspection;
- In-service inspection; and
- Health monitoring of polymer matrix aerospace composites.

Waller notes that E2533 can be used to select an appropriate nondestructive test depending on the type of flaw a user is trying to detect and to provide instruction on where in the life cycle of a composite material or component a particular test can be used. In addition, the advantages and limitations of each of the major nondestructive tests are discussed, with reference to relevant standards.



The aerospace industry will use new standards approved by Committee E07 on Nondestructive Testing in the development of future spacecraft.

Digital Imaging and Communication in Nondestructive Evaluation

A new standard developed by Subcommittee E07.11 on Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) will fill a need in the nondestructive testing industry for a transparent and industry standard data format with which to store digital inspection data.

E2663, Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for Ultrasonic Test Methods, will be used by manufacturers to develop ultrasonic test equipment that communicates and stores inspection data in a nonproprietary format that will be used for decades.

"Critical national and commercial infrastructure requires long-term data management solutions for inspection data," says Patrick Howard, GE Aviation, who notes that, in the United States, nuclear power plants are typically licensed for 40 years but can obtain an operating extension for an additional 20 years.

"Over such long time periods, inspection equipment is replaced with new models, and equipment vendors may go out of business while the need to access the data acquired with the equipment remains," says Howard. "There is a need to promote interoperability as inspection equipment is modernized to provide long-term data access."

E2663 will serve as a companion standard to E2339, Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE). While E2339 addresses digital data transmission and storage for all nondestructive evaluation modalities, E2663 addresses digital data transmission and storage specific to ultrasonic testing.

Howard also notes that E07.11 is now at work on the following related proposed practices:

- WK17435, Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for X-Ray Computed Tomography (CT) Test Methods;
- WK17436, Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for Digital Radiographic (DR) Test Methods;
- WK20537, Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for Eddy Current Test Methods; and

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November/December 2009
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Flat Panel Composites

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NASA White Sands Test Facility technicians perform radiographic inspection on a filament wound pressure vessel.

A series of standards on nondestructive inspection and examination of aerospace composites has been developed under the jurisdiction of ASTM International Committee E07 on Nondestructive Testing. Several years ago, with impetus and input from representatives of the U.S. National Aeronautics and Space Administration, a task group on NDE for aerospace composites was formed under Subcommittee E07.10 on Specialized NDT Methods.

The task group, chaired by George Matzkanin from the Texas Research Institute, Austin, was established to foster the development of standards for NDE of aerospace composites. A recently published standard, ASTM E2533, Guide for Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications, was developed under the guidance of task group and E07.10 subcommittee member Jess Waller, NASA White Sands Test Facility. This guide helps engineers select appropriate nondestructive testing methods to examine and characterize aerospace composites.

In addition to the guide, several standard practices have been developed and published to document and establish control requirements of current established industry practices so that these standards can be specified in contracts. One such practice is the new standard ASTM E2662, Practice for Radiologic Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications, developed under the guidance of task group member John Ellegood, Lockheed Martin Space Systems Co. This standard was developed under the jurisdiction of Subcommittee E07.01 on Radiology (X and Gamma) Method.

ASTM E2662 provides process control requirements for film and digital radiography of aerospace composite panels. "Using ASTM E2662 will improve accuracy and reliability of radiographic examinations for these low density structures," says Ellegood, a staff quality engineer and Level 3 radiographer. "Often, examinations are not performed at optimal levels due to inadequate experience and lack of requirements."

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Ellegood, who also serves on the Leadership Committee of the Federal Working Group on Industrial Digital Radiography, says that NASA, the U.S. Department of Defense and manufacturers of aerospace and aircraft structures using lightweight composite panels will be the primary users of ASTM E2662.

Three additional practices developed under the guidance of the task group and published earlier are:

- E2580, Practice for Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications;
- E2581, Practice for Shearography of Polymer Matrix Composites, Sandwich Core Materials and Filament-Wound Pressure Vessels in Aerospace Applications; and
- E2582, Practice for Infrared Flash Thermography of Composite Panels and Repair Patches Used in Aerospace Applications.

The task group is now moving forward with the development of proposed guides and practices for the inspection/examination of more complex composite components, such as composite overwrapped pressure vessels. All interested parties, including engineers working in nondestructive testing, materials and aerospace, are welcome to contribute to the ongoing development of these proposed standards.

CONTACT

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(E2662) John Ellegood, Lockheed Martin Space Systems Co., Denver, Colo.

Phone: 303-977-5755

ASTM Staff: George Luciw

Phone: 610-832-9710

NDE of COPV Standards

Background

Safe applications of Composite Overwrapped Pressure Vessels (COPVs) are a major concern:

- The NASA Engineering and Safety Center (NESC) conducted two major COPV Technical Assessment (concerns were passed on to associated programs)
  - NDE was not adequately implemented during Shuttle and ISS COPV manufacturing and provisions were not made for on-going COPV structural integrity or health checks
  - “Stress rupture” of Orbiter (Kevlar) and ISS (carbon) COPV is a major concern
    - Stress rupture failure of gas pressurized COPVs on the ground or in flight presents a catastrophic hazard

Background (con't)

Fundamental Gaps in NDE/NDI of Composites was identified at the September 2009, WSTF Composite Summit involving over 120 attendees, including Joint NASA, DOD/DOE/FAA, industry, and academia. High level needs were identified as:

1. Quantitative rather than qualitative NDE for composites applications
   - Sound process standards, realizing that physical defect standards are critical and must be directly representative of the structure being inspected.
   - Establish a direct linkage to modeling and damage tolerance criteria

2. Need NDE to be integrated into the manufacturing process to ensure significant flaws do not exist and ensure consistency
   - NDE is needed to avoid previous COPV issues that caused program impacts and avoid a catastrophic failure on NASA spacecraft, ensure other critical criteria requirements are met such as "Safe-Life

COPV Issues

- COPVs are currently accepted by NASA based on design and qualification requirements and generally not verified by NDE/NDI for the following reasons:
  - Manufactures and end users generally do not have experience and validated quantitative methods of detecting flaws and discontinuities of concern
    - If detected, the flaws are not adequately quantified and it is unclear how these relate to degradation in mechanical response.
    - Carbon vessels also extremely sensitive to handling damage and impacts may not be detected
      - If identified generally results in rejection since mechanical response is generally not know
- NDE response has not generally been fully characterized, POD established, and processes validated for evaluation of vessel condition as manufactured and delivered.

COPV Issues (con't)

- COPVs still demonstrate a large amount of variability in burst pressure and stress rupture progression rate.
  - NDE processes need to be integrated into manufacturing to reduce variability and improve quality
  - NDE can often be applied at each major step from fabrication through qualification with concerns to target:
    - Crack and grain boundary issues from liner spinning operation
    - Liner deformation and buckling issues following Autofrettage
    - Defect growth after Autofrettage
    - Liner to composite adhesive disbond and gaps from CTE mismatch during thermal cure
    - Composite weak areas from poor wetting or out gassing during cure
    - Bridging during winding
    - Tow tension issues resulting in excessive fiber breakage during autofrettage
    - As manufactured strain distribution sharing liner/overwrap

Technical Approach

The method/approach naturally flows from current ASTM efforts:

- ASTM E07 writing committees will document mature methods for COPV Liner, Composite, and Composite to liner interface Standards
  - Other promising, but less mature methods will be placed on a list for NNWG or NESC to evaluate and mature
    - NDE technique development and verification should be mapped to requirements, AIAA S-O81A plus a NASA COPV specification is also planned (only so far partly funded)
    - Attempts to evaluate enhanced flaw detection at 90/95 POD is planned at the coupon level in coordination with the NESC and the on-going JSC/NNWG physical standards program, but COPV effort will have to wait a while
  - Due to the scope, teaming with government and industry would add expertise and reduce overall cost
    - Participate is needed from organizations like the CPVWG, NNWG, M&P community, Air force, and Profile Composites/National Center for Manufacturing Science

Influence on Standards Generation

- ASTM COPV NDI standards are still broken down into 3 categories per previous ASTM meetings:
  - Composite outer layer
  - Liner and monolithic thin wall pressure vessels
  - Composite to liner interface

- Since the method maturity is NOT where we would like it to be in some cases, we first document our best mature processes and document improvements in revision when available:
  - NESC Liner method development for rapid scanning to detect small/shallow cracks and discontinuities
  - NESC/NNWG is working physical standard generation with shallow crack at (such as .3 aspect ratio – needs update from Bill Prosser)
    - May help to meet safe life requirements of ANSI/AIAA S-O81A

POD Resource (Dr. Edward Generazio)

- http://www.nnwg.org/Recent%20Publications/Directed%20Design.pdf

WK 29068

Standard Guide for
Nondestructive Testing of
Thin-Walled Metallic Liners in
Filament Wound Pressure Vessels Used in
Aerospace Applications

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ASTM WK29068

(What is a Work Item? / How to Input to a Work Item)

Work Item: ASTM WK29068 - New Practice for Examination of the Metallic Thin-Walled Liners in Filament Wound Pressure Vessels Used in Aerospace Applications by Nondestructive Testing

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1. Scope

1.1 This Practice discusses nondestructive testing (NDT) methods for detecting defects and flaws in thin-walled metallic pressure vessels (PVs) and composite overwrapped pressure vessels (COPVs) used in aerospace applications. In general, these COPVs have metal liner thicknesses less than 2.3 mm (0.090 in.) and a filament wound composite overwrap. 1.2 Although this Practice focuses on PVs and COPVs used at ambient temperature, it also has relevance to a) composite pressure vessels (CPVs), and b) COPVs and CPVs used at cryogenic temperatures. NDT of the composite overwrap of COPVs is beyond the scope of the Practice, however, a general overview of applicable NDT methods is provided in Guide E2533. 1.3 This Practice applies primarily to high pressure COPVs used for storing compressed gases

Work Item Status:
Date Initiated: 06-02-2010
Technical Contact: Jess Waller

Status: Draft Under Development

Standards Tracker

Standards Subscriptions

WK 29068 Goals

- Select A-list of NDE Methods
  - AE
  - ET
  - laser profilometry
  - LT
  - PT
  - RT (tangential x-ray so far for liner/overwrap separation)
  - UT (lamb wave)
  - other?
- Writing teams have been selected
- However, broader involvement is requested
  - NASA, DOD, DOE, FAA, NIST
  - NDE equipment manufacturers
  - Aeropace Industry
  - Academia

Candidate NDE Methods for COPV Liners

- A-List: 90% POD at 95% confidence level (90/95):
  - fluorescent dye penetrant testing (PT)
  - eddy current (ET)
  - ultrasound (UT) (phased array, lamb wave, pulse-echo?)
  - radiography (RT)
- B-List: Supplemental:
  - acoustic emission (AE) (see ASTM E 1419)
  - thermography (nuances different for liner vs. overwrap)
  - magnetic particle (MT) (is this sensitive enough?)
  - visual inspection (VT)
    - borescopy
    - laser profilometry

Current COPV Manufacturer NDE

- Used during:
  - (a) product and process design and optimization
  - (b) on-line process control
  - (c) after manufacture inspection (or prior to installation)
- Pre- & post-proof (autofrettage) radiography (RT)
  - — Tangential x-ray (buckling)
- Helium leak test (LT)
- Visual (VT)
- Unknown if Dye Penetrant (DT), eddy current (ET), ultrasound (UT) are being used
- Other?

WK 29068 Considerations

- Does sufficient NDE procedural detail exist for 90/95 POD and accept/reject?
- Will the new Standard be a Guide that references new and existing Test Methods and Practices
- NASA concern is for thin-walled metal liners for COPVs; however, the Guide will be applicable to PVs in general
- Focus will be on high pressure COPVs used in aerospace applications, however, standard may also have utility for automotive COPVs
- Not sure if focus should be on seamed or seamless liners
  - weld inspection of seamed liners using RT is common, for example
  - ASTM E 1419 is for AE of seamless PVs

WK 29068 Considerations

- The new Standard may have a manufacturing and/or end-user bias, NDE prerogatives will differ
  - need to inspect liner before wrapping or after autofrettage places responsibility on COPV manufacturers
  - need to periodically inspect liner during service places responsibility on end user
- In other words, the Standard could focus on any one of the following areas during the life cycle of the COPV:

  (a) product and process design and optimization

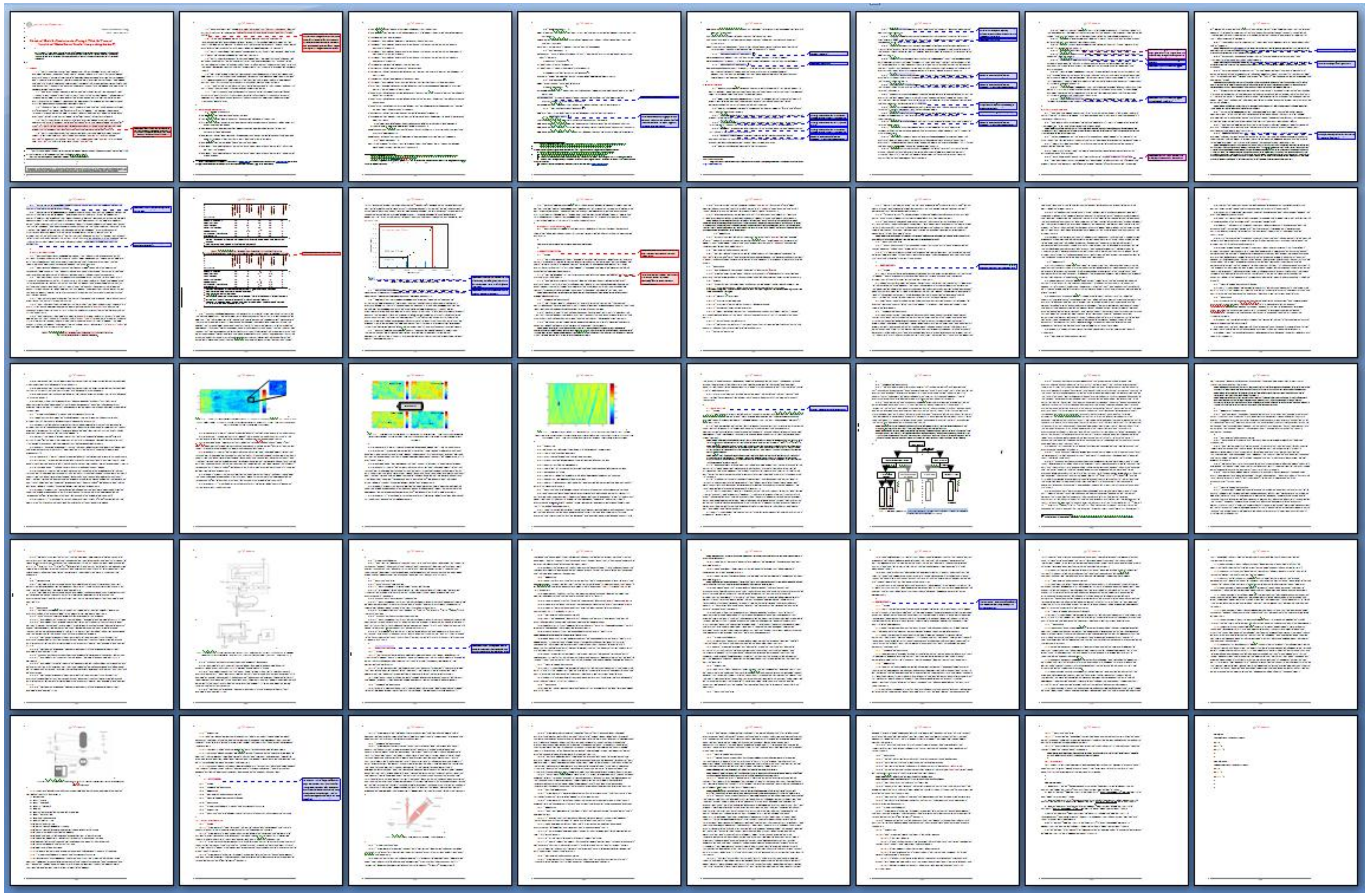
  (b) on-line process control

  (c) after manufacture inspection

  (d) in-service inspection

  (e) health monitoring

WK 29068 Boiler Plate Draft Exists



- Incorporates parts of draft NASA-HDBK on *Nondestructive Evaluation (NDE) For Composite Overwrapped Pressure Vessel Liners* (Forsyth, TRI)
- Procedural NDE detail needs to be added specific to COPVs

Candidate NDE Methods for COPV Liners

- Radiography (RT) – Engel proposes dividing into 2 parts

1) Radiographic Inspection of COPV Liner Welds

   1st section will either reference existing ASTM documents or import existing "radiographic inspection of weld" data into this specification. This section would address longitudinal seam, circumferential, dome and boss welds on the liners covering common liner materials.

2) Radiographic Inspection of Liners for Damage and Buckling

   2nd section would include real-time radiography and X-ray film methods to examine COPVs for damage & buckling. Some of the COPV manufacturers/end users may have some additional ideas on other items to include as well so I would be interested in getting input from them. This section will likely address both planar and tangential X-ray methods that would be subdivided to include liner walls and dome sections.

Candidate NDE Methods for COPV Liners

Radiographic Inspection of Composite Overwrap Pressure Vessel Liners

rough outline (Engel)

Scope

Reference Documents

Background

1) Radiographic Inspection of COPV Liner Welds

- Boilerplate specification data
- X-ray Techniques
  - Film
  - Flat Panel
  - Reference ASTM and other specifications (Flat panel detectors?)
- Liner Materials & Thicknesses
- Weld Types
  - Longitudinal Seam
  - Circumferential
  - Dome
  - Boss
- Technique Specifics

2) Radiographic Inspection of Liners for Damage and Buckling.

- Reference existing ASTM specifications for X-ray and/or Radioscopy/Real Time
- X-ray Techniques
  - Planar
  - Tangential
- Damage Locations
  - Liner Walls
  - Dome Sections
- Technique Specifics

Liner Writing Teams

- Dye Penetrant: Castner, Parker
  - Collingwood (E07.03 liaison)
- Radiography: TBD (Engel, interim lead)
  - Kropas-Hughes (E7-01 liaison)
- Eddy Current: Wincheski, Williams
  - Washabaugh (E07.07 liaison)
- Acoustic Emission: Hamstad, Gorman (performed before wrapping)
  - Carlos (E07.04 liaison)
- Profilometry (Saulsberry)
- Ultrasound: TBD (Westinghouse, JPL?)
  - Ruddy (E07.06 liaison)
- Magnetic Particle: ?
  - Washabaugh (E07.07 liaison)
- Thermography: TBD (Shepard, Koshti?)
  - Clausing (E07.10 liaison)

WK 29034

Standard Practice
for Examination of the Composite Overwrap in Filament Wound Pressure Vessels Used in Aerospace Applications by Nondestructive Testing

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ASTM WK29034

(What is a Work Item? / How to Input to a Work Item)

Work Item: ASTM WK29034 - New Practice for Examination of the Composite Overwrap in Filament Wound Pressure Vessels Used in Aerospace Applications by Nondestructive Testing

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1. Scope

1.1 This Practice discusses nondestructive testing (NDT) methods for detecting flaws, defects, and accumulated damage in filament wound pressure vessels, also known as composite overwrapped pressure vessels (COPVs), used in aerospace applications. In general, these vessels have metal liner thicknesses less than 2.3 mm (0.090 in.), and fiber loadings in the composite overwrap greater than 60 percent by weight. 1.2 Although this Practice focuses on COPVs used at ambient temperature, it also has relevance to 1) composite pressure vessels (CPVs), 2) monolithic metallic pressure vessels, and 3) COPVs and CPVs used at cryogenic temperatures. 1.3 This Practice applies to 1) low pressure COPVs used for storing liquid propellants at maximum allowable working pressures (MAWPs) up to 35

Work Item Status:
Date Initiated: 06-01-2010
Technical Contact: Jess Waller

Status: Draft Under Development

Standards Tracker

Standards Subscriptions

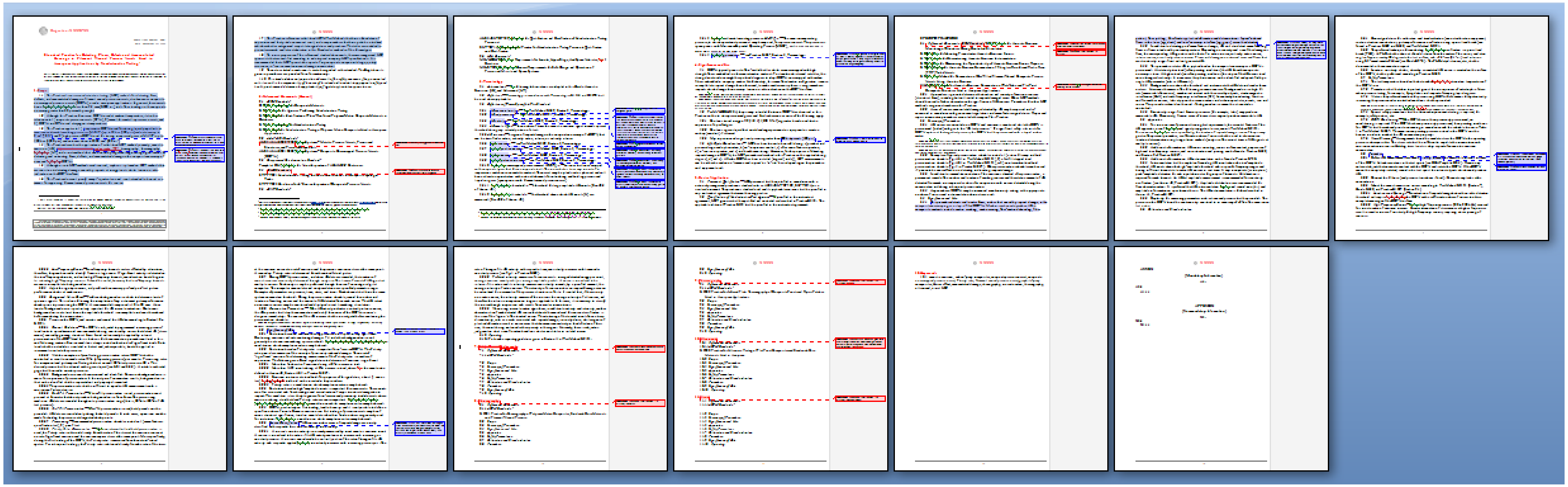
WK 29034 Goals

- Select A-list of NDE Methods
- Select writing Teams, writing team POCs, and begin writing

WK 29034 Candidate NDE Methods for COPV Overwraps

- A-List:
  - nothing exists that meets 90/95 POD currently
    - Acoustic Emission
    - Radiography
    - Shearography
    - Thermography
    - Ultrasound
    - Visual
- B-List:
    - Eddy Current (only applicable to conductive graphite fiber reinforced COPVs)

WK 29034 Boiler Plate Draft Exists



- Procedural NDE detail needs to be added specific to COPVs

WK 29034 Considerations

- The new Standard may have a manufacturing or end-user bias, NDE prerogatives will differ
  - need to inspect liner before wrapping or after autofrettage places responsibility on COPV manufacturers
  - need to periodically inspect liner during service places responsibility on end user
- In other words, the Standard could focus on any one of the following areas during the life cycle of the COPV:

  (a) product and process design and optimization

  (b) on-line process control

  (c) after manufacture inspection

  (d) in-service inspection

  (e) health monitoring

WK 29034 Composite Overwrap NDE

- COPV manufacturer NDE used during:
  - (a) product and process design and optimization
  - (b) on-line process control
  - (c) after manufacture inspection (post-proof)
- End User NDE used during:
  - (c) after manufacture inspection (receiving or pre-installation inspection)
  - (d) in-service inspection
  - (e) health monitoring

WK 29034 Overwrap Writing Teams

- Acoustic Emission: Hamstad (WK12759, E 2533)
  - Gorman (Digital Wave Corp., ASME STP-PT-021)
  - Newhouse (Lincoln Composites)
  - Walker (MSFC), Waller (WSTF), Madaras (LaRC)
  - Carlos (E07.04 liaison)
- Radiography: TBD (Engel, Ellegood, WSTF)
  - Kropas-Hughes (E7-01 liaison)
- Shearography: Newman
  - Clausing (E07.10 liaison)
- Thermography: Shepard, Koshti
  - Clausing (E07.10 liaison)
- Ultrasound: (Djordjevic, James)
  - Ruddy (E07.06 liaison)

WK 29034 Invited Participation

- Other NASA
  - JSC (Forth, Ray)
  - MSFC (Walker, Russell)
- Other COPV Manufacturers:
  - Arde (Sneddon)
  - ATK (Turner, Seles)
  - HyperComp (Patterson)
  - Cobham/Carleton (Harris)
  - Lincoln Composites (Newhouse)
- Commercial Aerospace
  - Lockheed (Nightingale)
  - Microcosm
  - Scaled Composites
  - Space X