The Resonating Realities of Single Sided Ultrasonic Inspection of Metal Bonded Assemblies

Airlines for America (A4A) Conference,

San Francisco, CA

September 23, 2014

Presented by Larry Culbertson

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Acknowledgements

- NORDAM Group Senior Leadership
  - Repair Division-Basil Barimo and Mark Greenhaw
  - Interiors and Structures- Phil Marshall and Darryl Graham
- NORDAM I&S MAUS Team
  - Technicians-Dan Bougher and Danny Stringfellow
  - Quality Engineer-Dave Fowler
- Boeing
  - Nancy Wood
- QNDT Services
  - Bryan Culbertson, Director of NDT Operations
  - Mark Warchol, Associate Level 3, WFAM
- NDT Solutions
  - Jesse Skramstad and Kevin Hulbert

Nondestructive Testing Introduction

- Quality control of aerospace bonded structures is utilized at all stages, from design to manufacture to in-service, including maintenance at the repair station level.
- Each specific NDT technique will detect a particular flaw(s). At present there is not one single NDT method which can determine the level of qualitative or quantitative value within an adhesive bond. Some methods yield better results based on the techniques and characteristics of the material and associated flaw. Some just because of accessibility issues.
- NDT is complex toolbox for engineers to insure the structural integrity which was designed into the components. The main objective is that the integrity remains throughout the predicated life of the component and that any defects that could affect the structural integrity of the part can be detected.

History

- Ultrasonic Resonance methods have been utilized for the inspection of adhesively bonded structures extensively and continuously valued dating back to early 1950s and is relied upon extensively through present day.
- At that time the use of adhesive bonding in metallic components of aircraft structure was limited to secondary structures and has increased dramatically to the point where most aircraft delivered today utilize some degree of adhesive bonding in primary structures.
- Recognizing that characteristics with metalbond durability, inspection consistency, process control variability, effects of defects and nondestructive inspection method tendencies has challenged our ability to reliably detect defects in adhesively bonded assemblies. Types of bonded joints are key to the degree of difficulty for inspection.

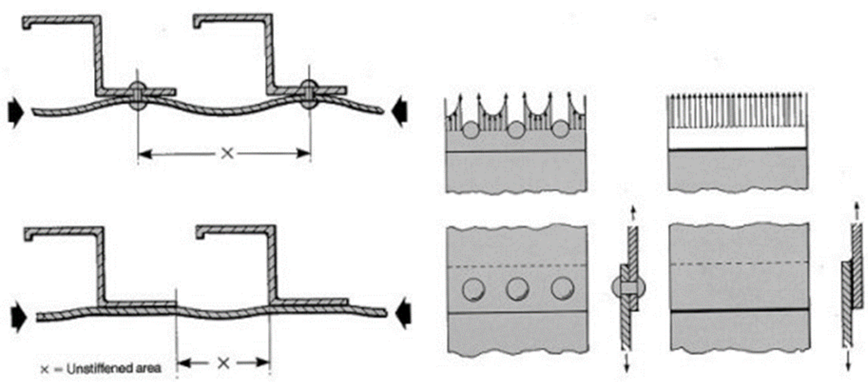
Resonating Realities of Resonance Inspection

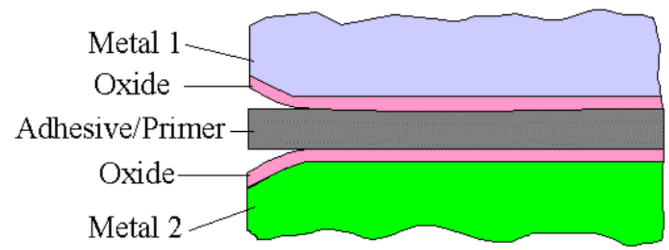
- This presentation will discuss metalbond fuselage configurations without mechanical fasteners and without honeycomb materials.
  - Typical Aluminum bonded structures discussed are;
    - Single metal to metal bondlines
    - Multiple material stack-ups with up to four bondlines.
    - Adhesive utilized is FM300 and the Aluminum substrates are processed using a Boric Sulfuric process with the application of a Phosphor Anodize and a BR 127 Adhesive Primer.
- Due to bonded configurations, the inspection approach was to employ the same inspection method utilized for production as the baseline for potential in-service inspections.
- We will not address the lack of nondestructive testing (NDT) methods that may be utilized for the detection of "kissing bonds" or "determining strength" of bonds.

This phenomenon is primarily based on the process controls of metal bonding.

Metalbond Design

- Design approach for metal bonds



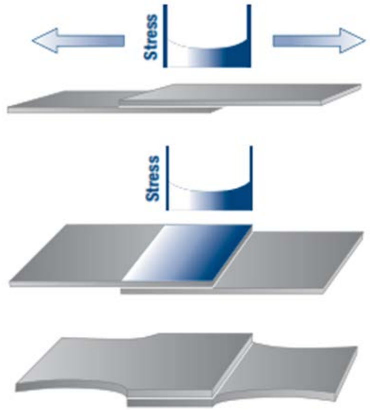


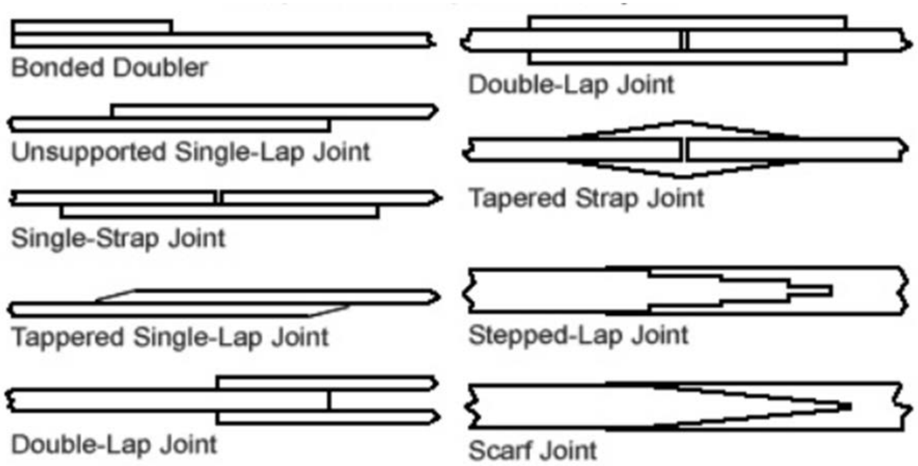
- Adhesive bonding gives a smooth appearance to designs, there are no protruding fasteners such as fasteners or rivets, along with no spot weld marks.
- The bonded structure is a safer structure because, fewer fasteners and less severe concentrations of stresses, fatigue cracks are less likely to occur. A fatigue crack in a bonded structure will propagate more slowly than in a riveted structure or even in a machined profile because the bond lines act as a crack dampener.

Bonding Configuration

- Structural bonding has been very important in the advancement of the of aircraft industry. Aluminum has been a major substrate for the outer skins, being while retaining strength and durability. Combining adhesive bonds and rivets has been a typical assembly construction to further optimize weight savings, strength, and durability.

- Adhesively bonding the metal components will disperse the loads over larger areas. Adhesives used in these applications include epoxy-based materials, often applied as a film. The surfaces are cleaned and primed prior to bonding and cure is typically accomplished in an autoclave.

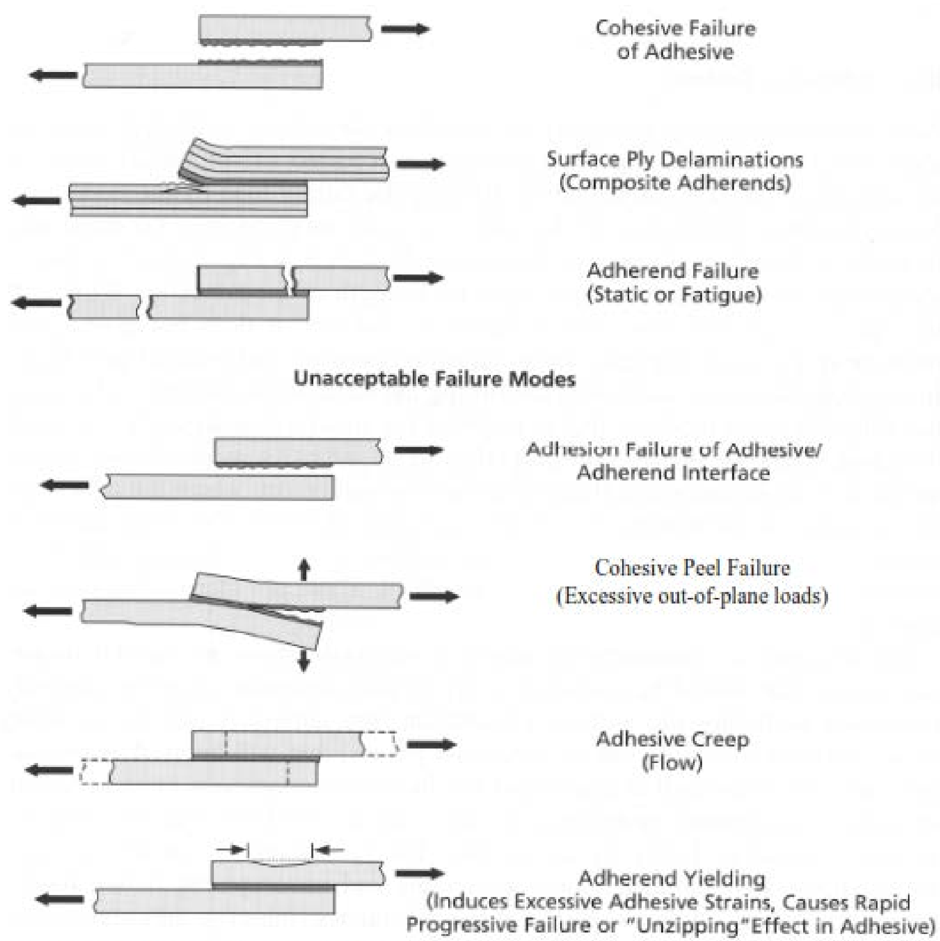




Typical Failure Modes

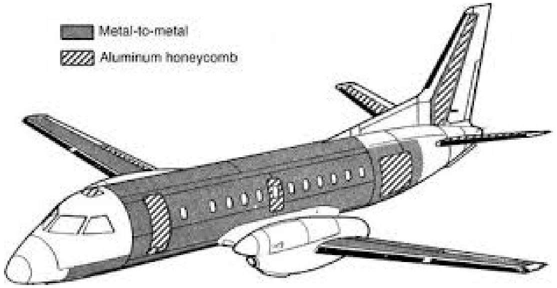
Failure of all test specimens should be examined.

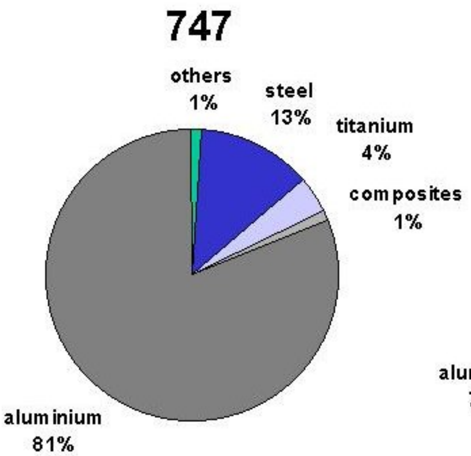
- An acceptable failure is cohesive failure, which is a rupture of the adhesive bond where the separation is within the adhesive.
- An unacceptable failure is adhesive failure, which is a rupture of the adhesive bond where the separation is at the adhesive-adherend interface, which could be an indication of a surface preparation problem.

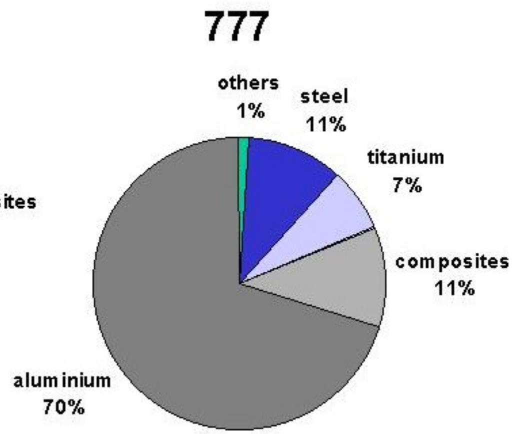


Failure Modes of Adhesively Bonded Joints (Campbell, 2006)

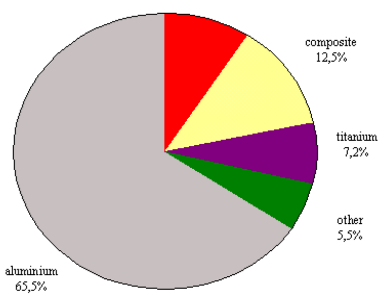
Utilization of Metalbonds



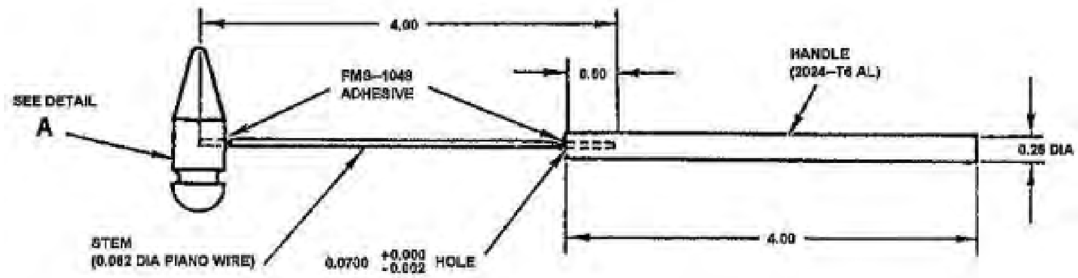




Airbus 320



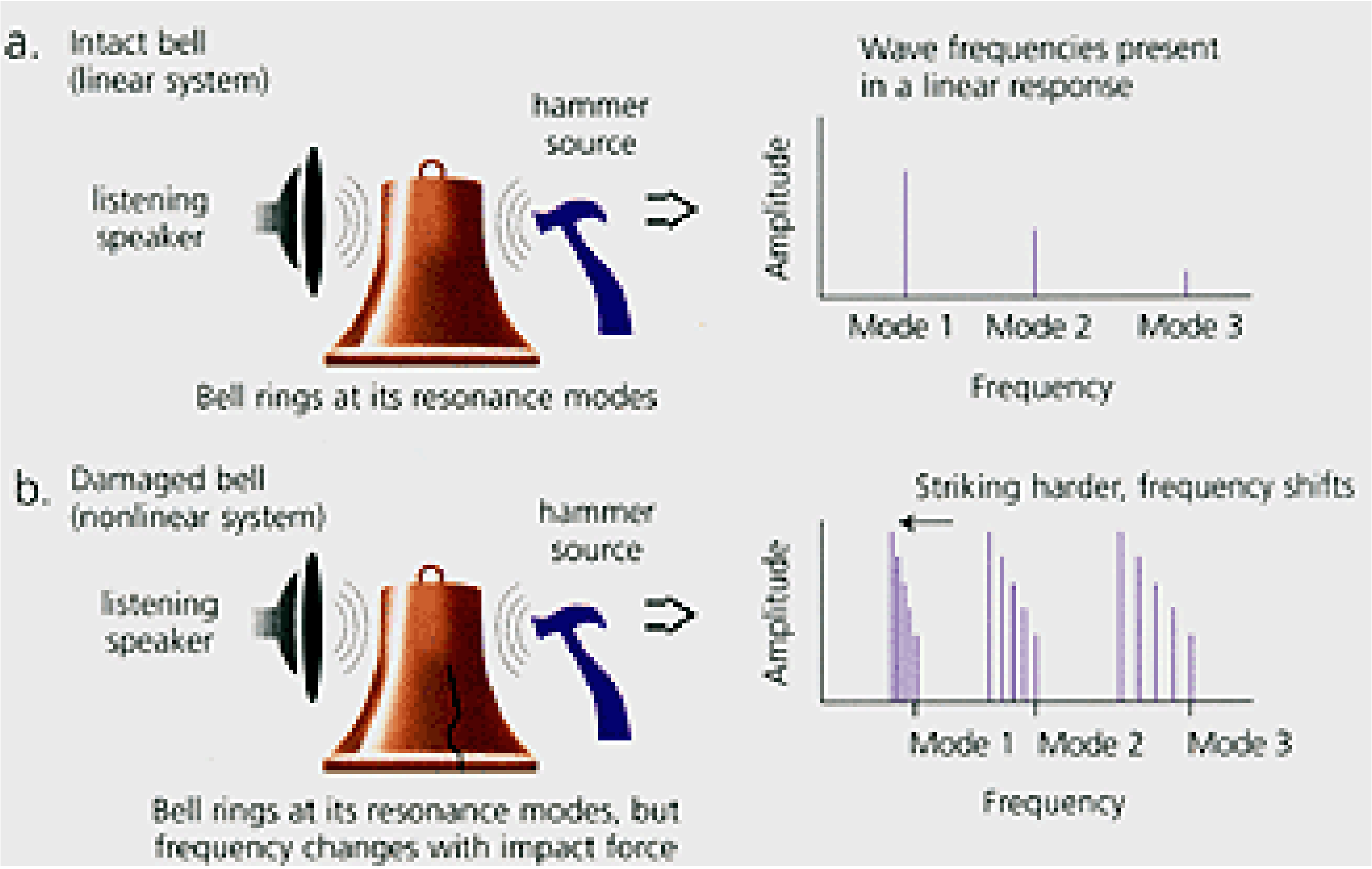
Coin or Hammer Tap - Resonance



The "coin tap test" is one of the oldest methods of nondestructive test (NDT). It requires an operator to tap with a coin-like light tool on each point of the structure to be inspected, feeling or listening to the subtle difference of impact force and hearing the resulting sound to discriminate defective objects from normal ones. Although this is the one of the most cost-effective NDT methods for detection of unbond in multi-layered materials, the test technology still remains largely subjective, and there has been considerably uncertainty about the physical principles behind it.

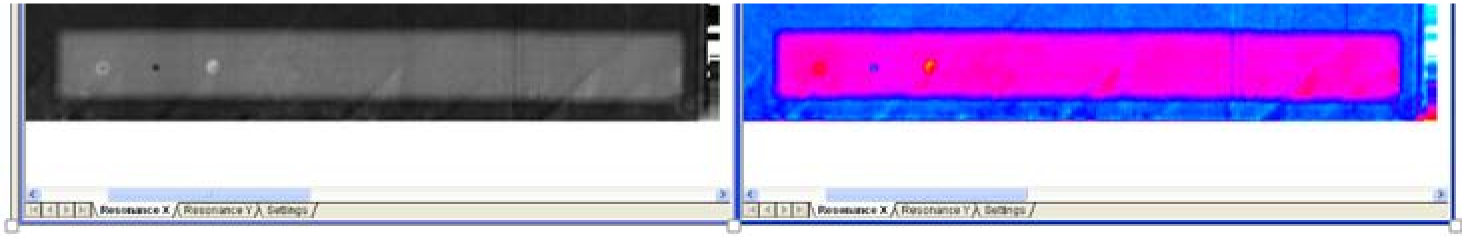
When was the inspection technique "coin tap" first utilized?

Resonance

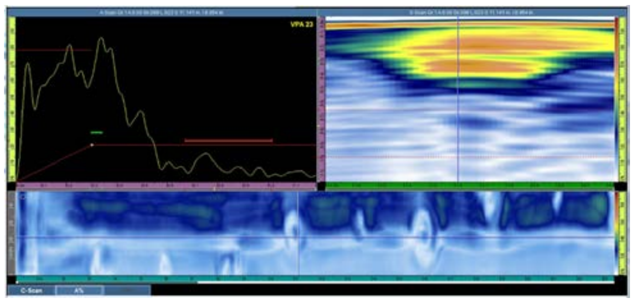


a.
Intact bell
(linear system)
hammer
source
listening
speaker
Bell rings at its resonance modes
Wave frequencies present
in a linear response
Amplitude
Mode 1
Mode 2
Mode 3
Frequency
b.
Damaged bell
(nonlinear system)
hammer
source
listening
speaker
Bell rings at its resonance modes, but
frequency changes with impact force
Striking harder, frequency shifts
Amplitude
Mode 1
Mode 2
Mode 3
Frequency

Why Resonance?

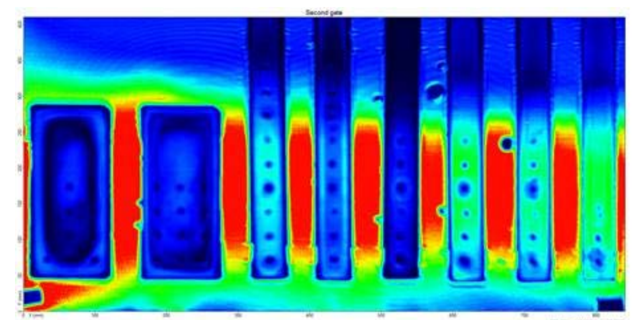


UT Resonance



UT Phased Array

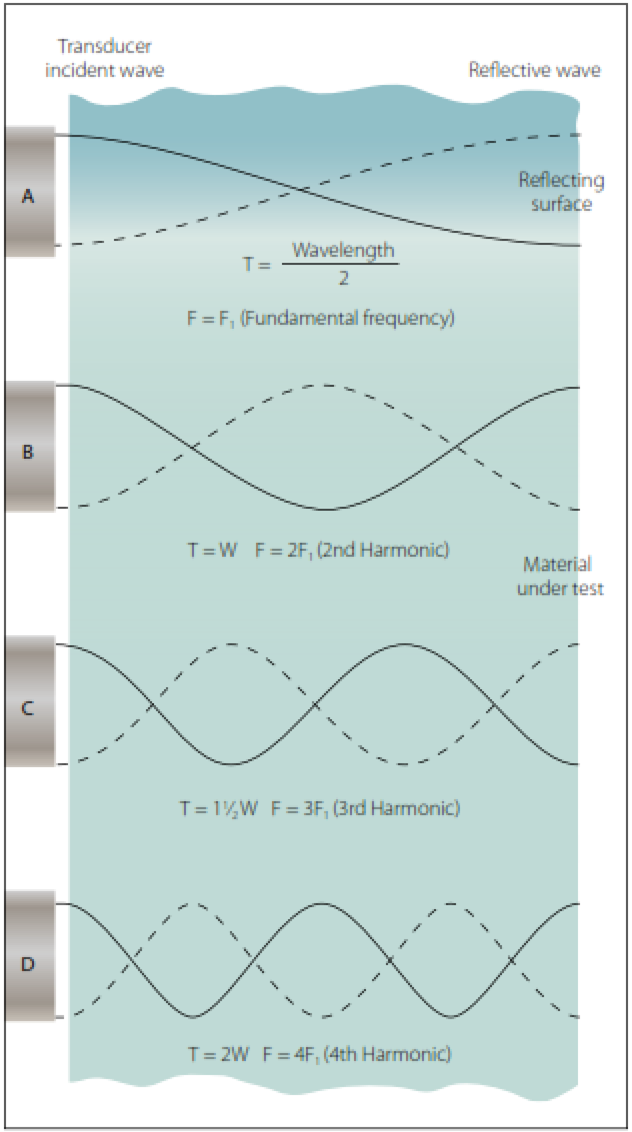
UT TTU C-scan



UT Reflector Plate

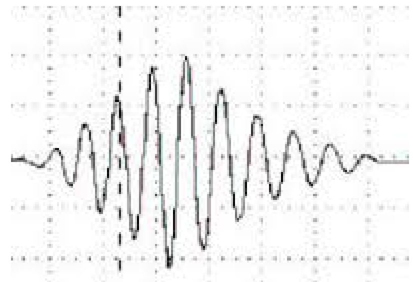
- No definitive a-scan, utilizing a multiple pattern, along with a ring down effect that is dependent on gate location.
- Phase inversion effecting the scan varied +6dB vs -4dB on repeat scans.
- Ultrasonic physics when inspecting thin materials is challenging.

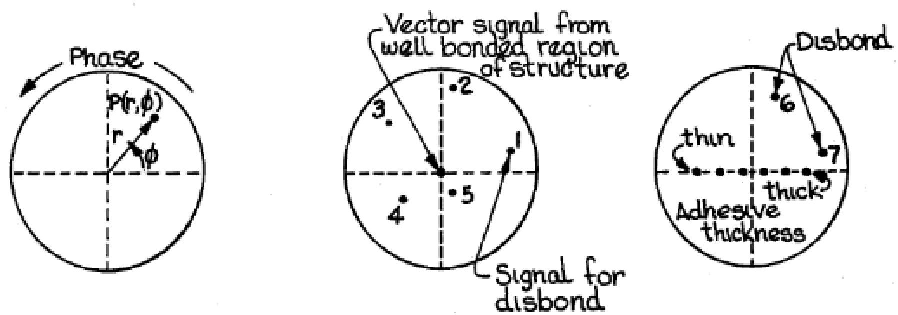
Resonance “Ringing Method”



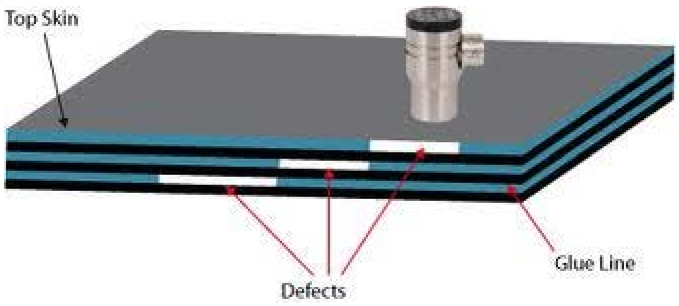
Standardization should be made with reference test blocks to guard against possible drift of frequency. If the frequency of an ultrasonic wave is such that its wavelength is twice the thickness of a specimen (fundamental frequency), then the reflected wave will arrive back at the transducer in the same phase as the original transmission so that strengthening of the signal will occur. If the frequency is increased such that three times the wavelength equals four times the thickness, the reflected signal will return completely out of phase with the transmitted signal and cancellation will occur.

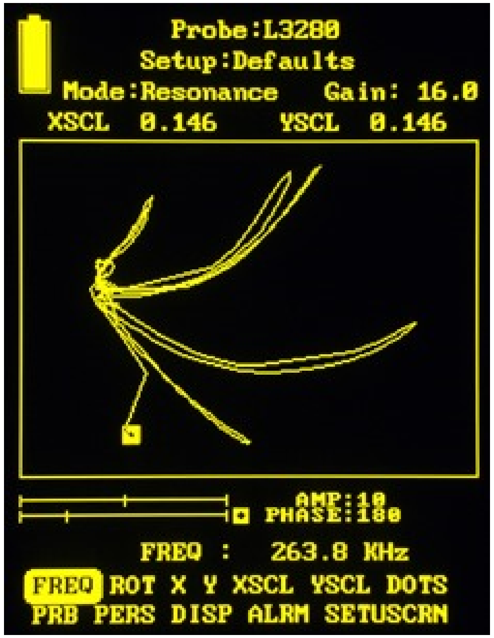
Resonance Testers

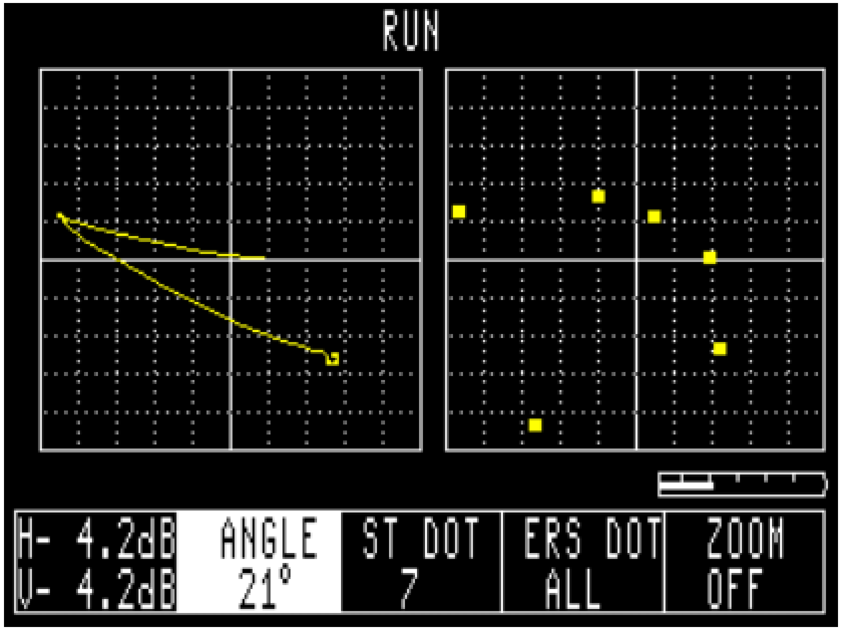




Resonance Testers



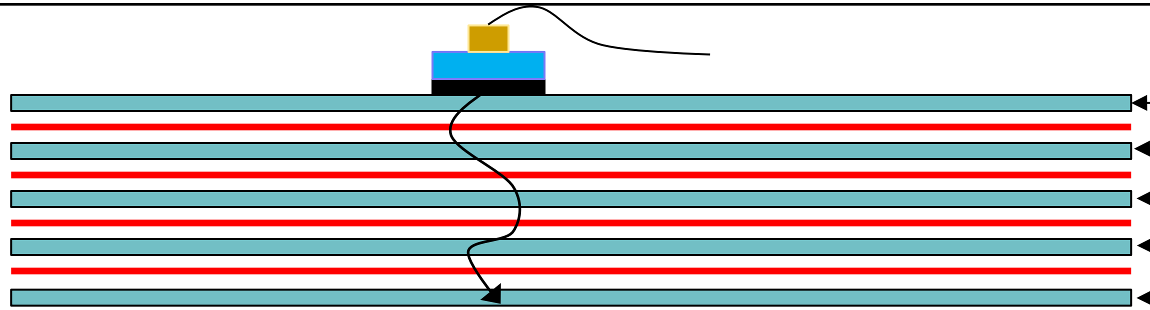




Resonance Principles

- Ultrasonic resonance principle relies on the effect of vibrations under load creating the natural resonant frequency of the transducer.
- In simpler terms, the resonant frequency of a transducer is the frequency where continuous sound vibration is produced. Load is imposed on the crystal/transducer while it is coupled to the structure being inspected. This causes the resonant frequency of the transducer to change based on the mass of the part to which it's coupled.
- When a disbond is present, the mass of medium through which the vibrations are travelling is reduced and the resonant frequency is changed. Resonance testing relies on measuring the transducer's resonant frequency that changes between a good area of the part vs and unacceptable indication such as a disbond.

Resonance Principles

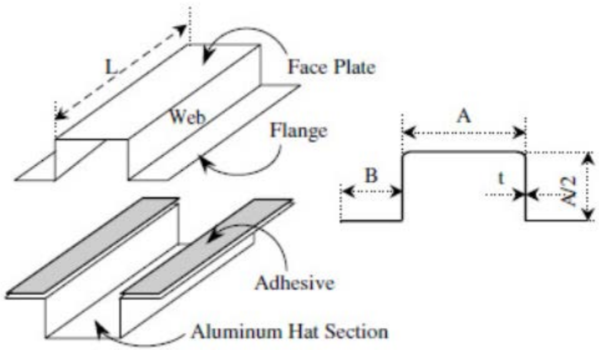


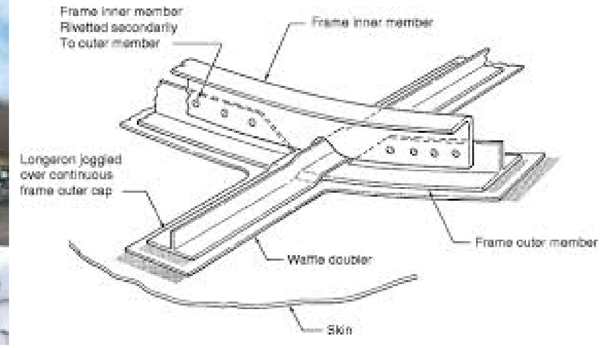
- Ultrasonic resonance is applied in a through thickness direction and when inspecting an adhesively bonded joint can be regarded as an oscillating system. In its simplest form, this system consists of two masses " the adherend" separated by a spring "the adhesive".

"Any Variation from a given standard has the potential to indicate a presence of a defect"

- This continuous wave mode induced is created at a fixed frequency to a very narrow banded probe. When the probe is coupled to the sample under test, the acoustic impedance changes within the material based on materials and structure characteristics loading the probe in a manner that affect its resonant frequency and amplitude.

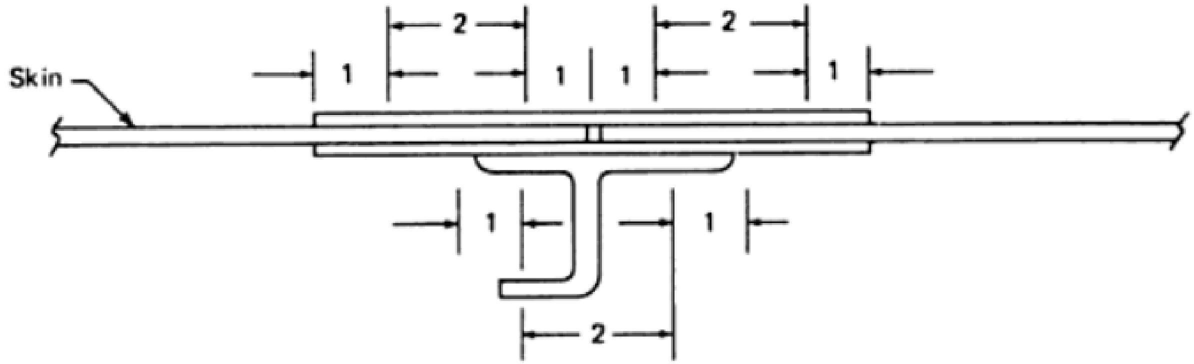
Resonance Principles





- Frequency and Amplitude changes are the first two modes of through thickness vibrations of a system comprising of the joint measured that are influenced the most. Various displays of this characteristics depend on the equipment.
- These parameters depend on both the adherend and the bond-line thicknesses as well as the material properties.
- Typical frequencies operate between .2 and 1.0 Mhz.
- Small void and disbonds at different depths in a multi-layer joint(s) can be detected reliably.

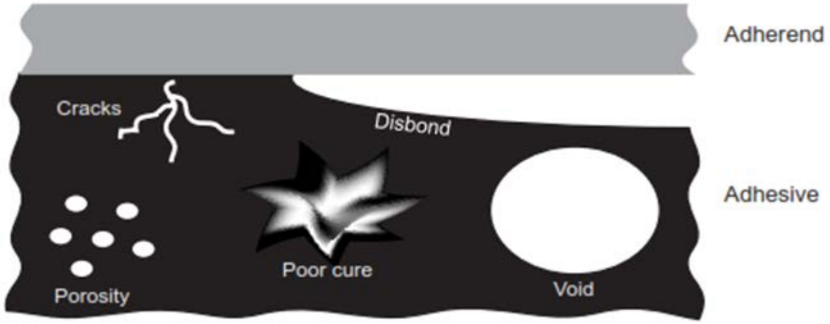
Inspection Criteria

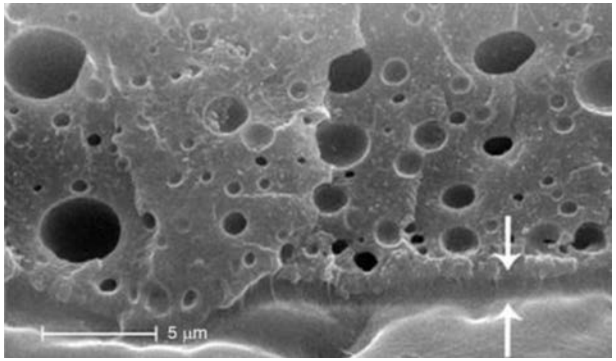


- NDT serves as a basis for process control and monitors quality standards imposed by the design engineer. Various loading characteristics of the structure requires an acceptance criteria of a bonded assembly that is directly related to the quality level based on the performance and safety requirements of structure.
- Typical criteria are usually in the form of frequency (number of flaws per unit area) and/or severity (maximum allowable size).
- Minimum Detectable vs Rejectable.

Porosity

- There are a number of defects associated with adhesive bonding which can reduce the bond strength. Adhesive bond defects include disbonds, cracks, over/under curing, edge damage, impact damage, voids and porosity. Typical adhesive bond defects are shown





- A disbond is the separation between the adherends. Edge and impact damage are an effect of an external source. A void is characterized by an air gap between the adherends, caused by air entrapment or insufficient

Resonance Testing

- The resonance method uses special narrow-bandwidth ultrasonic contact probes. The method is based on the change in impedance of the sharply resonant high-Q ultrasonic transducer when acoustically coupled to a material. The measured electrical impedance of the transducer is affected by the acoustic impedance of the test sample. The acoustic impedance in a specific composite is altered by any lack of bonding.
- A disbond acts as a thin plate that vibrates, generating a standing wave when the thickness is equal to odd number multiples (1, 3, 5, etc.) of the length of the acoustic wave in the plate.
- For one wavelength: l = v/f, where v = sound velocity in the material and f is the resonance frequency. The thinner the layer, the higher the resonance frequency.

MAUS-Resonance

Using the continuous Sin wave method and generating a burst of three cycles which is not quite continuous.

For this purpose, three cycles clearly establishes the sin wave response so we process it as if it is a continuous sin wave. We have a reference sin wave and the signal sin wave that we compare – similar to the overlay below. Both signals go into a bridge circuit that allows us to electrically analyze the two signals relative to each other.

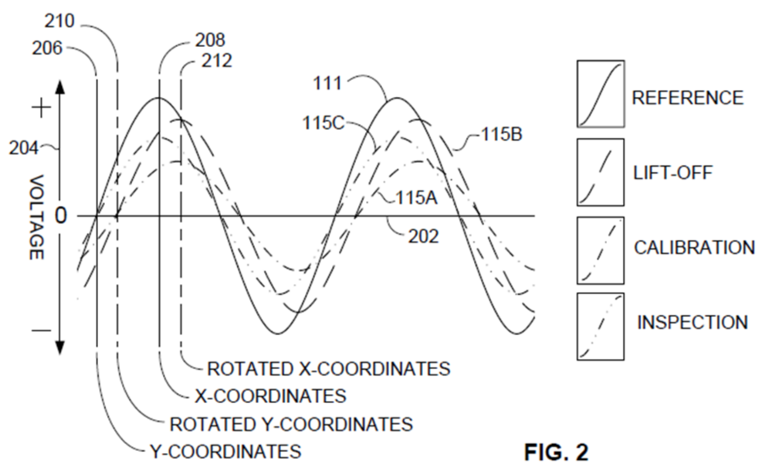


FIG. 2

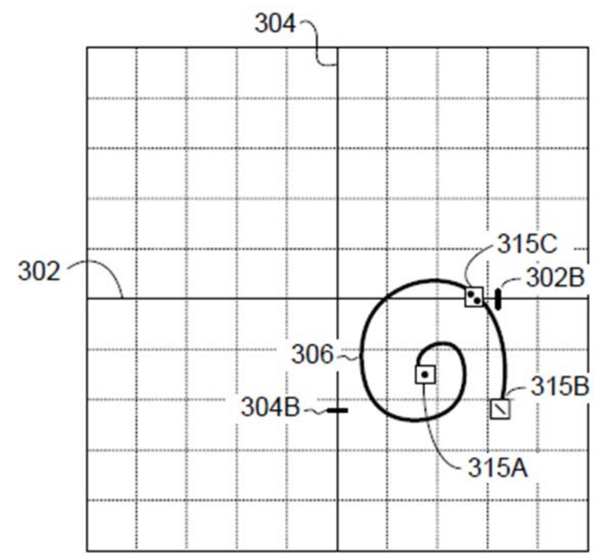


FIG. 3

MAUS-Resonance

NORDAM

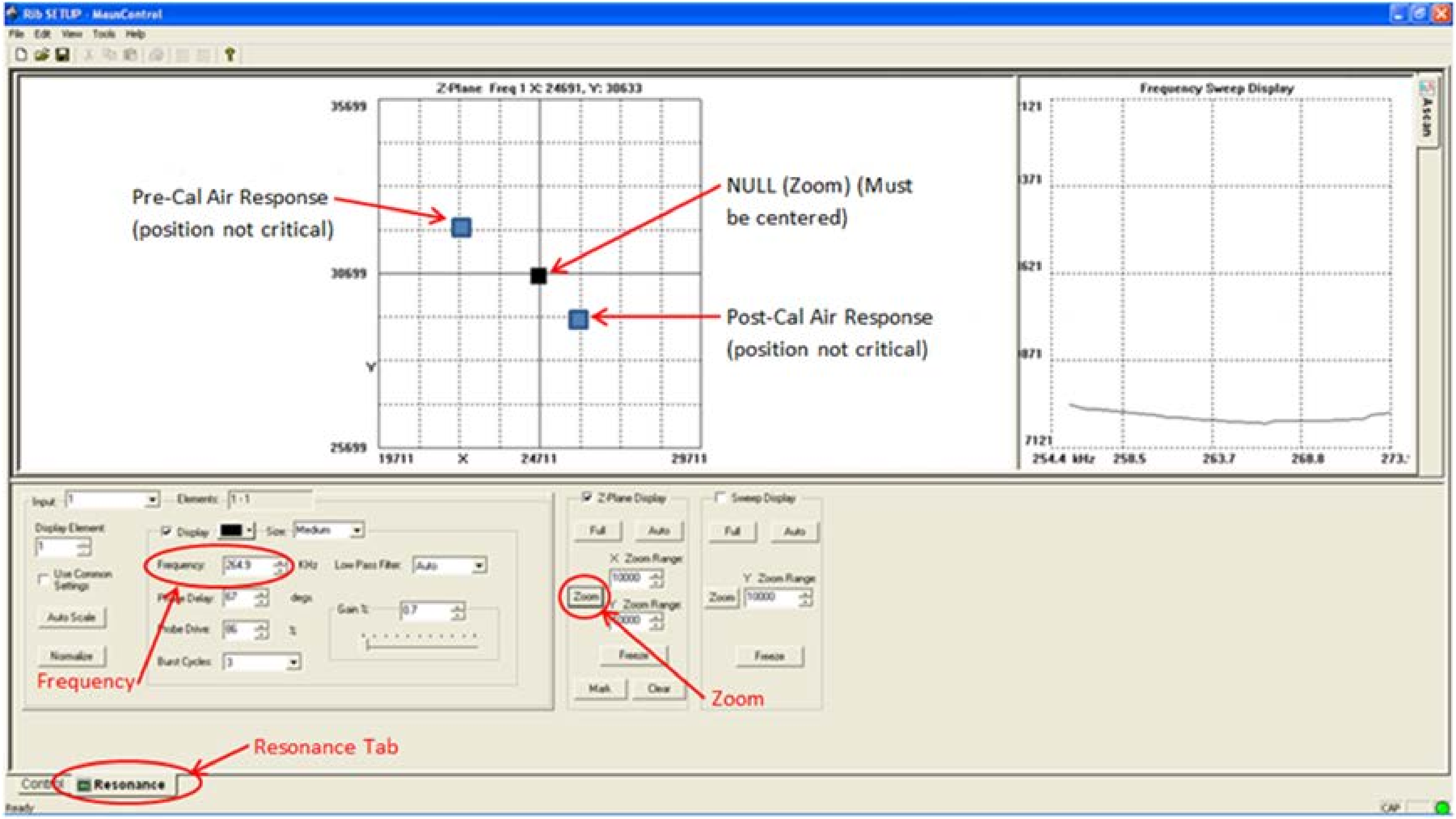
Simplicity is bliss!

What happens out of this bridge circuit is described below – it's not exactly how an electrical engineer would describe it but it is essential what is happening…. ***(as stated from Nancy Wood)***

- The technician finds the zero cross point on the reference sin wave and then measures the difference in signal height from the reference (0 volts) and the signal. This is the X value in the impedance plane.
- Next, we go 90 degrees along the sin wave and measure the difference between the reference sin wave and the signal. This is the Y value in the impedance plane.
- So …. The signal can be different heights (amplitudes) or at a different phase (shifted left or right compared to the reference waveform) but we can tell these changes by the changes that we see in the X and Y values.

Resonance MAUS at NORDAM

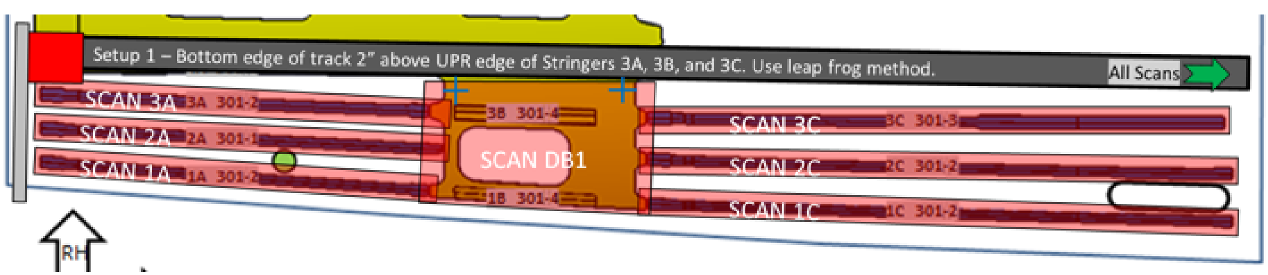
MAUS-Resonance



MAUS-Resonance, NORDAM Setup

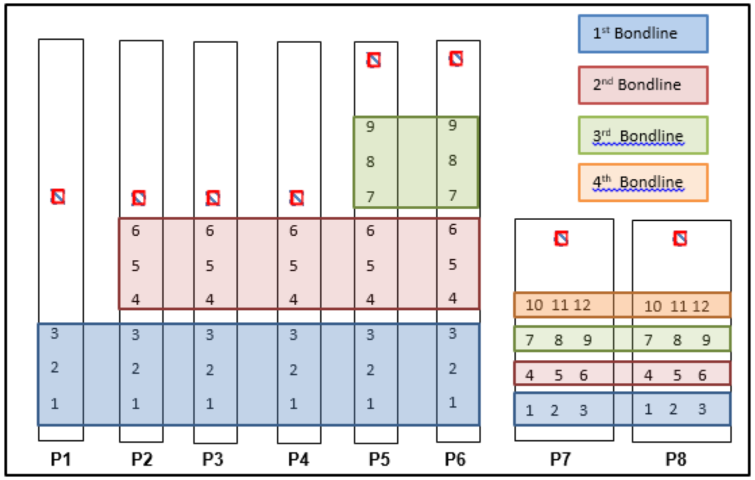
The MAUS DR11 was utilized for all of inspection applications.

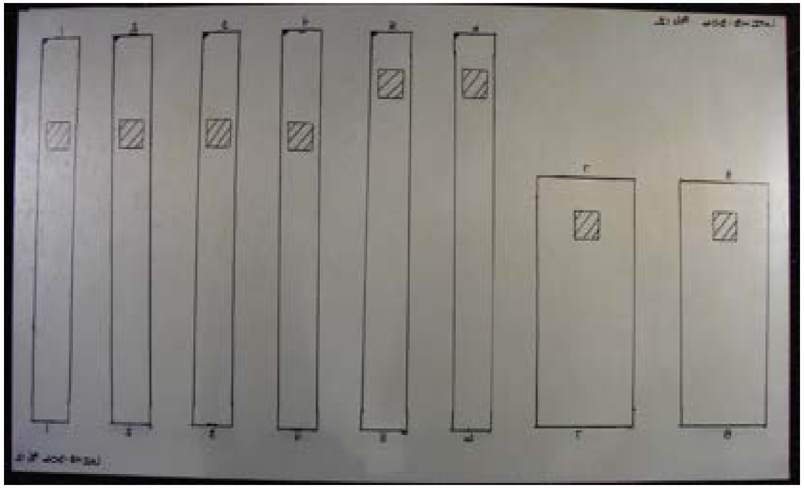
Setup	Bond Lines	Reference Standard	Comments
1	1A, 1B, 1C, 2A, 2C, 3A, 3B 3C, & DB1	Plank 1 – 0.040", 0.080" Plank 2 – 0.050", 0.080" Plank 3 – 0.063", 0.080" Plank 4 – 0.050", 0.063", 0.080" (SP)	See Figure 3A for part orientation. Secondary Inspection per section 6 UT/RES Bondmaster required around cutout DB1.

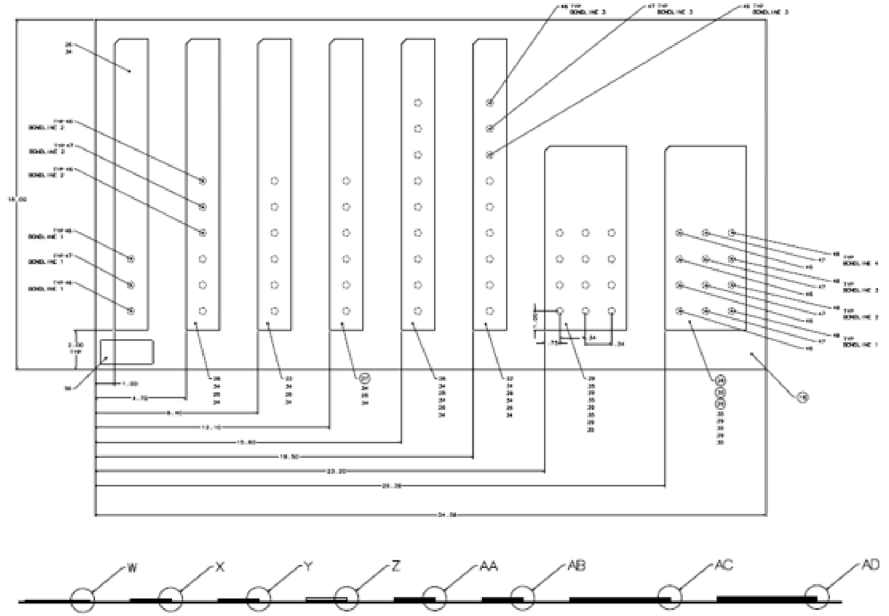


Track locations approximate.Operator must assure complete coverage of required bondlines with minimum ¼" excess.

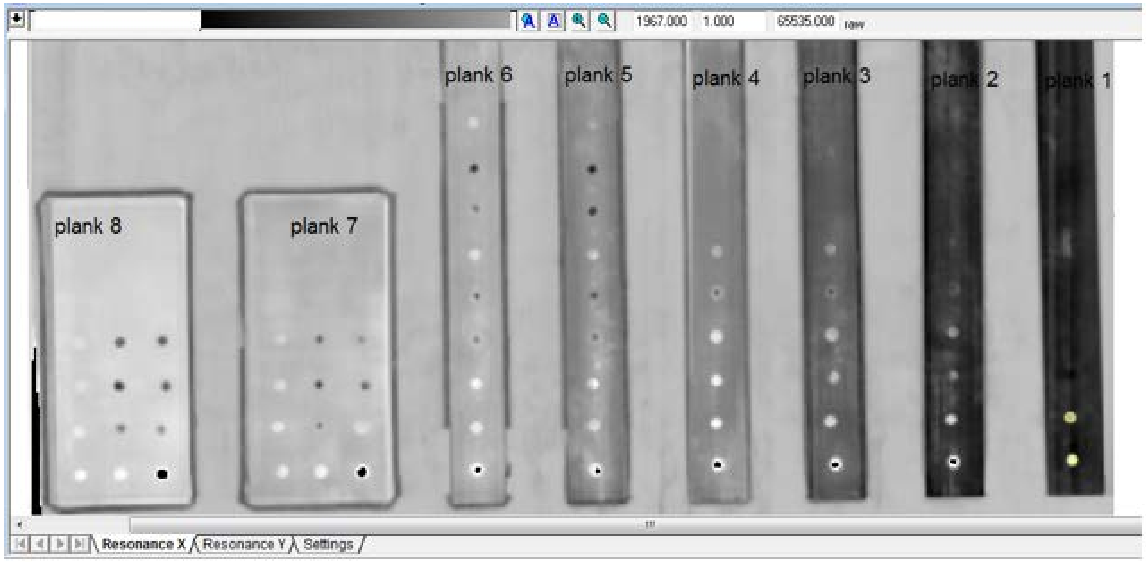
MAUS-Resonance Reference Standard

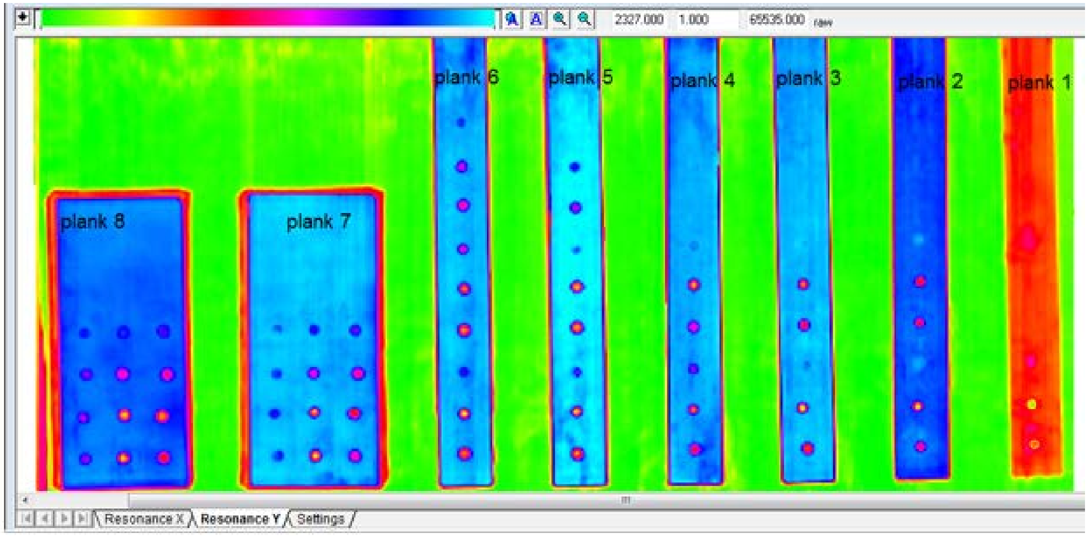






MAUS-Resonance Standardization





MAUS & UT Through Transmission

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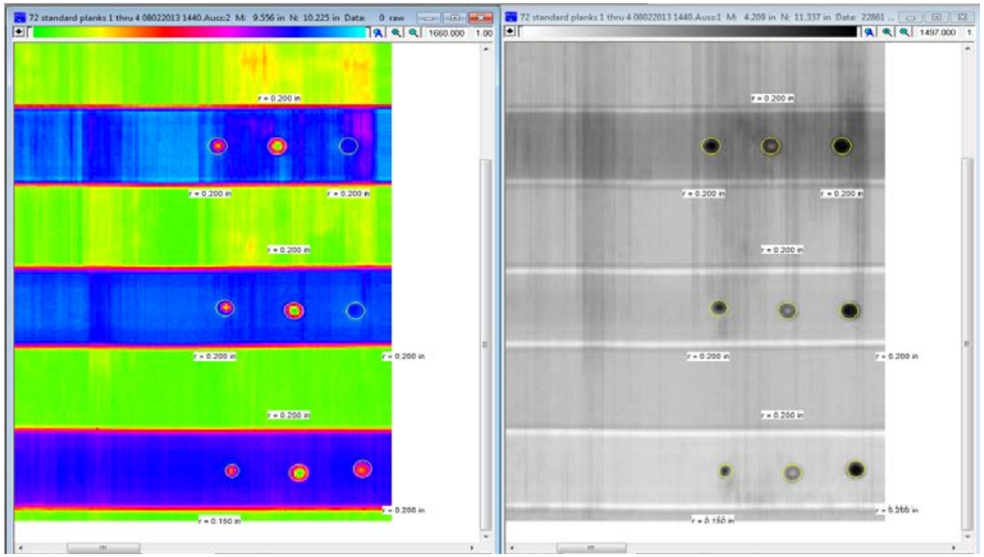
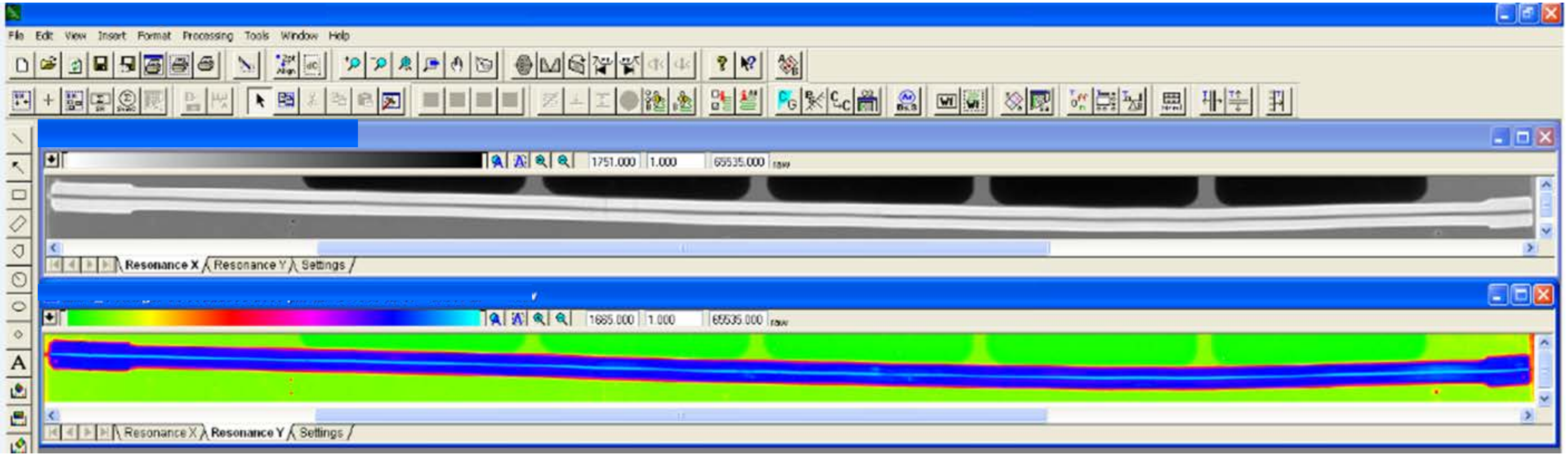
Acceptance Summary for Nondestructive Test Standard(s)

UT/TTU Attenuation Value dB			UT/TTU Sizing "Diameter"	MAUS Detection & Sizing	UT/TTU Attenuation Value dB			UT/TTU Sizing "Diameter"	MAUS Detection & Sizing
#1	**1**	12.2 dB	≥.340"	X/Y <.340"	**#6**	**3**	3.4 dB	≥.340"	X/Y ≥.340"
	2	13.9 dB	≥.340"	X/Y <.340"		**4**	8.8 dB	≥.340"	X/Y ≥.340"
	3	3.2 dB	≥.340"	Y[1]≥.340"		**5**	9 dB	≥.340"	X/Y ≥.340"
#2	**1**	7.8 dB	≥.340"	X/Y ≥.340"		**6**	5 dB	<.340"	X/Y ≥.340"
	2	9.4 dB	≥.340"	X/Y ≥.340"		**7**	6.2 dB	≥.340"	X/Y ≥.340"
	3	2.1 dB	<.340"	X/Y[1] <340"		**8**	7.7 dB	≥.340"	X/Y ≥.340"
	4	8.7 dB	≥.340"	X/Y ≥.340"		**9**	3 dB	<.340"	X/Y <.340"
	5	7.5 dB	≥.340"	X/Y ≥.340"	**#7**	**1**	2.5 dB	≥.340"	X/Y ≥.340"
	6	2.3 dB	≥.340"	Y[1] ≥.340"		**2**	3.4 dB	≥.340"	X/Y ≥.340"
#3	**1**	10.7 dB	≥.340"	X/Y ≥.340"		**3**	5.3 dB	≥.340"	X/Y ≥.340"
	2	12.8 dB	≥.340"	X/Y ≥.340"		**4**	5.7 dB	≥.340"	X/Y ≥.340"
	3	3.3 dB	≥.340"	X[1]<340"		**5**	7.3 dB	≥.340"	X/Y ≥.340"
	4	10 dB	≥.340"	X/Y[1] ≥.340"		**6**	6.6 dB	≥.340"	X/Y ≥.340"
	5	9.8 dB	≥.340"	X/Y ≥.340"		**7**	6.9 dB	<.340"	X/Y <.340"
	6	4.2 dB	<.340"	X ≥.340"		**8**	8.7 dB	<.340"	X/Y <.340"
#4	**1**	8.5 dB	≥.340"	X/Y ≥.340"		**9**	4.7 dB	≥.340"	X/Y ≥.340"
	2	10.8 dB	≥.340"	X/Y ≥.340"		**10**	5.2 dB	<.340"	X/Y <.340"
	3	7 dB	≥.340"	X/Y ≥.340"		**11**	4.7 dB	<.340"	X/Y <.340"
	4	5.9 dB	<.340"	X/Y ≥.340"		**12**	6.2 dB	<.340"	Y <.340"
	5	13.6 dB	≥.340"	X/Y ≥.340"	**#8**	**1**	3.8 dB	≥.340"	X/Y ≥.340"
	6	2.8 dB	≥.340"	X[1] ≥.340"		**2**	5.5 dB	≥.340"	X/Y ≥.340"
#5	**1**	4.9 dB	≥.340"	X/Y ≥.340"		**3**	5.4 dB	≥.340"	X/Y ≥.340"
	2	5.2 dB	≥.340"	X/Y ≥.340"		**4**	4.3 dB	≥.340"	X/Y ≥.340"
	3	1.5 dB	≥.340"	X/Y <.340"		**5**	7.3 dB	≥.340"	X/Y ≥.340"
	4	6.9 dB	≥.340"	X/Y ≥.340"		**6**	8.4 dB	≥.340"	X/Y ≥.340"
	5	6.5 dB	≥.340"	X/Y ≥.340"		**7**	8.8 dB	≥.340"	X/Y ≥.340"
	6	3.3 dB	≥.340"	X <.340"		**8**	6.1 dB	≥.340"	X/Y ≥.340"
	7	3.3 dB	≥.340"	X/Y <.340"		**9**	4.1 dB	≥.340"	X[1] ≥.340"
	8	4.9 dB	<.340"	X/Y <.340"		**10**	3.2 dB	≥.340"	X/Y ≥.340"
	9	1.8 dB	<.340"	[1] <.340"		**11**	4 dB	≥.340"	X/Y ≥.340"
#6	**1**	8.3 dB	≥.340"	X/Y ≥.340"		**12**	3.1 dB	<.340"	X[1] <.340"
	2	7.4 dB	≥.340"	X/Y ≥.340"					

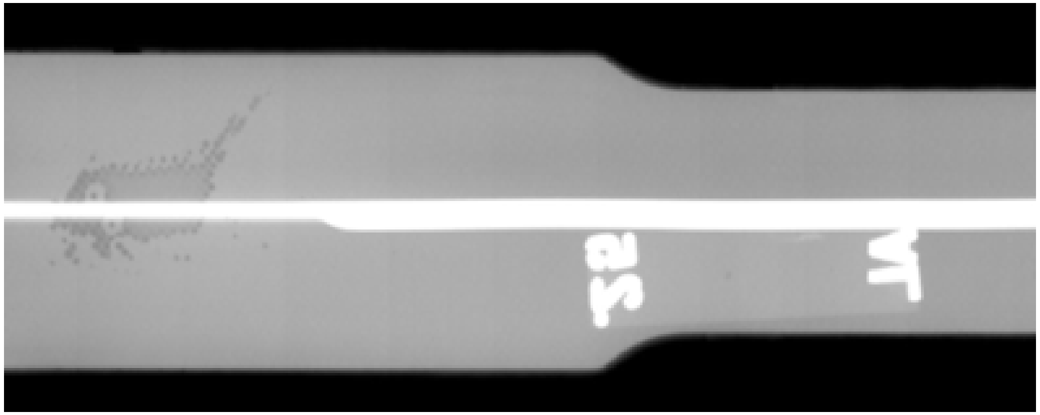
1. Detection noted during palette leveling with both Resonance Vectors X (Shades of Gray) & Y (Color) during evaluation

Typical MAUS Standardization and Scan



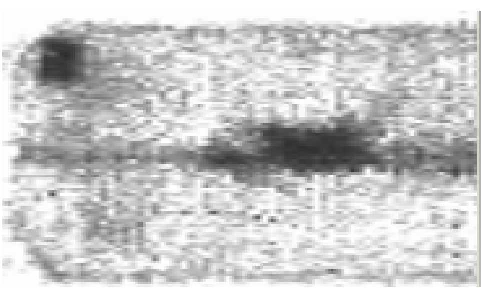


MAUS & Correlating Indications



Digital Radiography concurs with an Adhesive void

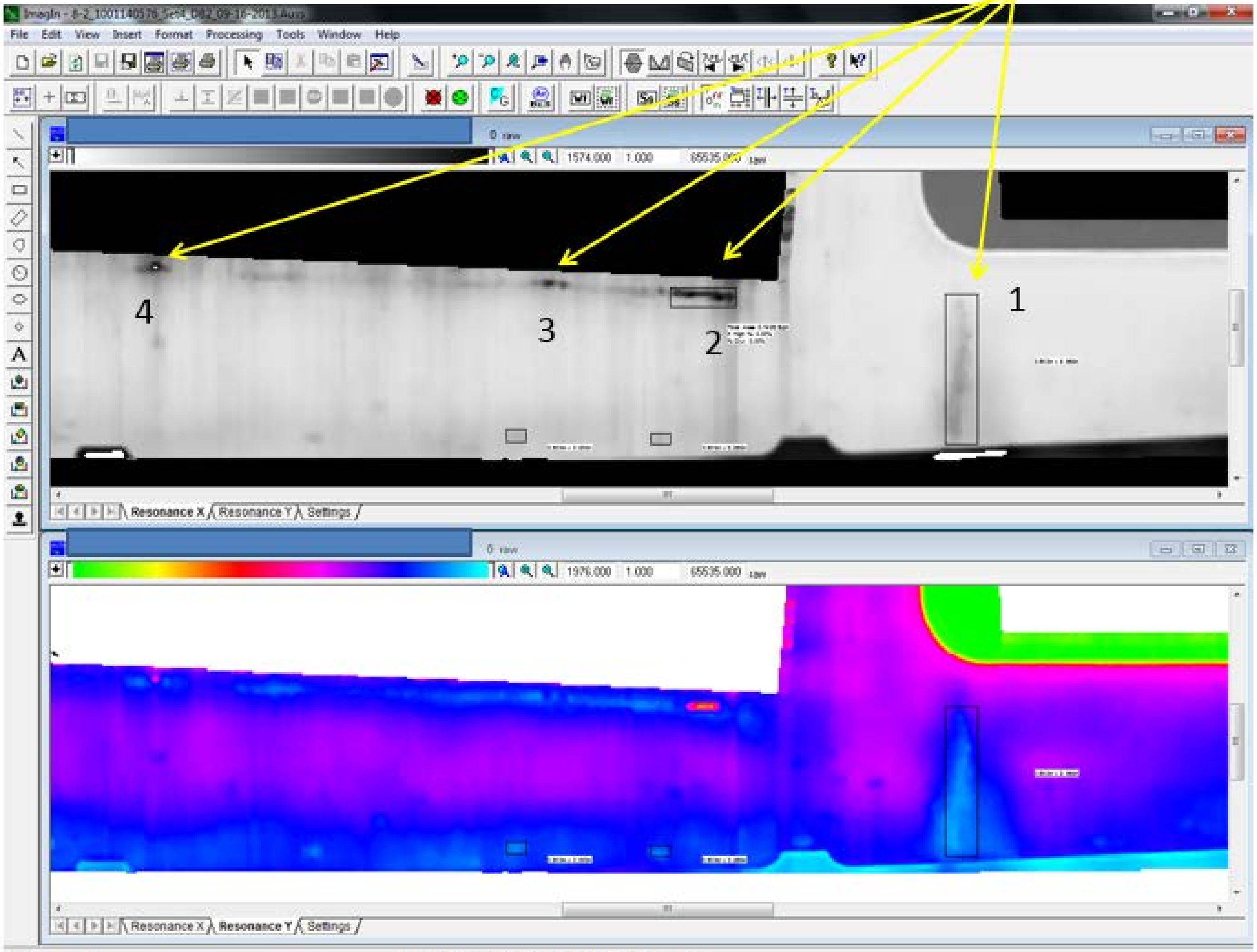
MAUS Scan Resonance X Indication .562” x 1.050



Ultrasonic UT/TTU confirms indication to exceed 12 dB exceeding allowable

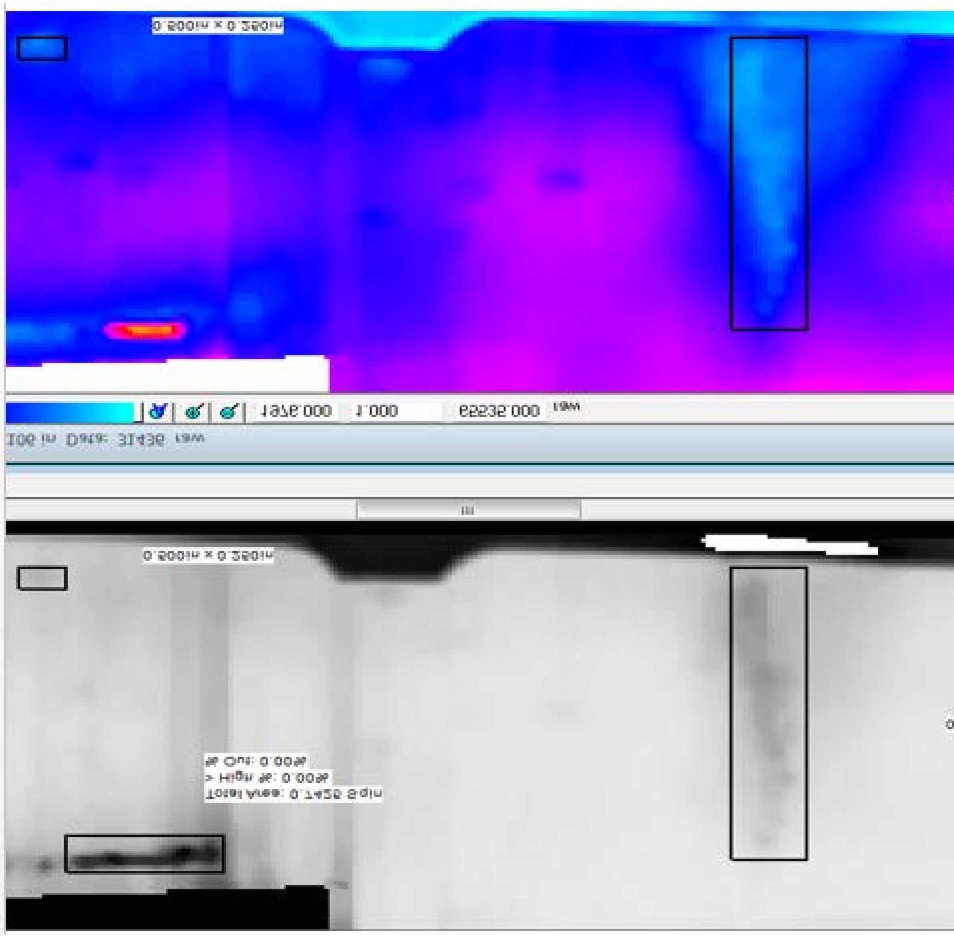
MAUS & Correlating Indications

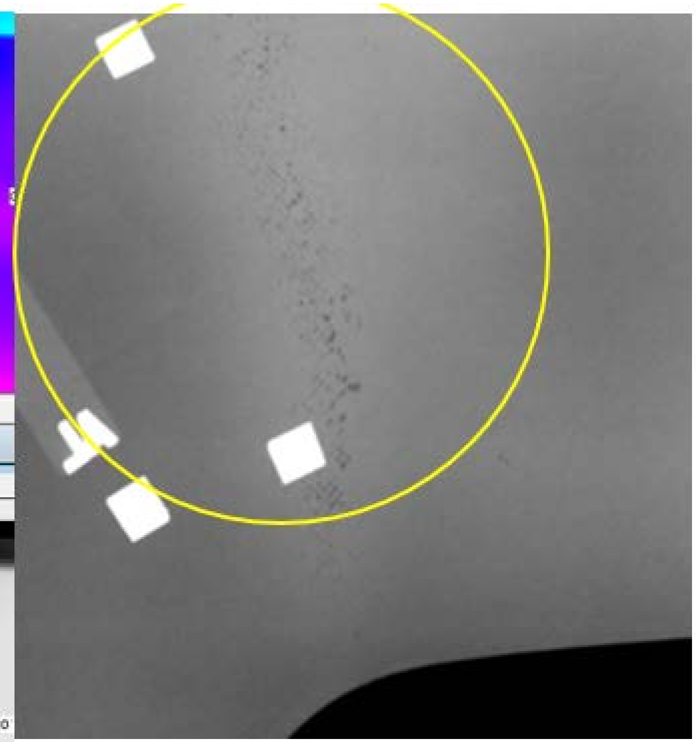
MAUS identified 4 areas



MAUS & Correlating Indications

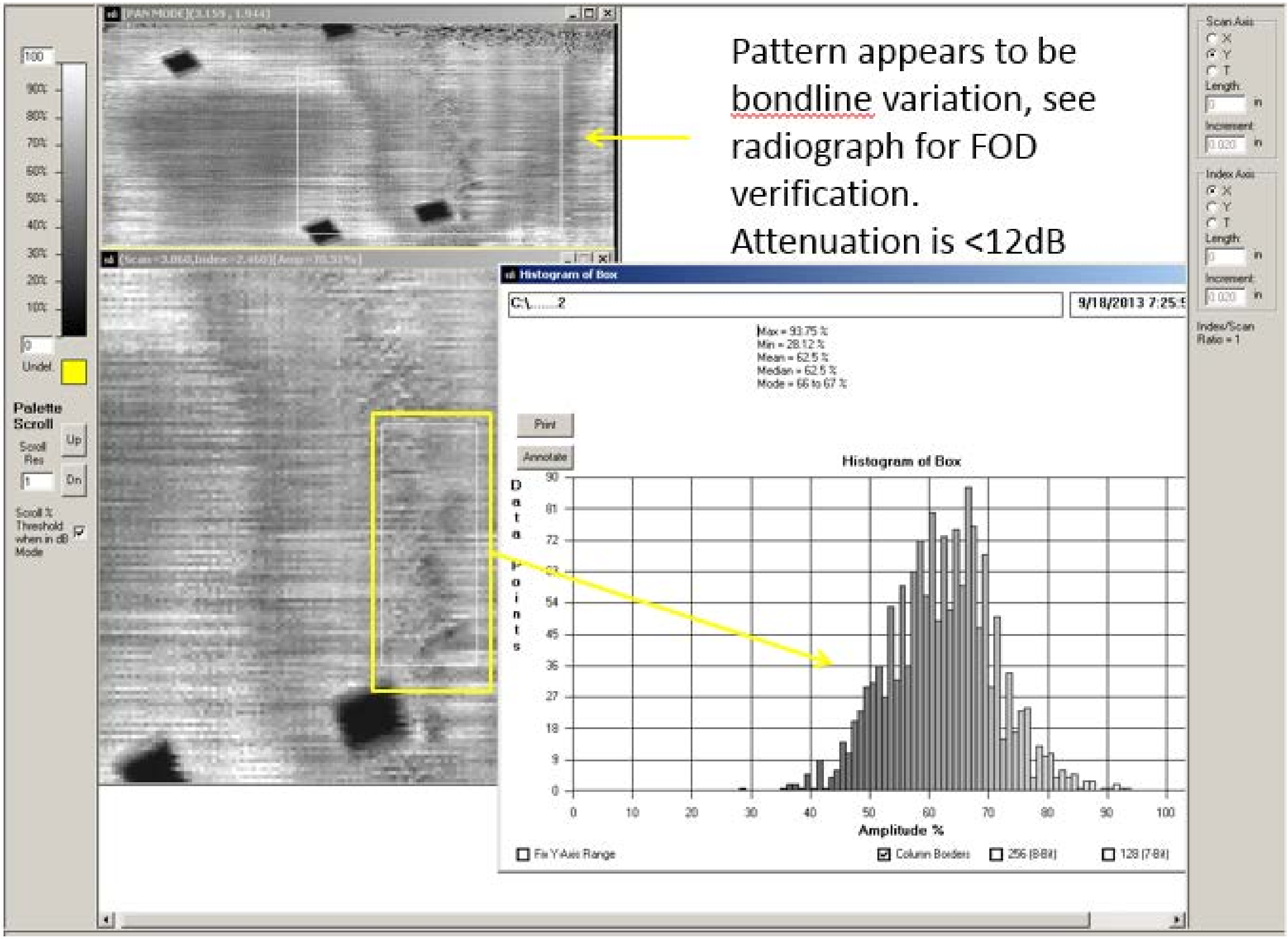
NORDAM



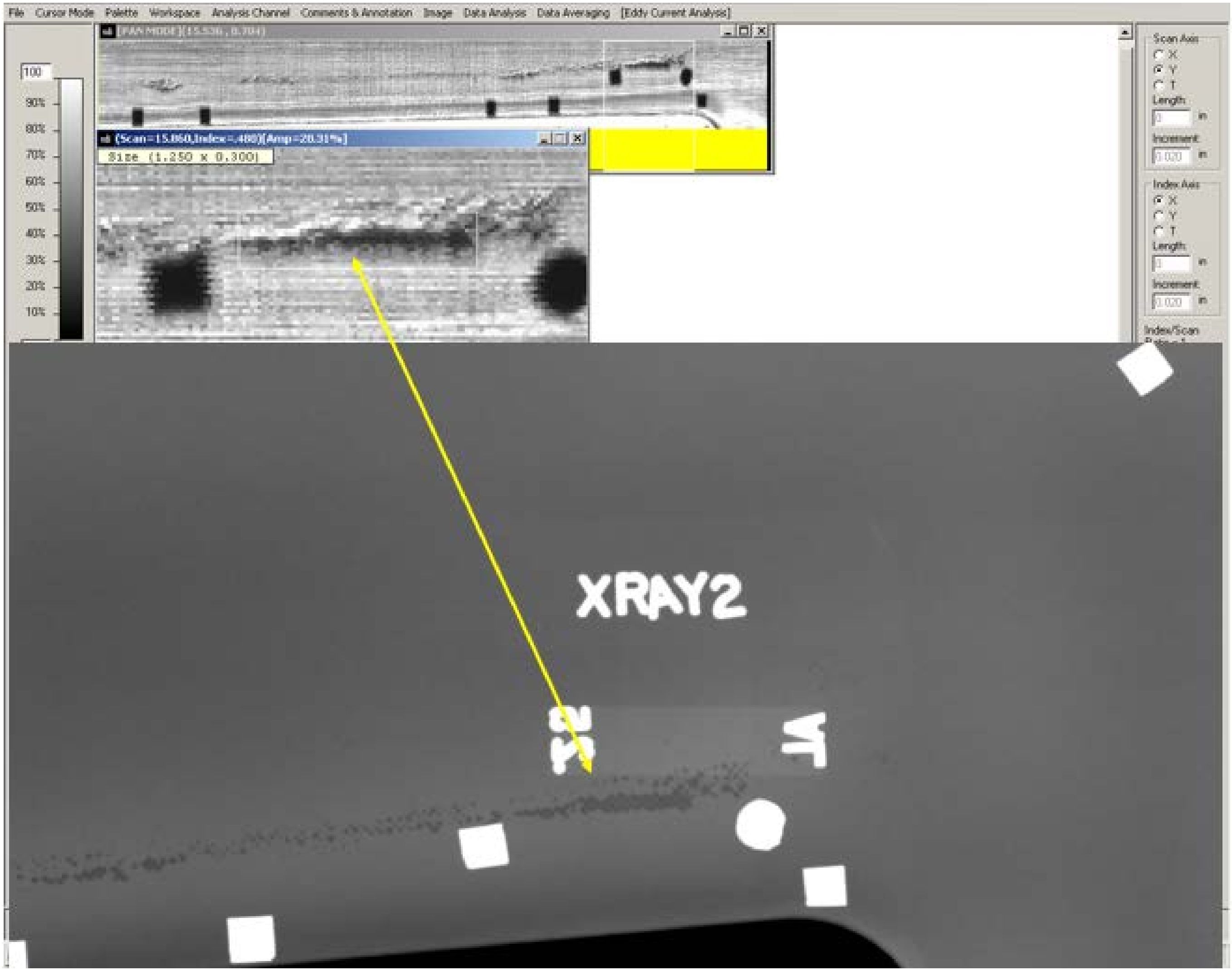


Porosity and varying bondline thickness noted.

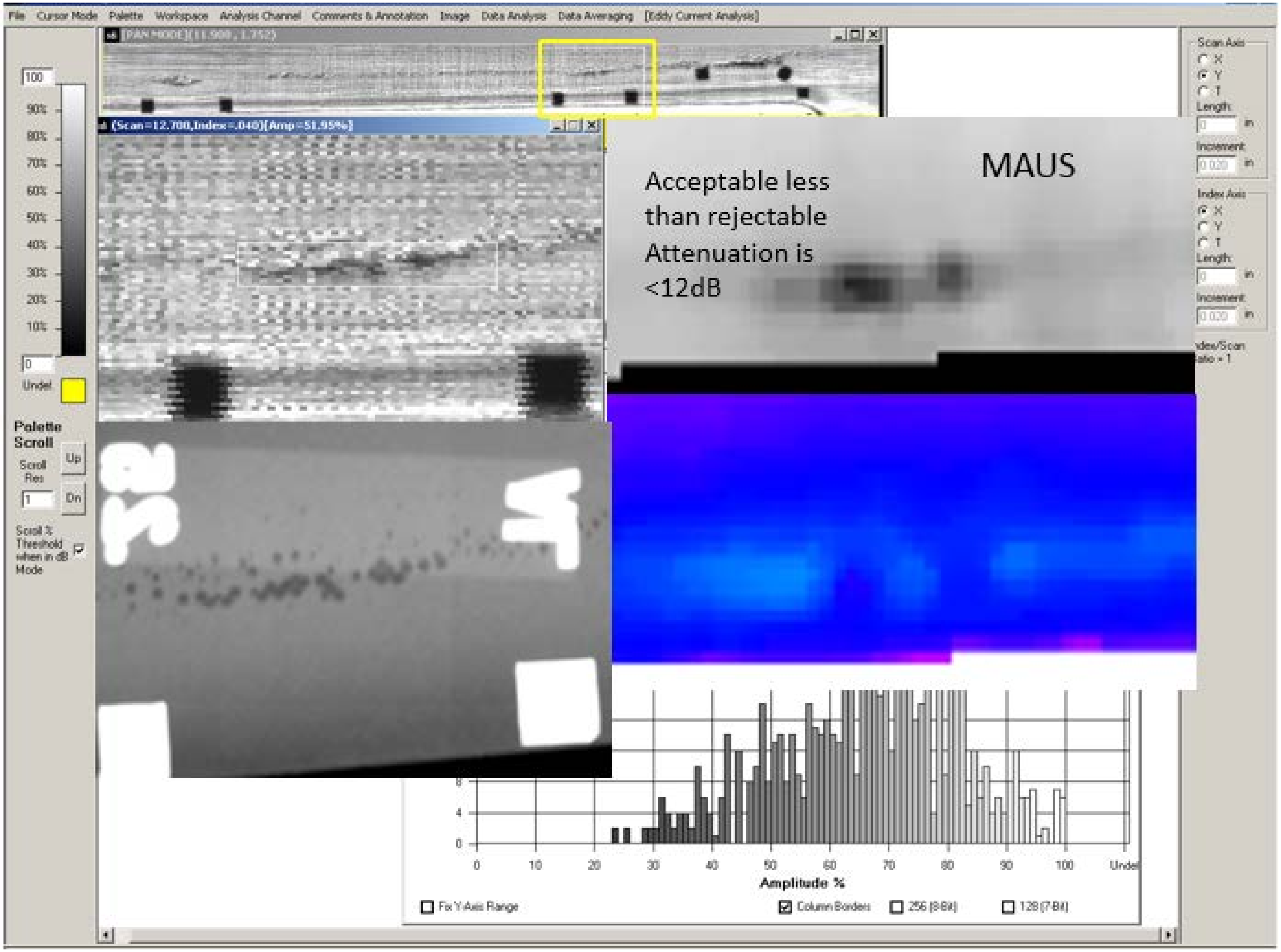
MAUS & Correlating Indications



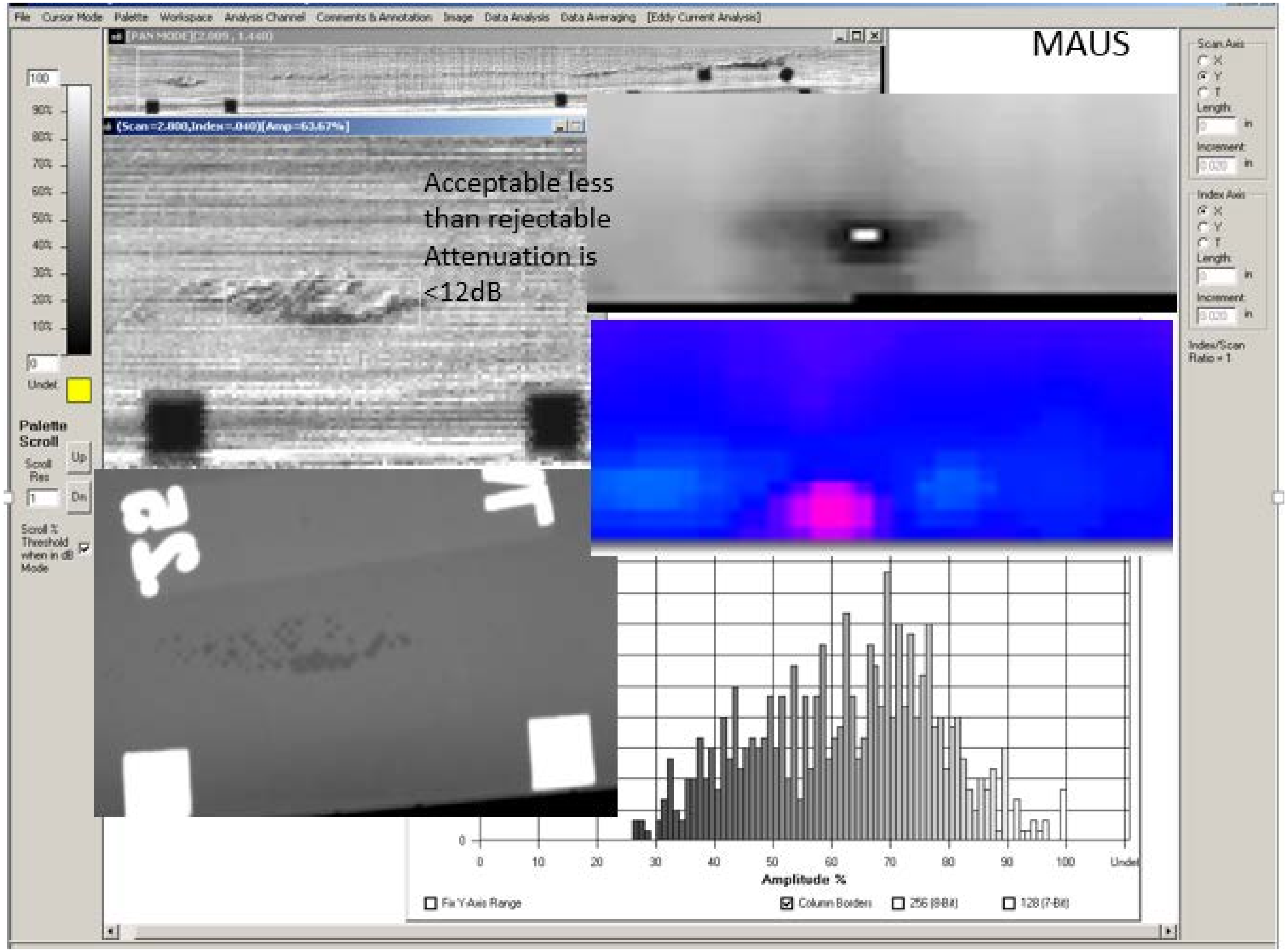
MAUS & Correlating Indications



MAUS & Correlating Indications



MAUS & Correlating Indications



Conclusion and Reality

- Understand the contracted requirements, technique limitation, acceptance criteria, directives, specifications and procedures!
- The test performed is only as good as the reference standard utilized for the standardization.
- NDT Technicians need to understand this simple yet complex technique as any variation from a given standard could cause a false call or a false positive.
- Matching older technology with computerized approach yields a dynamic way to evaluate bonded assemblies.
- MAUS Resonance is very sensitive and continued efforts to correlate with Ultrasonic Data is on going at NORDAM.
- NORDAM initial program objective has been achieved, follow-on development of inspection methodologies is underway.

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Questions

Thank You!