

TRISMAC 2015 Trilateral FTF



Qualification of Products Fabricated via Additive Manufacturing Using Nondestructive Evaluation

May 21, 2015

Jess Waller, NASA WSTF

Brad Parker, NASA GSFC

Ken Hodges, NASA GSFC

James Walker, NASA MSFC

Doug Wells, NASA MSFC

Eric Burke, NASA LaRC

Ed Generazio, NASA LaRC

Evgueni Todorov, EWI

Alex Price, BSI

Steve James, Aerojet Rocketdyne

Ben Dutton, MTC

ESA-ESRIN Frascati, Italy

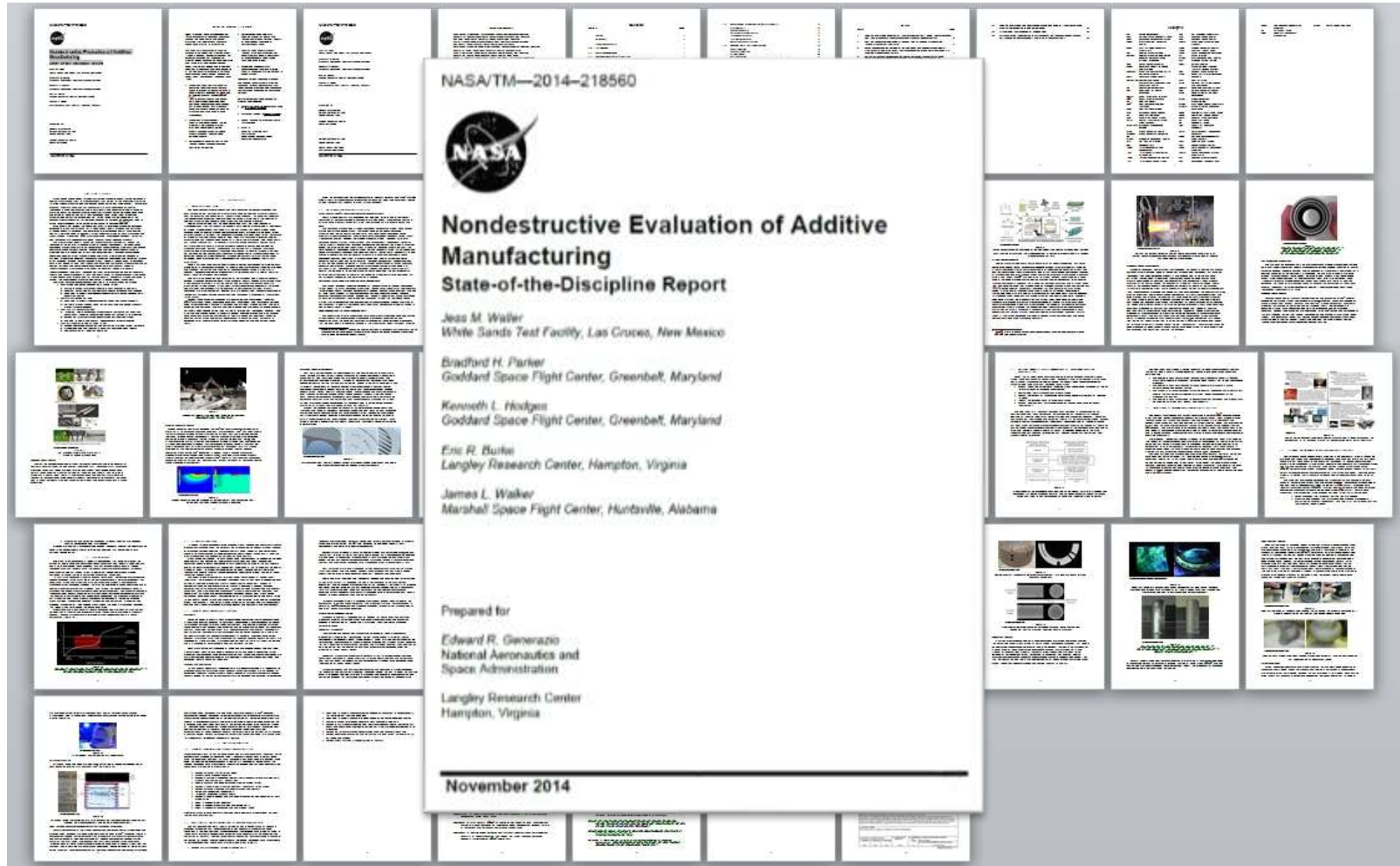
Virtual 16:10:00-16:25:00

NASA and non-NASA Players: NDE of Additive Manufacturing

- Workshops and technical interchange meetings attended by NASA have identified NDE as a universal need for all aspects of additive manufacturing.



- NASA/ESA/JAXA have an opportunity to push the envelope on ground-based manufacturing of lightweight design-to-constraint parts, and space-based manufacturing of flight spares and replacement hardware crucial for long-duration missions.



Industry, government and academia have been actively solicited to share their NDE experience relative to additive manufacturing



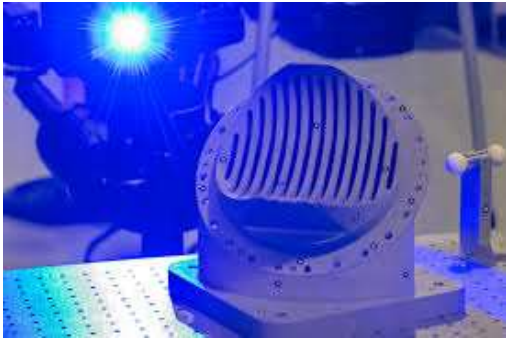
NASA/TM-2014-218560

Acknowledgements

Jose Carlos S. Abesamis, Jet Propulsion Laboratory, Pasadena, California
Eric R. Burke, NASA Langley Research Center, Hampton, Virginia
Kenneth C. Cheung, NASA Ames Research Center, Moffett Field, California
Ben Chin, NASA Ames Research Center, Moffett Field, California
Justin S. Jones, NASA Goddard Space Flight Center, Greenbelt, Maryland
Ajay Koshti, NASA Johnson Space Center, Houston, Texas
Christopher B. Kostyk, NASA Armstrong Flight Research Center, Palmdale, California
Richard E. Martin, NASA Glenn Research Center, Cleveland, Ohio
Lynn J. Rothschild, NASA Ames Research Center, Moffett Field, California
Richard W. Russell, NASA Kennedy Space Center, KSC, Florida
Regor L. Saulsberry, NASA White Sands Test Facility, Las Cruces, New Mexico
Miles Skow, NASA Kennedy Space Center, KSC, Florida
David M. Stanley, NASA Johnson Space Center, Houston, Texas
John A. Slotwinski, National Institute of Science and Technology, Gaithersburg, Maryland
Karen B. Taminger, NASA Langley Research Center, Hampton, Virginia
LaNetra C. Tate, NASA STMD, Washington, DC
Michael C. Waid, NASA Johnson Space Center, Houston, Texas



NASA Agency Activity



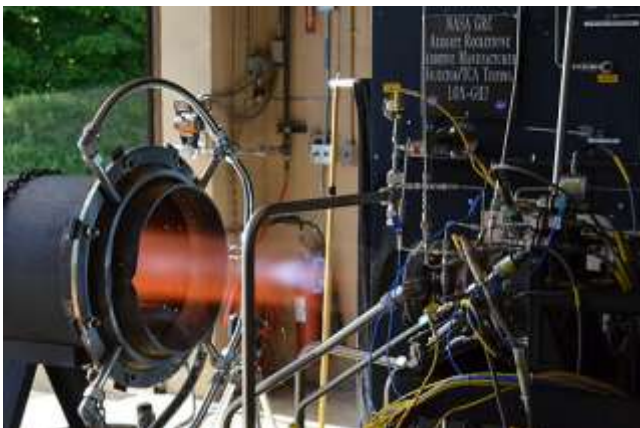
Inconel Pogo-Z baffle for RS-25 engine for SLS



Reentrant titanium tube made by AM for a cryogenic thermal switch for the ASTRO-H Adiabatic Demagnetization Refrigerator



EBF3 system during parabolic flight testing



Hot-fire testing of RL-10 engine copper alloy thrust chamber assembly and injector



Prototype titanium to niobium gradient rocket nozzle



Metallic Aerospace Components

NASA's rocket injectors manufactured with traditional processes would take more than a year to make, but with these new 3D printing processes, the parts can be produced in less than four months, with a **70 percent reduction in cost**.



28 element Inconel 625 fuel injector built using SLM process

Using traditional manufacturing methods, **163 individual parts** would be made and then assembled. But with 3-D printing technology, **only two parts were required**, saving time and money and allowing engineers to build parts that enhance rocket engine performance and are less prone to failure.





Metallic Aerospace Components

“Through 3D printing, robust and high-performing engine parts can be created at a fraction of the cost and time of traditional manufacturing methods,”

“It’s a very complex engine, and it was very difficult to form all the cooling channels, the injector head, and the throttling mechanism. Being able to print very high strength advanced alloys ... was crucial to being able to create the SuperDraco engine as it is.” said Elon Musk.¹

Compared with a traditionally cast part, the strength, ductility, fracture resistance, and variability in materials properties of a printed part must be verified and validated.



SpaceX SuperDraco combustion chamber for Dragon V2 made from Inconel using the DMLS process



¹ <http://www.newspacejournal.com/2014/05/30/spacex-unveils-its-21st-century-spaceship/>



Metallic Aerospace Components

GE will install 19 fuel nozzles into each Leading Edge Aviation Propulsion (LEAP) jet engine manufactured by CFM International, which is a joint venture between GE and France's Snecma. **CFM has orders for 6000 LEAPs.**

Lighter in weight – the weight of these nozzles will be **25% lighter** than its predecessor part.

Simpler design – reduced the number of brazes and welds **from 25 to 5.**

New design features – more intricate cooling pathways and support ligaments will result in **5X higher durability** vs. conventional manufacturing.

"Today, post-build inspection procedures account for as much as 25 percent of the time required to produce an additively manufactured engine component," said Greg Morris, GE Aviation's business development leader for additive manufacturing. "By conducting those inspection procedures while the component is being built, (we) will expedite production rates for GE's additive manufactured engine components like the LEAP fuel nozzle."



GE Leap Engine fuel nozzle. CoCr material fabricated by direct metal laser melting (DMLM), GE's acronym for DMLS, SLM, etc.



NDE Challenges

- Complex geometry
- As-built rough surface finish
- Variable and complex grain structure
- Undefined critical defect types, sizes and shapes
- Lack of effect-of-defect studies
- Lack of physical reference standards
- Lack of written inspection procedures for AM processes
- Lack of probability of detection (POD) data
- Lack of mature In process monitoring techniques



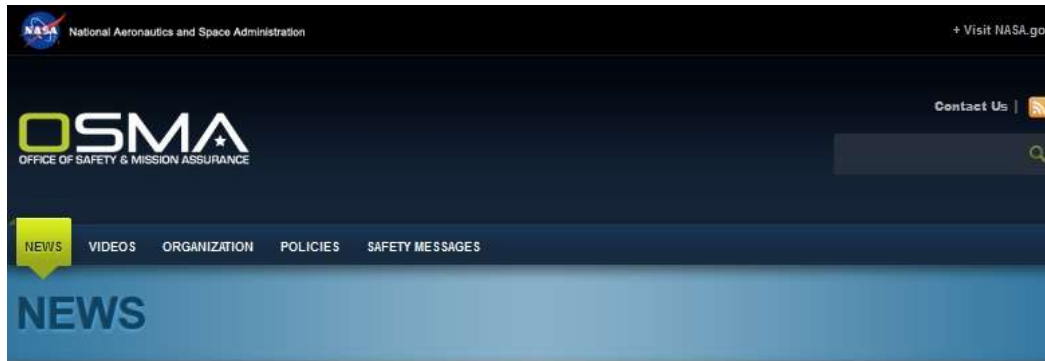
NDE Recommendations

- Develop **ASTM E07-F42 standards** for NDT of AM parts
- Develop **in-process NDT** to improve feedback control, to maximize part quality and consistency, and to obtain certified parts that are ready-for-use directly after processing
- Develop **post-process NDT** of finished parts
- Apply NDT to **understand effect-of-defect**, and establish acceptance limits for certain defect types and defect sizes
- Fabricate physical reference standards to verify/validate NDT data
- Apply NDT to understand scatter in design allowables database generation activities
- Develop better physics-based process models using and corroborated by NDT
- Develop **NDT-based qualification and certification protocols** for flight hardware that rely on testing and modeling

NASA OSMA Publicity of NDE of AM Effort



<https://sma.nasa.gov/news/news/2015/03/04/nasa-explores-nde-options-for-evaluating-additively-manufactured-parts>



Search News

Recent Posts



NASA Explores NDE Options for Evaluating Additively Manufactured Parts

Mar 04, 2015



SMA Leadership Profile: Greg Blaney

Mar 02, 2015



SMA Discussion Forum: Counterfeit Parts Avoidance, Part II

Feb 18, 2015



NASA Explores NDE Options for Evaluating Additively Manufactured Parts

Mar 04, 2015

Although Additive Manufacturing (AM) has been around for decades, increasing awareness of the significant benefits of flying 3D printed parts and using 3D printers in space has pushed NASA and the aerospace industry to take a close look at how to evaluate and certify AM parts to assure safety and mission success.

"[With 3D printing], you can print an entire part," explained LaNetra Tate, principal investigator for NASA's Space Technology Mission Directorate. "With traditional methods you can build, inspect, build, inspect, but with 3D printing, you're doing it in one swoop. We need to understand how we are going to verify and qualify and certify these parts."

AM has the potential to produce lighter parts, enhance the strength and reliability of materials, create less waste, reduce up-mass, and ultimately result in cost savings. However, there is a significant challenge in utilizing these promising parts — the most readily performed methods for evaluating 3D printed parts are



Certification (Doug Wells)

Doug Wells at MSFC has put together several sets of charts on the Certification process for Powder Bed Fusion AM Parts, the following information is from Doug's presentations.

Certification is the affirmation by the program, project, or other reviewing authority that the verification and validation process is complete and has adequately assured the design and as-built hardware meet the established requirements to safely and reliably complete the intended mission.

Certification process has two parts:

Design Certification

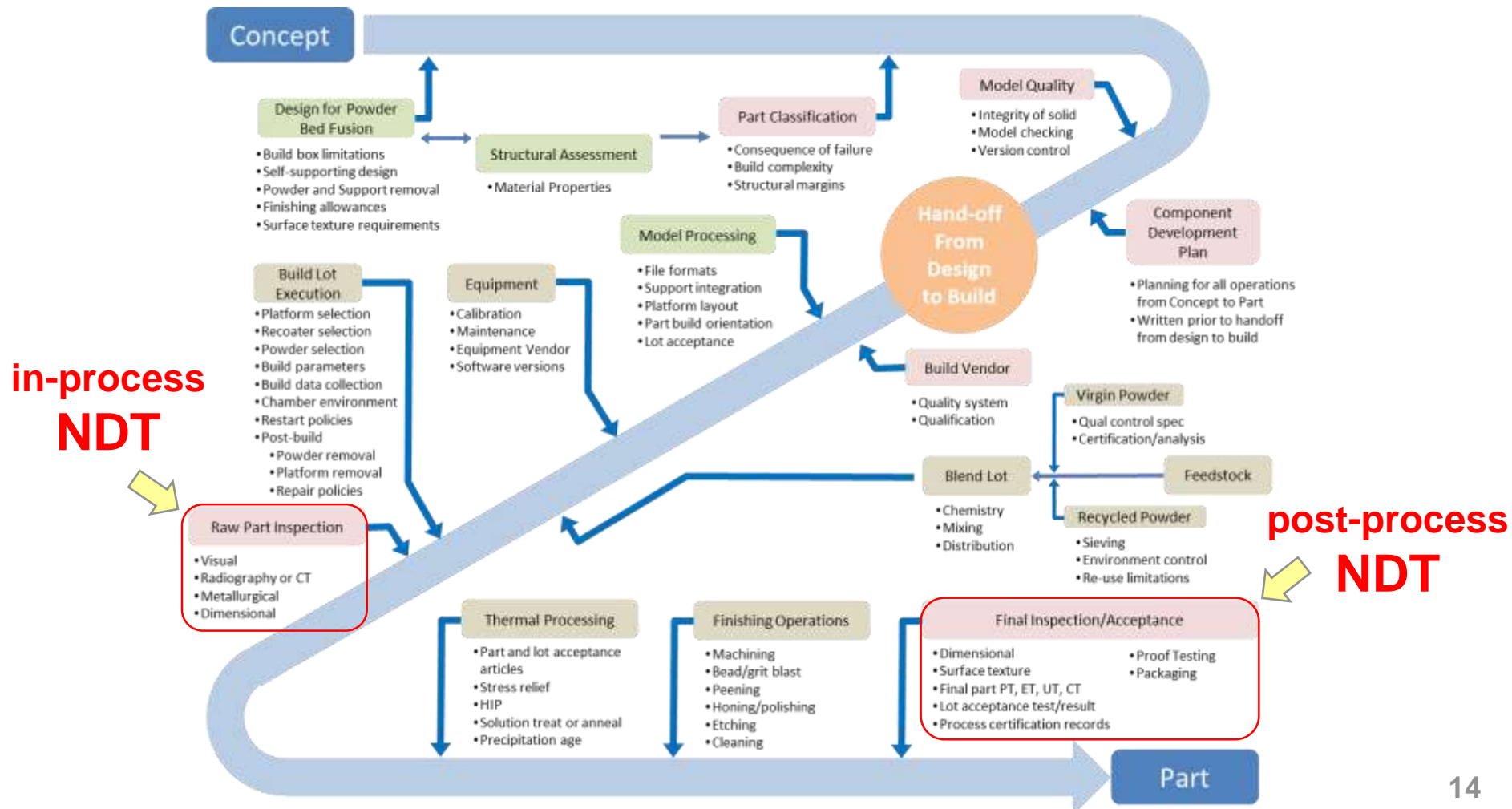
Design certification is a stand-alone event that typically occurs at the completion of the design process, but prior to use, or following a significant change to the design, understanding of environments, or system behavior.

As-built Hardware Certification

Hardware certification occurs throughout the life-cycle of the hardware to ensure fabricated hardware fully meets the intent of the certified design definition at the time of flight. All hardware in the flight system will have verification of compliance leading to final Certification of Flight Readiness (CoFR).



Certification



Qualification and Certification



Announcement: Government Workshop on Additive Manufacturing (for metals)
conducted in conjunction with the 2015 AA&S / P-SAR Conferences
April 3, 2015

Location: The Baltimore Marriott Waterfront, Room Dover A/B

You are invited to attend the Government Workshop on Additive Manufacturing (for metals) that will take place on *Friday, April 3 2015 (8:00 am – 12:30 pm)* following the AA&S 2015 and P-SAR 2015 conferences in Baltimore, MD. *Attendance is limited to US government agencies.* The main focus of the Workshop will be on certification / qualification issues associated with AM components for Aerospace applications. Therefore, several agencies with certification and/or airworthiness responsibilities are invited to give their agency's "perspective" presentations that will be followed by a roundtable discussion. Workshop's scope / objectives and draft agenda are provided in the *Appendix* below.

**Organized by Rollie Dutton of the U.S. Air Force
and Michael Gorelik of the FAA**

Qualification and Certification



Technical Exchange on Coordination of Standards Development for Additive Manufacturing

October 7th and 8th, 2015

University Park, PA

Wednesday, October 7th

Session I: Opening Session with Presentations from Standards Organizations

General Assembly with All Participants:

- 1:00 Welcome and Introductory Remarks
- 1:10 ASTM Presentation with Discussion
- 1:50 SAE Presentation with Discussion
- 2:30 Break
- 3:00 ASME Presentation with Discussion
- 3:40 AWS Presentation with Discussion
- 4:20 ISO Presentation with Discussion
- 5:00 Adjourn Session I

Evening Reception and Networking Event



Thursday, October 8th

Session II: Presentations from User Perspectives

General Assembly with All Participants:

- 8:00 Presentation on Industry Perspective on Needs for Standards and Discussion
- 8:40 Presentation on NIST Perspective on Needs for Standards and Discussion
- 9:20 Presentation on Government Perspective of Needs for Standards and Discussion
- 10:00 Break
- 10:30 Presentation on Concepts for Performance Qualification and Discussion
- 11:10 Presentation on Material Property Data Bases and Discussion
- 11:50 Objective and Guidelines for Collaborative Session
- 12:00 Adjourn Session II

Collaboration Group A:

- 1:00 Dialogue on Coordination of U.S. Standards

Collaboration Group B:

- 1:00 Dialogue on Qualification and Certification

Session IV: Summaries and Discussion

General Summaries with All Participants:

- 3:30 Summary of Collaboration Group A and Discussion
- 4:15 Summary of Collaboration Group B and Discussion
- 5:00 Adjourn Technology Exchange

Organized by Shane Collins of Incodema
and Rich Martukanitz at PSU CIMP 3D

ASTM E07 Committee on Nondestructive Testing



All

LOGOUT

PRODUCTS & SERVICES | GET INVOLVED | ABOUT | NEWS Languages | Contact | Cart

Products and Services / Standards & Publications / Standards Products

- MyChoices
- MyCommittees
- MyAccount
- Invite A Colleague
- Join Additional Committees
- Drop Subcommittees
- Help

ASTM WK47031

Work Item: ASTM WK47031 - New Guide for Nondestructive Testing of Additive Manufactured Metal Parts Used in Aerospace Applications

Developed by Subcommittee: [E07.10](#) | Committee [E07](#) | Contact [Staff Manager](#)

Go to Collaboration Area

- [MORE E07.10 STANDARDS](#)
- [RELATED PRODUCTS](#)
- [COPYRIGHT/PERMISSIONS](#)

Work Item Status

Date Initiated:
08-14-2014

Technical Contact:
Jess Waller

Status:
Draft Under Development

Recommended

2015 Committee Weeks In Anahelm

- Network with industry representatives
- No registration fee to attend for members and non-members.

1. Scope

1.1 This Guide discussed the use of established and emerging nondestructive testing (NDT) procedures used during the life cycle of additive manufactured metal parts. 1.2 The parts covered by this Guide are used in aerospace applications; therefore, the inspection requirements for discontinuities and inspection points will in general be different and more stringent than for vessels used in non aerospace applications. 1.3 The metals under consideration include but are not limited to ones made from aluminum alloys, titanium alloys (Ti-6Al-4V), nickel-based alloys, cobalt-chromium alloys, and stainless steels. NOTE The combustion and ignition properties of finished part need to be taken into account for safe use in aerospace applications. 1.4 Protocols for controlling input materials, and established processes and post-process methods are cited whenever possible. The processes under consideration include but are not limited to Electron Beam Free From Fabrication (EBF3), electron beam melting (EBM), Direct Metal Laser Sintering (DMLS), and Selective Laser Melting (SLM). 1.5 This Guide does not establish or recommend procedures for NDT of additive manufactured metal parts made in space. 1.6 The Guide describes the application of established and emerging NDT procedures used during and after the additive manufacturing process; namely, Computed Tomography (CT, Section 7), Eddy Current Testing (ECT, Section 8), Infrared Thermography (IR, Section 9), Neutron Diffraction (Section 10), Penetrant Testing (PT, Section 11), Process Compensated Resonant Testing (PCRT, Section 12), Structured Light (SL, Section 13), and Ultrasonic Testing (UT, Section 14 including Phased Array Ultrasonic Testing (PAUT)). These procedures can be used by cognizant engineering organizations for detecting and evaluating flaws and defects during and after fabrication.. These procedures can be used by cognizant engineering organizations for detecting and evaluating flaws and defects during and after fabrication. 1.7 This Guide describes established practices that have a foundation in experience, and new practices that have yet to be validated. The latter are included to promote research and later elaboration in this Guide as methods of the former type. 1.8 This Guide does not specify accept-reject criteria to be used in procurement or used as a means for approving additively manufactured parts for service. Any acceptance criteria specified are given solely for purposes of refinement and further elaboration of the procedures described in this

Current WK47031 NDE on AM Draft



Currently assembling writing teams of NDE SMEs



Current ASTM WK47031 Scope

1. Scope

1.1 This Guide discusses the use of established and emerging nondestructive testing (NDT) procedures used during the life cycle of additive manufactured metal parts.

1.2 The parts covered by this Guide are used in aerospace applications; therefore, the inspection requirements for discontinuities and inspection points in general may be different and more stringent than for materials and components used in non-aerospace applications.

1.3 The metals under consideration include but are not limited to ones made from aluminum alloys, titanium alloys (Ti-6Al-4V), nickel-based alloys, cobalt-chromium alloys, and stainless steels.

NOTE — The combustion and ignition properties of finished parts need to be taken into account for safe use in enriched oxygen aerospace applications.

1.4 Protocols for controlling input materials, and established processes and post-process methods are cited whenever possible. The processes under consideration include but are not limited to Electron Beam Free Form Fabrication (EBF³), electron beam melting (EBM), Direct Metal Laser Sintering (DMLS), and Selective Laser Melting (SLM).

1.5 This Guide does not establish or recommend procedures for NDT of additively manufactured metal parts made in space.

1.6 The Guide describes the application of established and emerging NDT procedures used during (in-process NDT) and after (post-process NDT) the additive manufacturing process; namely, Computed Tomography (CT, [Section 7](#)), Eddy Current Testing (ECT, [Section 8](#)), Infrared Thermography (IR, [Section 9](#)), Neutron Diffraction ([Section 10](#)), Penetrant Testing (PT, [Section 11](#)), Process Compensated Resonant Testing (PCRT, [Section 12](#)), Radiologic Testing (RT, [Section 13](#)), Structured Light (SL, [Section 14](#)), and Ultrasonic Testing (UT, [Section 15](#), including Phased Array Ultrasonic Testing (PAUT)). This guide provides insight and recommendations that can be used by cognizant engineering organizations for detecting and evaluating flaws and defects during and after fabrication.

1.7 This Guide is based largely on established practices contained in ASTM Section 3 Volume 03.03 Nondestructive Testing, while also evaluating new practices that have yet to be

NDT SMEs
being sought



Current ASTM WK47031 Members

PCRT	Eric Biedermann	-505-338-2576	ebiedermann@vibrantndt.com		
	John Brausch	937-656-9151	john.brausch@us.af.mil		
	Damaso Carreon	405-734 1882	damaso.carreon@US.AF.MIL	✓	USAF
	Terry Clausing	513-831-9625	TERRYC@VIRTUALSPECTRUM.COM	✓	
ISO TC 261	Ian Cooper	+441639873100	Ian.Cooper@twi.co.uk	✓	
	Michael Dragon	513-552-4521	michael.dragon@ae.ge.com	✓	GE Aerospace
	Jim Engel	714-896-3203	jim.engel@boeing.com	✓	Boeing
	David Geis	-847-657-5300	dgeis@magnaflux.com	✓	
	Timothy Holmes	-314-615-6921	tim.holmes@lickenbrocktech.com	✓	
	Patrick Howard	513-5524646	PATRICK.HOWARD@GE.COM	✓	GE Aerospace
PCRT	Lemna Hunter	-505-314 1488	LHUNTER@VIBRANTNDT.COM		
	Steve James	818-586-0243	steve.james@rocket.com	✓	Aerojet
	Ken LaCivita	937-255-3590	kenneth.lacivita@wpafb.af.mil	✓	USAF
	Kathleen McClung	610-832-9717	kmcclung@astm.org	✓	
	Marianne McKeever	610-832-9723	mmckeeve@astm.org	✓	
	Charles Nichols	5753124136	charles.nichols@nasa.gov		
LMCO	Jerome Rownd	303-971-9281	jerome.c.rownd@lmco.com		
Honeywell	Surendra Singh	602-231-7028	surendra.singh@honeywell.com	✓	
	Gerben Sinnema	-0715654642	gerben.sinnema@esa.int	✓	ESA
Former NIST	John Slotwinski	240-228-7769	john.slotwinski@jhuapl.edu	✓	
	James Walker	256-961-1784	james.l.walker@nasa.gov	✓	NASA
	Jess Waller (Technical Contact)	575-5245249	Jess.M.Waller@nasa.gov	✓	NASA

Approach: Incorporate U.S. Air Force Expertise and Findings



AFRL-RX-WP-TR-2014-0162

**AMERICA MAKES: NATIONAL ADDITIVE
MANUFACTURING INNOVATION INSTITUTE (NAMII)**
Project 1: Nondestructive Evaluation (NDE) of Complex Metallic
Additive Manufactured (AM) Structures

Evgueni Todorov, Roger Spencer, Sean Gleeson, Madhi Jamshidinia, and Shawn M. Kelly
EWI

JUNE 2014
Interim Report

Distribution A: Approved for Public Release; Distribution is unlimited.
See additional restrictions described on inside page.

AIR FORCE RESEARCH LABORATORY
MATERIALS AND MANUFACTURING DIRECTORATE
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7750
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

Evgueni Todorov, et al., did a superb job on an initial handling of NDE and AM.

Document has a ranking system based on complexity to direct NDE of AM efforts.

Early results on NDE application to AM are documented.

Approach for future work based on CT and PCRT.

Approach: Incorporate U.S. Air Force Expertise and Findings



While most NDE techniques are applicable to complexity Groups[§] 1 (Simple Tools and Components) and 2 (Optimized Standard Parts), and some to 3 (Embedded Features), only PCRT and xCT would be applicable to Groups 4 (Design to Constraint Parts) and 5 (Free-Form Lattice Structures):

1



2



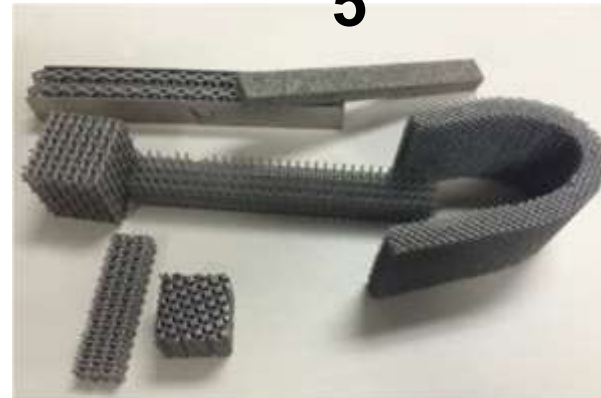
3



4



5



§ O. Kerbrat, P. Mognol, J.Y. Hascoet, "Manufacturing Complexity Evaluation for Additive and Subtractive Processes: Application to Hybrid Modular Tooling", IRCCyN (Institut de Recherche en Communications et Cybernétique de Nantes), MO2P Team1 rue de la Noë, BP 92101, 44321, Nantes Cedex 03, France., pp 519-530, September 10, 2008

Approach: Incorporate U.S. Air Force Expertise and Findings



Application of NDE techniques to complexity Groups 1-5

NDE Technique	Geometry Complexity Group					Comments
	1	2	3	4	5	
VT	Y	Y	P ^(c)	NA	NA	
LT	NA	NA	Y	Y	NA	Screening
PT	Y	Y	P ^(a)	NA	NA	
PCRT	Y	Y	Y	Y	Y	Screening; size restrictions (e.g., compressor blades)
EIT	Y	Y	NA	NA	NA	Screening; size restrictions
ACPD	Y	Y	P ^(c)	NA	NA	Isolated microstructure and/or stresses
ET	Y	Y	P ^(c)	NA	NA	
AEC	Y	Y	P ^(c)	NA	NA	
PAUT	Y	Y	P ^(b)	NA	NA	
UT	Y	Y	P ^(b)	NA	NA	
RT	Y	Y	P ^(d)	NA	NA	
X-Ray CT	Y	Y	Y	Y	NA	
X-ray Micro CT	Y	Y	Y	Y	Y	

Key:

Y = Yes, technique applicable

P = Possible to apply technique given correct conditions

NA = Technique Not applicable

Notes:

(a) Only surfaces providing good access for application and cleaning

(b) Areas where shadowing of acoustic beam is not an issue

(c) External surfaces and internal surfaces where access through conduits or guides can be provided

(d) Areas where large number of exposures/shots are not required

Approach: Incorporate BSI Expertise (A. Price)



Table 1: NDT method

In-process:	Ultrasonic	Infrared	Visual inspection	Thermal cameras	
Post-process:	Ultrasonic	X-ray	Vibro-acoustic	3D x-ray CT	Process Compensated Resonance Testing

Table 2: NDT standards

Ultrasonic
BS EN 1330-4:2010. Non-destructive testing. Terminology Terms used in ultrasonic testing
BS EN ISO 16810:2014. Non-destructive testing. Ultrasonic testing. General principles
BS EN ISO 16827:2014. Non-destructive testing. Ultrasonic testing. Characterization and sizing of discontinuities
Infrared
BS ISO 10878:2013. Non-destructive testing. Infrared thermography. Vocabulary
Visual Inspection
BS ISO 3058:1998. Non-destructive testing. Aids to visual inspection. Selection of low-power magnifiers
BS 7910:2013. Guide to methods for assessing the acceptability of flaws in metallic structures
Thermal cameras
No standards found
X-ray
BS EN 12543-1:1999. Non-destructive testing. Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing Scanning method
Vibro-acoustic
BS EN ISO 10846-1:2008. Acoustics and vibration. Laboratory measurement of vibro-acoustic transfer properties of resilient elements Principles and guidelines
3D x-ray CT
ASTM E2767 - 13. Standard Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for X-ray Computed Tomography (CT) Test Methods
Process Compensated Resonance Testing
ASTM E2534 - 10. Standard Practice for Process Compensated Resonance Testing Via Swept Sine Input for Metallic and Non-Metallic Parts

Courtesy of
Alex Price
Lead
Programme
Manager



“UK side
happy to
collaborate”

NDE Detection of Typical AM Defects





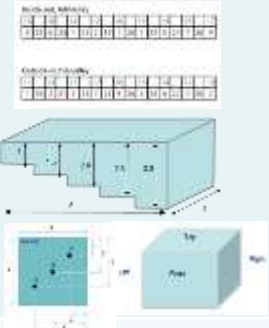
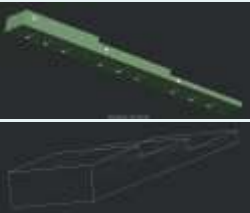



Defect/effect on part	Issue	Why	In-process detection	Post process detection	Comments
Porosity/due to unconsolidated powder	Incomplete powder feed	Powder run out Bridging of powder in the hopper / poor flow properties	Yes - check if powder is flowing from the feed hopper	Difficult to detect	HIP recoverable
Layer/(large area)	"Drags" (lines) in powder layer	Agglomerated powder or contamination	Vision system Laser scanning of layer	Very difficult to detect	HIP recoverable
Layer/unconsolidated powder	Poor fusing due to interruption to laser/EBM delivery	Interruption to powder supply, optics systems errors (laser) or errors in data.	View fusing using IR cameras or back scatter methods	Difficult – very difficult to detect depending on magnitude	HIP recoverable
(localised area)	Incorrect laser/EBM power	Incorrect choice of parameters Uncontrolled change in laser /EBM power	Yes – if have in-line measurement of power	Tell tale signs on the part provided that the effect is not transient	Should be a relatively easy fix
Layer shift/ unconsolidated powder (large or small areas)	Layer shift	SLM –scan head/optics problems EBM – presence of EMF Build platform shift	Beam sensors may reduce the risk but best method is to compare the laser or EBM trace with the desired slice pattern	Usually easy as part has step on surface (but localised defects may go unnoticed)	
Over or under melted material	Contamination of powder (interstitials)	New powder out of spec or degraded through reuse	Almost impossible	Check powder at end of process and mechanical properties / level of contamination of fused parts	Need to check the powder before use
Inclusion/steps in part	Contamination of powder (foreign body)	Debris from AM or post processing equipment	Almost impossible	Depends on the nature of the contamination May be able to detect using ultrasound / Xray/ Xray-CT	Remove all potential sources of contamination Sieve / analyse powder to check
Reduced mechanical properties (may get higher modulus but lower elongation)	Incorrect scaling/beam offset	Scaling/offset factors are effected by part geometry , beam intensity and the density of the powder bed	Difficult Need method of very accurately tracking the position of the laser/EBM or the edge of the consolidated powder	Just measure the part Or benchmark	
	Incorrect scan strategy	Poor selection of parameters Errors in the precision of beam delivery	May be difficult to detect –can be quite subtle but leads to major defects . Sometime shows as gaps/holes in the layer as it is being formed – this could be detected by IR monitoring	Depends on the nature of the contamination May be able to detect using ultrasound / Xray/ Xray-CT	
Porosity/depends on the type of contamination	Gas-atomised powder particles	Contain entrapped gas bubbles	Almost impossible	Could be observed by OM or SEM but difficult to be distinguished from other types of pores	HIP recoverable
Poor accuracy	Poor localised layer surface quality	Localised disturbance of molten pool/lack of molten material feeding at some localised area	Almost impossible	Could be detected by OM or SEM	HIP recoverable
voids/ unconsolidated powder	Development of high internal stress in some types of materials	Heavily alloyed material or materials with composition that couldn't accommodate high residual stress	May be detected by IR monitoring	Visible or could be detected by OM/SEM/X-ray/X-ray CT	Depends on material. Some of them could be fixed by HIP

NASA

Physical Reference Standards



	MSFC-GRC	GSFC	LaRC	JSC-LaRC	KSC
AM process method	DMLS	DMLS (metal), LS (plastic)	LS	EBF ³	EBM
alloys	titanium, Inconel, and aluminum	titanium, SS PH1, vero-white RGD835	SS	titanium	titanium
reference standard geometries			<p>Conventional:</p>  <p>AM (planned):</p> 	<p>wrought (JSC) and AM (LaRC):</p> 	<p>2nd iteration (AM):</p>  <p>future (AM):</p> 
features interrogated	complex geometries; large/thick/dense and very thin cross sections; (universal NDE standard, slabs, rods, gage blocks)	rectangular prisms, rows of cylinders, cylinders, flat-bottom holes, cone	steps, flat bottom holes	bead arrays, steps, holes	36 printed in-holes beginning at surface; 9 printed in-spheres internal to the part; cold plate (future)
AM defects interrogated	porosity/unfused matl. (restart, skipped layers), cracks, FOD, geometric irregularities	hole roughness and flatness/centricity	porosity, lack of fusion	grain structure, natural flaws, residual stress, microstructure variation with EBF ³ build parameters	internal unfused sections
NDE method(s) targeted	post-process 2 MeV and μ CT; PT, RT, UT, ET	post-process ? MeV CT	post-process ? MeV CT	post-process UT, PAUT	in-process NDE, not UT
Comments	collaboration with MSFC AM Manufacturing Group & Liquid Engines Office	flat IQI not suitable due to 3D CT artifacts	x-ray CT LS step wedge	Transmit-Receive Longitudinal (TRL) dual matrix arrays	collaboration with CSIRO

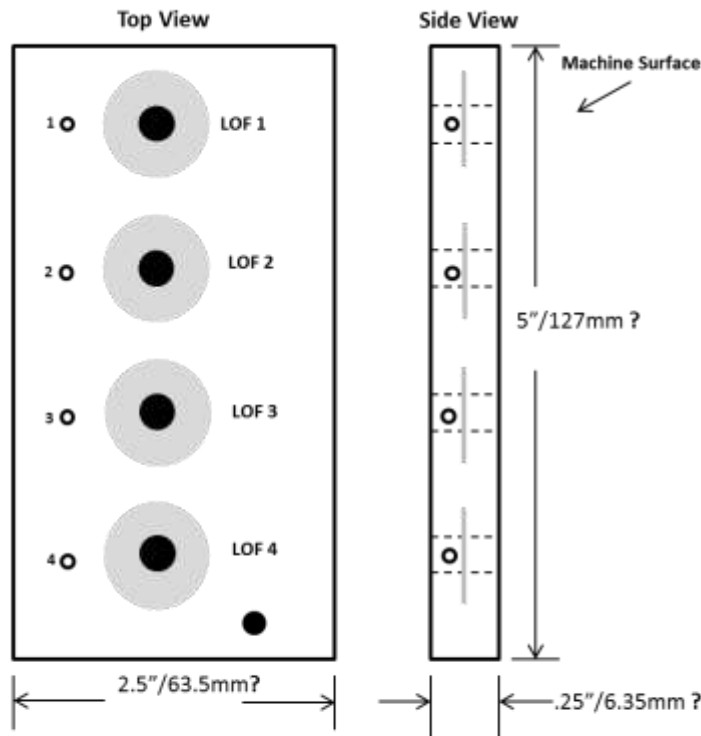
WK47031 Round-Robin Test Physical Reference Standards (S. James)







Proposed ASTM F42.01 standard:

Standard Guide for Determining Non-Destructive Inspection (NDI) Detection Limits for Additively Manufactured (AM) Parts Via Intentional Seeding Of Defects

Multi Use Sample (MUS)



-  Area (.75"/19.05mm dia.) of Lack of Fusion for RT, UT, ET
-  Through Hole for ET .25"/6.35mm
-  FBH for UT
-  Pores 1 - 4

Artifact Lack of Fusion	Depth	Diameter	Orientation to build direction
LOF 1	1% of Thickness or 1 layer x 1/4t	TBD	0°
LOF 2	2% of Thickness or 2 layers x 1/4t	TBD	0°
LOF 3	3% of Thickness or 3 layers x 1/4t	TBD	0°
LOF 4	4% of Thickness or layers x 1/4 t	TBD	0°

Artifact	Diameter
Pore 1	.5% of t
Pore 2	1% of t
Pore 3	1.5% of t
Pore 4	2% of t

WK47031 Round Robin Test Goal



- The goal is to fabricate consistent parts using controlled materials and processes (F42), which are then distributed to various labs for a round-robin study.
- The NDE capability of the various labs is assessed internally and compared to external labs to establish both repeatability and reproducibility.
- The detectability of intentionally added AM flaws type and sizes is then evaluated for down-selected consensus NDE methods.
- Ultimately, the goal is to determine repeatability and reproducibility, generate Precision & Bias statements that can be used in accept-reject (i.e., an ASTM Test Method) and as a *means to qualify and certify AM flight hardware* used in space applications.



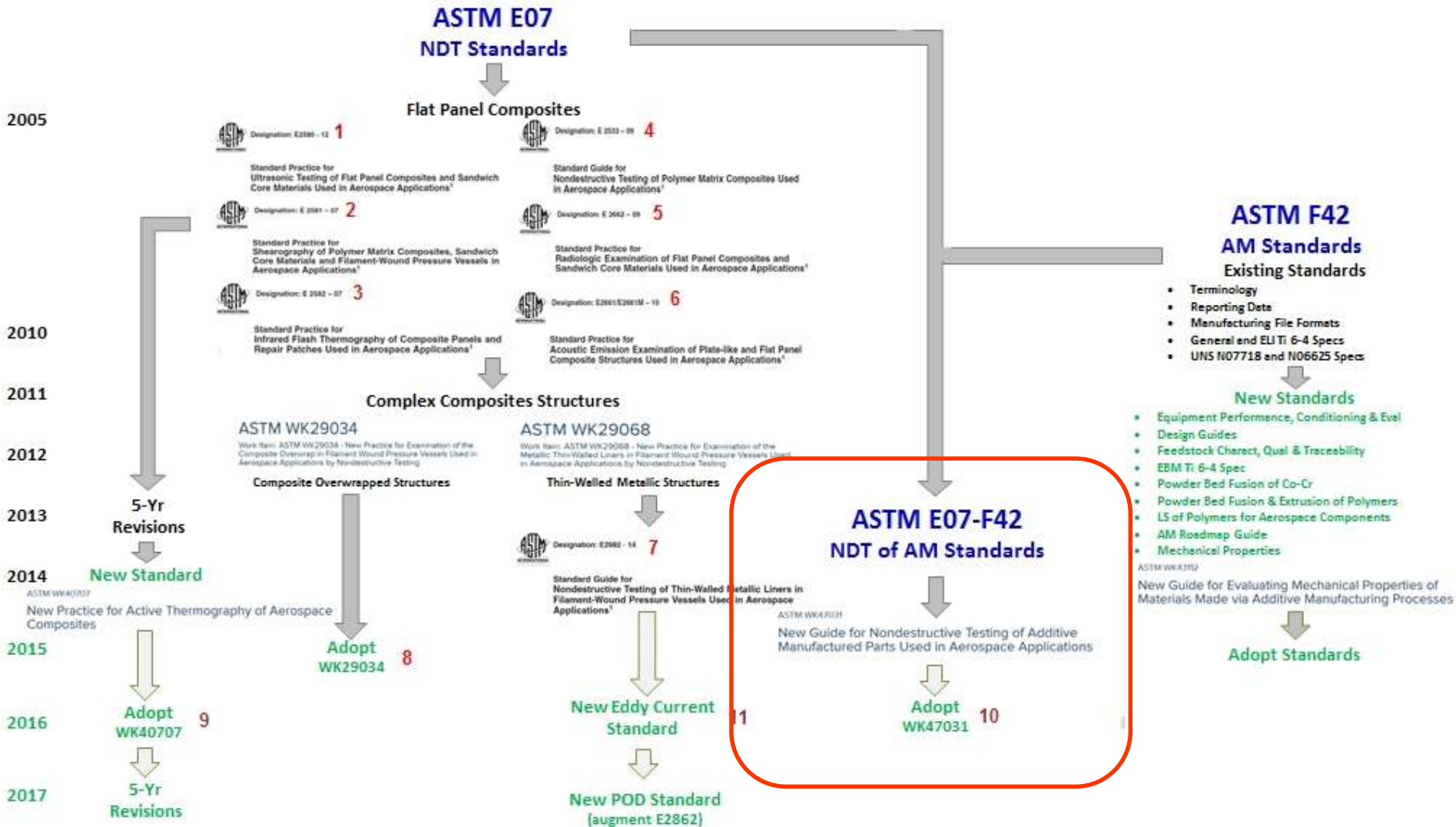
Back-up



Gap Analysis: NDE's Role

- Lack of design allowables. NDE should be performed on test specimens to help correlate data scatter to build variability (effect of defects).
- Lack of in-process NDE. IR thermal imaging of melt zone and high speed visual imaging to validate defect free fabrication process.
- Development of post processing protocols. Before and after NDE to confirm effectiveness of post processing techniques.
- Build-to-build and machine-to-machine repeatability. NDE for part dimensioning and defect detection.
- Qualification and Certification. Robust NDE techniques to screen for critical defects.

ASTM E07-F42 NDE of AM Parts Standard



Approach: Incorporate U.S. Air Force Expertise and Findings



NDE Technique	Common Acronym	Material and Flaw Types Detected	Surface or Interior	Global Screening or Detect Location
Visual Testing	VT	In any solid material, any condition and/or defect affecting visual light reflection.	Surface	Detects and images location
Leak Testing	LT	Solid material. Discontinuities.	Through thickness	Detects location
Liquid Penetrant Testing	PT	Any solid material. Discontinuities - cracks, pores, nicks, others.	Surface breaking	Detects and images location
Process Compensated Resonance Testing	PCRT	Any solid material. Any defect or condition.	Surface and subsurface	Global screening
Impedance computed tomography or Electrical impedance tomography	ICT or EIT	In electrically conductive material, any condition and/or defect affecting electrical conductivity.	Surface and subsurface	Detects and images location
Alternate Current Potential Drop	ACPD	In electrically conductive material, any condition and/or defect affecting electrical conductivity.	Surface and subsurface	Detects location
Eddy Current Testing	ET	In electrically conductive material any condition and/or defect affecting electrical conductivity, magnetic permeability and/or sensor-part juxtaposition	Surface and slightly subsurface	Detects location

- **Optical Method (OM)**
- **parts where liquid/gas leak tightness reqd.**
- **post-machining reqd., line of sight issues**
- **ASTM E2534**
- **correlate R , σ with mechanical props**
- **correlate σ with microstructure and residual stresses**
- **measurement of compressive elastic stresses by peening**

Approach: Incorporate U.S. Air Force Expertise and Findings



NDE Technique	Common Acronym	Material and Flaw Types Detected	Surface or Interior	Global Screening or Detect Location
Array Eddy Current Testing	AEC	In electrically conductive material any condition and/or defect affecting electrical conductivity, magnetic permeability and/or sensor-part juxtaposition	Surface and slightly subsurface	Detects and images location
Phase Array Ultrasonic Testing	PAUT	In any solid material, any condition and/or defect affecting sound attenuation, propagation, acoustic velocity and/or sensor-part juxtaposition.	Surface and subsurface	Detects and images location
Ultrasonic Testing	UT	In any solid material, any condition and/or defect affecting sound attenuation, propagation, acoustic velocity and/or sensor-part juxtaposition.	Surface and subsurface	Detects location
Radiographic Testing	RT	In any solid material, any condition and/or defect affecting X-ray absorption.	Surface and subsurface	Detects and images location
X-Ray Computed Tomography	X-Ray CT	In any solid material, any condition and/or defect affecting X-ray absorption.	Surface and subsurface	Detects and images location
Microfocus X-Ray Computed Tomography	X-ray MicroFCT	In any solid material, any condition and/or defect affecting X-ray absorption.	Surface and subsurface	Detects and images location

fast scanning of large areas with minimal sweeps

surface adaptive UT for complex shapes, use advanced time reversal focusing algorithms

influenced by microstructure, grain size, anisotropy

inspection of Group 1 and 2, and limited application for 3

broad in-house NASA capability

ASTM E07 Committee on Nondestructive Testing



All Search topic, title, ...

MYASTM

Get Involved / Technical Committees / Committee E07

Technical Committees

Membership

Students & Professors

Meetings & Symposia

Committee E07 on Nondestructive Testing

Staff Manager: [Kathleen McClung](#) 610-832-9717

ASTM Committee E07 on Nondestructive Testing was formed in 1938. E07 meets twice a year, in January and June, with approximately 100 members attending four days of technical meetings and concludes on the fifth day with a plenary session of the Main Committee. The Committee, with a membership of over 400, currently has jurisdiction of over 175 standards, published in October in the Annual Book of ASTM Standards; Volume 03.03. E07 has 12 technical subcommittees that maintain jurisdiction over these standards. Information on this subcommittee structure and E07's portfolio of approved standards and Work Items under development are available from the List of Subcommittees, Standards and Work Items below. These standards have, and continue to play, a preeminent role in all aspects relating to traditional and emerging methodologies for Radiology (X, Gamma and Neutron), Liquid Penetrant, Magnetic Particle, Acoustic Emission, Ultrasonics, Electromagnetics, Leak Testing, and Reference Radiological Images.

Recommended



ASTM Proficiency Testing: improve your lab's performance

Meet accreditation requirements, compare your performance with other labs, document your expertise.

ASTM F42 Committee on Additive Manufacturing Technologies



All



PRODUCTS & SERVICES | GET INVOLVED | ABOUT | NEWS

Languages | Contact | Cart

Get Involved / Technical Committees / Committee F42

- Technical Committees
- Membership
- Students & Professors
- Meetings & Symposia

Committee F42 on Additive Manufacturing Technologies

Staff Manager: [Pat Picariello](#) 610-832-9720

ASTM Committee F42 on Additive Manufacturing Technologies was formed in 2009. F42 meets twice a year, usually in January and July, with about 70 members attending two days of technical meetings. The Committee, with a current membership of approximately 215, has 4 technical subcommittees; all standards developed by F42 are published in the Annual Book of ASTM Standards, Volume 10.04. Information on the F42 subcommittee structure, portfolio of approved standards, and Work Items under development, is available from the List of Subcommittees, Standards and Work Items below. These standards will play a preeminent role in all aspects of additive manufacturing technologies.



See all ASTM Intl. videos at [YouTube](#)

America Makes Member Organizations



3D Systems Corporation*

3M
Alcoa
Allegheny Technologies Incorporated*
Applied Systems and Technology Transfer (AST2)*
Arkema, Inc.
ASM International
Association of Manufacturing Technology*
Bayer Material Science*
The Boeing Company
Carnegie Mellon University*
Case Western Reserve University*
Catalyst Connection*
Concurrent Technologies Corporation*
Deformation Control Technology, Inc.
DSM Functional Materials
Energy Industries of Ohio*
EWI
The ExOne Company*
General Electric Company (GE)*
General Dynamics Ordnance and Tactical Systems
Hoeganaes Corporation
Illinois Tool Works, Inc.
Johnson Controls, Inc.*
Kennametal*
Kent Display*
Lehigh University*
The Lincoln Electric Company

Lockheed Martin*

Lorain County Community College
M-7 Technologies*
MAGNET*
Materion Corporation
MAYA Design Inc.
Michigan Technological University
Missouri University of S&T
MIT Lincoln Laboratory
Moog, Inc.
NorTech*
North Carolina State University
Northern Illinois Research Foundation
Northrop Grumman*
Ohio Aerospace Institute*
Optomec*
Oxford Performance Materials*
Pennsylvania State University*
PTC ALLIANCE
Raytheon Company*
Rhinestahl Corporation
Robert C. Byrd Institute (RCBI)*
Robert Morris University*
RP+M
RTI International Metals, Inc. *
SABIC
Sciaky, Inc.
SME*
Solid Concepts
South Dakota School of Mines & Technology

Stony Creek Labs

Stratasys, Inc.
Strategic Marketing Innovations, Inc.
Stratronics*
TechSolve*
Texas A&M University
The Timken Company*
Tobyhanna Army Depot
United Technologies Research Center
University of Akron*
University of California, Irvine
University of Connecticut
University of Dayton Research Institute
University of Louisville
University of Maryland – College Park
University of Michigan Library
University of Pittsburgh*
University of Texas – Austin
University of Texas at El Paso
University of Toledo
USA Science and Engineering Festival
Venture Plastics, Inc.
Westmoreland County Community College*
West Virginia University
Wohlers Associates, Inc.*
Wright State University
Youngstown Business Incubator*
Youngstown State University*
Zimmer, Inc.

Lead Members listed in RED(\$200K)

Full Members listed in BLUE (\$50K)

Supporting Members in BLACK (\$15K)

* Original Members (39)



ASTM WK47031

Round-Robin Test Distribution



Affiliation	NDE Interest	Industry Group Members & Affiliation	Phone Number	Email Address	notes	WK 47031 CA member
ASTM	admin	Caitlin Farrell		cfarrell@astm.org	ASTM ILS coordinator	
ASTM E07	AE	Mark Carlos, ASTM, Mistras Group		Mark.Carlos@mistrasgroup.com	ASTM E07 member	
ASTM E07	admin	Terry Clausing, ASTM, Chair E07.10	513-831-9625	TERRYCL@VIRTUALSPECTRUM.COM	ASTM E07 staff	Y
ASTM E07	admin	Kate McClung, ASTM E07	610-832-9717	kmcclung@astm.org	ASTM E07 staff	Y
ASTM E07	admin	Marianne McKeever, ASTM E07	610-832-9723	mmckeeve@astm.org	ASTM E07 staff	Y
ASTM E07	UT	Michael Ruddy, ASTM E07.06 Chair		Michael.Ruddy@nov.com	ASTM E07 member	
ASTM E07	ECT	Andrew Washabaugh, ASTM, MIT		Washabaugh@alum.MIT.edu	ASTM E07 member	
ASTM F42	admin	Pat Picariello, ASTM F42		PPicariello@astm.org	ASTM F42 staff	
DOE	general interest	Blake Marshall	202.586.2367	Blake.Marshall@EE.Doe.Gov	Advanced Manufacturing Office, EERE, doesn't target	
DOE	ND	Thomas Watkins		watkinstr@ornl.gov	ND NDE, NIST-ORNL effort	
EDU	CT/RT	Griffin Jones			PSU CIMP-3D NDE expert	
EDU	CT/RT	Rich Martukanitz		rxm44@psu.edu	PSU CIMP-3D	
EDU	general AM	John Slotwinski, F42.01 Test Methods Chair	240-228-7769	john.slotwinski@jhuapl.edu	ASTM F42 member, ISO TC 261	Y
EDU	NIR	Thomas L. Starr	(502) 852-1073	tom.starr@louisville.edu	Univ. of Louisville	
ESA		Johannes Gumpinger		Johannes.Gumpinger@esa.int	ESA	
ESA		Laurent Pambaguian		Laurent.Pambaguian@esa.int	ESA	
ESA	general NDE	Gerben Sinnema	715654642	gerben.sinnema@esa.int	ESA	Y
EU	NIR	V. Carl		Carl@t-zip.de		
EU	ND	Mike Curtis-Rouse	Sci. & Technol. Facilities Council	mike.curtis-rouse@stfc.ac.uk	AM ND NDE	
EU		Michel Janssens	Materialize		AM TQM, FE models	
EU		Fernanado Lasagni	CATEC		NDE of AM Launchers	
EU		Florent Lebrun	Thales Alenia Space		AM process qualification	
EU		Jorge Vilanova	Airbus		NDE of AM Launchers	
EU	MET	Wim Cuypers	GOM Branch Benelux	w.cuypers@gom.com	AM QC, ATOS 3D Digitizer	
EU		Nikolai Zaepernick	EOS		EOSTATE QA	
EU, EADS	NDT expert	Andre Droese	EADS	andre.droese@astrium.eads.net	EADS, NDE expert in Vorel's Group	
EU, EADS	CT/RT, PT	Amy Glover	EADS	Amy.GLOVER@astrium.eads.net	EADS, AM quality of Airbus brackets	
Industry, AEROJ		Jeff Haynes, Aerojet Rocketdyne	561-882-5322	Jeffrey.Haynes@Rocket.com		
Industry, AEROJ	UT	Steve James, Aerojet Rocketdyne	818-586-0243	steve.james@rocket.com	ASTM E07 member	Y
Industry, AEROJ		Vic Marconcini, Aerojet Rocketdyne	1(916) 355-4338	victor.marconcini@Rocket.com	ASTM E07 member	
Industry, AEROJ		Keith Randolph, Aerojet Rocketdyne	818-586-7996	Keith.Randolph@rocketdyne.com		
Industry, AEROJ	RT/PT	Richard Stiff, Aerojet Rocketdyne	818-596-1325	Richard.Stiff@rocketdyne.com		
Industry, Boeing	RT/UT/PT	Jim Engel, Boeing	714-896-3203	jim.engel@boeing.com	ASTM E07 member	Y
Industry, Boeing	RT/UT/PT	Joe Gabris, Boeing		Joseph.j.gabris@boeing.com	ASTM E07 member	

ASTM WK47031

Round-Robin Test Distribution



Affiliation	NDE Interest	Industry Group Members & Affiliation	Phone Number	Email Address	notes	WK 47031 CA member
Industry, EWI		Evgueni Todorov, EWI		etodorov@ewi.org	Lead Author AFRL-RX-WP-TR-2014-0162	
Industry, GE		Michael Dragon	513-552-4521	michael.dragon@ae.ge.com	ASTM E07 member	Y
Industry, GE		Pat Howard	513.552.4646	patrick.howard@ge.com	Consulting Engineer - Nondestructive	Y
Industry, Honeyw	UT/PCRT/PT/RT	Surendra Singh, Honeywell	602-231-7028	surendra.singh@honeywell.com	ASTM E07 member	Y
Industry, Incoden	general AM	Shane Collins, F42.05 Materials & Processes Chair		scollins@incodema3d.com	ASTM F42 member	
Industry, LMCO	UT	Jerome Rownd, LMCO	303-971-9281	jerome.c.rownd@lmco.com	ASTM E07 member	Y
Industry, SpaceX		Holley Doucette		Holley.Doucette@spacex.com	SpaceX	
Industry, Vibrant	PCRT	Eric Biedermann, Vibrant Technologies Inc.	(505) 338-2576	ebiedermann@vibrantndt.com	ASTM E07 member	Y
Industry, Vibrant	PCRT	Lem Hunter, Vibrant Technologies Inc.	505-314-1488	LHUNTER@VIBRANTNDE.COM	ASTM E07 member	Y
ISO TC 261				jalbajez@unizar.es	ISO TC 261	
ISO TC 261		Ian Cooper	4.4164E+11	Ian.Cooper@twi.co.uk	ISO TC 261	Y
ISO TC 261		Christian Diller		c.diller@concept-laser.de	ISO TC 261	
ISO TC 261	CT/RT, UT, ECT	Ben Dutton	+44 (0)7753309184	ben.dutton@the-mtc.org	ISO TC 261	
ISO TC 261		Shannon P. Farrell, Ph.D.	902-427-3437	Shannon.Farrell@drdc-rddc.gc.ca	ISO TC 261	
ISO TC 261		Bastian Heymel, Voxeljet.de		bastian.heymel@voxeljet.de	ISO TC 261	
ISO TC 261		Alex Price, BSI Group		alex.price@bsigroup.com	ISO TC 261	
ISO TC 261		Martin Schaefer		martin.schaefer@siemens.com	ISO TC 261	
ISO TC 261	MET, CT/RT	Peter Woolliams	-020 8487 3839	Peter.woolliams@npl.co.uk	National Physical Laboratory, ISO TC 261, ASTM E07 m	
ISO TC 261		Lutz Wrede		lutz.wrede@din.de	ISO TC 261 Secretary	
JAXA		Mitsui Masami		mitsui.masami@jaxa.jp	JAXA	
JAXA		Kazuhiro Nakamura		nakamura.kazuhiro@jaxa.jp	JAXA, NDE of AM POC	
NASA-GRC	CT/RT, UT, PT	Rich Martin, NASA GRC	216.433.3684	richard.e.martin-1@nasa.gov	NNWG	
NASA-GSFC		Kenneth Hodges, NASA GSFC	301.286.4193	kenneth.l.hodges@nasa.gov	NNWG	
NASA-GSFC	CT/RT, ref.stds.	Justin Jones, NASA GSFC	301.286.4197	justin.s.jones@nasa.gov	NNWG	
NASA-GSFC	CT/RT, PT	Brad Parker, NASA GSFC	301.286.8548	bradford.h.parker@nasa.gov	NNWG	
NASA-JPL	CT/RT, UT	Scott Roberts, NASA JPL	818.354.5175	scott.n.roberts@jpl.nasa.gov	JPL SME, AI part post-processing, can connect to JPL N	
NASA-JSC	UT, CT/RT	Ajay Kosti, NASA JSC	281.483.0262	ajay.koshti-1@nasa.gov	NNWG	
NASA-JSC		David Stanley	281.483.5016	david.m.stanley@nasa.gov		
NASA-KSC		Rick Russell, NASA KSC	321.861.8618	richard.w.russell@nasa.gov	NNWG, Spacecraft and Launch Vehicle Specialty Engin	
NASA-KSC		Miles Skow	321.867.2857	miles.skow-1@nasa.gov		
NASA-LaRC	NIR, Qual and Cert	Eric Burke, NASA LaRC	757.864.7724	eric.r.burke@nasa.gov	NNWG	
NASA-LaRC		Elliot Cramer, NASA LaRC	757.864.7945	k.elliott.cramer@nasa.gov	NDE Liaison	
NASA-LaRC	general NDE	Ed Generazio, NASA LaRC	757.864.4968	edward.r.generazio@nasa.gov	NNWG Chair	
NASA-LaRC		Robert Hafley, NASA LaRC	757.864.8078	robert.a.hafley@nasa.gov	ASTM F42 member	

ASTM WK47031

Round-Robin Test Distribution



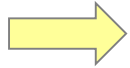
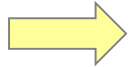
Affiliation	NDE Interest	Industry Group Members & Affiliation	Phone Number	Email Address	notes	WK 47031 CA member
NASA-LaRC	modeling	Cara Leckey	757.864.8622	cara.ac.leckey@nasa.gov		
NASA-LaRC	AM, EBF3, space-ba	Karen Taminger, NASA LaRC	757.864.3131	karen.m.taminger@nasa.gov	NAMWG, EBF3, LENS	
NASA-LaRC	NIR	Joseph Zalameda, NASA LaRC	757.864.4793	joseph.n.zalameda@nasa.gov		
NASA-MSFC		Mike Suits, NASA MSFC	256.544.8336	Mike.suits@nasa.gov	NASA MSFC	
NASA-MSFC	/RT, MET, ECT, ref.st	James Walker, NASA MSFC	256-961-1784	james.l.walker@nasa.gov	NNWG	Y
NASA-MSFC	Qual and Cert	Douglas Wells, NASA MSFC	256.544.3300	douglas.n.wells@nasa.gov	ASTM F42 member, wants to stay informed	
NASA-STMD	general interest	LaNetra Tate, NASA STMD	202.358.1071	lanetra.c.tate@nasa.gov	NASA STMD, AM Program Manager	
NASA-WSTF	general NDE	Charles Nichols, NASA WSTF	575-312-4136	charles.nichols@nasa.gov	NNWG	Y
NASA-WSTF	general NDE	Regor Saulsberry, NASA WSTF	575-635-7970	regor.l.saulsberry@nasa.gov	NNWG	
NASA-WSTF	general NDE	Jess Waller, NASA, ASTM WK 47031 Leader	575-524-5249	Jess.M.Waller@nasa.gov	ASTM E07, F42, NNWG	Y, POC
NASA-WSTF	admin	Jim Williams, NASA WSTF	575-524-5543	james.h.williams@nasa.gov	NASA export control	
NASA-WSTF	ompatibility of AM p	Jon Tylka	575.524.5762	jonathan.m.tylka@nasa.gov	NASA WSTF	
NESC NDE TDT	UT	Boro Djordjevic		bbd@mast-inc.com	add per recommendation of E. Generazio, ASTM E07 m	
NESC NDE TDT		George Matzkanin	(303) 926-0582	matzkanin@ntiac.com	add per recommendation of E. Generazio, ASTM E07 m	
NESC NDE TDT	Reliability/PT	Ward Rummel		wrum007@q.com	add per recommendation of E. Generazio	
NESC NDE TDT		Tom Yolken		tyolken@gmail.com	add per recommendation of E. Generazio	
NIST		Shawn Moylan, NIST	301-975-4352	shawn.moylan@nist.gov		
USAF		John Braush, US Air Force, Dayton	937-656-9151	john.brausch@us.af.mil	ASTM E07 member	Y
USAF	general interest	Charles Buynak		charles.buynak@wpafb.af.mil	TTCP TP1 (AM) National Lead	
USAF		Damaso Carreon, US Air Force Tinker AFB	405-734-1882	damasco.carreon@us.af.mil	ASTM E07 member	Y
USAF	general interest	Jennifer Fielding		jennifer.fielding@wpafb.af.mil	America Makes, former NAMII	
USAF		Ken LaCivita, US Air Force, Dayton	937-255-3590	kenneth.lacivita@wpafb.af.mil	ASTM E07 member	Y
USAF	general NDE	Eric Lindgren	(937) 255-6994	eric.lindgren@us.af.mil	Materials State Awareness and Supportability Branch	
USAF		Mike Paulk, US Air Force Tinker, AFB		michael.paulk.3@us.af.mil		
	Reliability	Jennifer Brown, Consultant		brown9095@comcast.net	ASTM E07 member, POD	
		Bharat Chaudhry, Thermal Wave	248-414-3730 ext. 303	bchaudhry@thermalwave.com		
		David Geis	1(847) 657-5300	dgeis@magnaflux.com	ASTM E07 member	Y
	UT	Ed Ginzal, Consultant		eginzel@mri.on.ca	ASTM E07 member	
		Timothy Holmes	314-615-6921	tim.holmes@lickenbrocktech.com	ASTM E07 member	Y
		Nadimpalli Karthik				
		Brandon Lee			from 2/11 meeting notes	
	Engineering	Nicholas Mule	818-586-3133	Nicholas.Mule@rocketdyne.com		
		Tom Nelligan		Thomas.Nelligan@olympusndt.com		
		Mark Warchol	+1.512.615.4476	mwarchol@tri-austin.com	ASTM E07 member	

ASTM ILS – Quantitative NDT Standard Test Method – Accept/Reject



Interlaboratory Study Program Precision and Bias

round-robin testing



Additional Information: [Ruggedness Testing](#) [Pilot Testing](#)

There are two measurements that serve to express precision in the evaluation of a standard test method. They are commonly referred to as "repeatability" and "reproducibility" and provide the boundaries between which precision exists.

- **Repeatability** - addresses variability between independent test results gathered from within a single laboratory (otherwise known as intralaboratory testing).
- **Reproducibility** - addresses variability among single test results gathered from different laboratories (otherwise known as interlaboratory testing).

Bias, on the other hand, is defined as a systematic error that contributes to the difference between the mean of a large number of test results and an accepted reference value. When included in a standard test method, this statement describes the bias and the methods utilized to provide corrected test results. It is important to remember that if an accepted reference value is not available, then the bias cannot be established. However, if the bias is unknown but the direction or bounds of the bias can be estimated, this information should be included in the bias statement.

As precision and bias are mandatory sections of an ASTM standard test method (per [Section A.21 Form and Style for ASTM Standards](#)), the utmost care should be taken to ensure that the final data, as well as the steps that were taken to generate the data, are as precise and accurate as possible. A standard test method that is incapable of doing what it purports can be misleading. Precision and bias statements strengthen the perceived validity of the standard test method and provide the user of the document with the added confidence of knowing that the standard test method has been laboratory tested.

ILS HOME

REGISTER A NEW ILS STUDY

RESEARCH REPORTS

FAQ

CONTACT

Target – Ultrasonic Sample (Multiple or 1 thickness) Compare Wrought to AM

Primarily used in thickness measurements

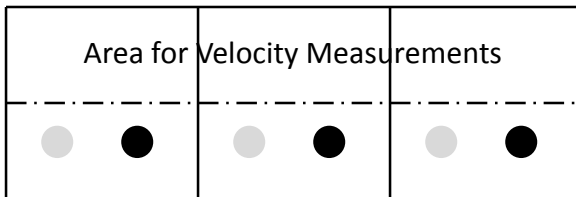
Conceptual Sketches

Stepped vs. One Thickness

Side View



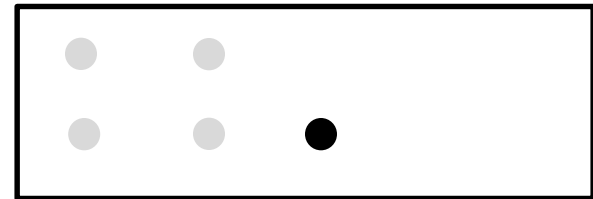
Top View



Side View



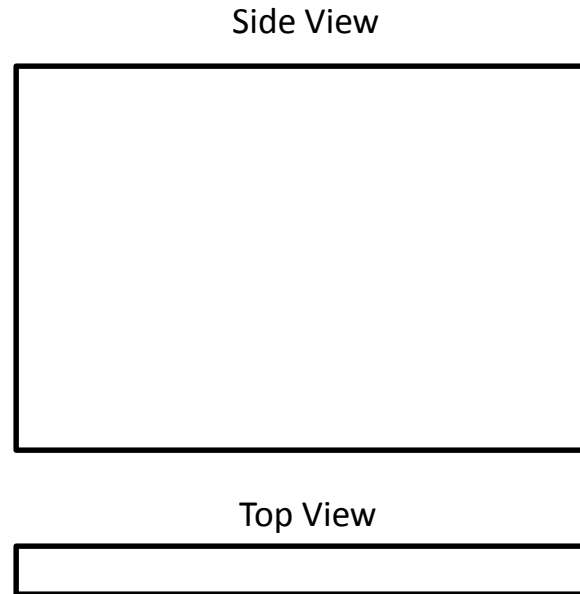
Top View



- Lack of Fusion Vary % of t
- Flat Bottom Hole

Same plane = Same & Different Mat 'l Thickness

Target – Penetrant Sample (Fatigue Crack or Surface Texture)



Sample uses Fracture Critical Penetrant Crack Panel Experience
An AM panel is fabricated in the orientation to be evaluated. Once built
The panel has an Electrode Discharge Machine (EDM) notch placed on one side
And cycled to grow a through crack for evaluation on the opposite side of
The EDM notch. This allows an evaluation of a tight crack on an as built surface or
The development/technical review of penetrant removal (high background issue)

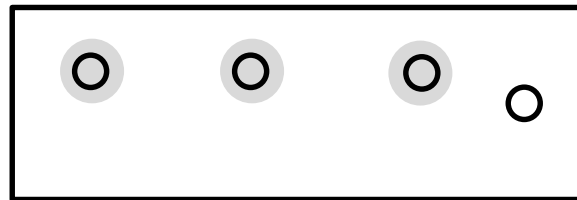
Target – Eddy Current Sample Compare EDM notches in Wrought to LOF conditions

Conceptual Sketch

Side View



Top View



- Lack of Fusion Vary % of t
- Drilled Hole

Approach: Incorporate European Union NDE of AM Expertise



- **Standardized Qualification Approach of Metallic Additive Manufacturing Processes**
Florent Lebrun, Beatrice Sandanassamy, THALES ALENIA SPACE
- **Ways to Aerospace Quality with Additive Manufacturing**
Udo Behrendt, EOS GmbH
- **Qualification of Additive Manufactured Structural Brackets for Space Applications**
Amy Glover, Andrew Bloyce, Airbus Defence and Space
- **On the Investigation of Processing Parameters and NDT Inspection on Additive Manufacturing Materials for Future Launchers**
Fernando Lasagni, Amadís Zorrilla, Antonio Periñán, Santos Tudela, CATEC – Center for Advanced Aerospace Technologies; Jorge Vilanova, AIRBUS DEFENCE & SPACE
- **Quality Control in Additive Manufacturing**
Evelien Winant, Wim Cuypers, GOM Branch Benelux
- **Total Quality Management for Additive Manufacturing**
Michel Janssens, Materialise
- **Neutron Diffraction NDT of Additive Manufactured Components**
Mike Curtis-Rouse, Joe Kelleher, STFC

*Partial list of presentations given at the Oct. 2014 ESA-sponsored
Workshop on Additive Manufacturing for Space Application*