A comparison of Techniques for Ultrasonic Inspection of Composite materials

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What are composites:

- “**Composite materials** are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct within the finished structure.” (from wikipedia)
- Contain matrix and reinforcement, the matrix supports the reinforcement which provides tensional strength.

Composites

- Not New
  - Early construction techniques used a reinforcement of twigs or straw in a matrix of mud or animal dung.
  - At this stage NDT requirements were minimal
- We like to think we have moved on since then.
  - Now we have much nastier materials to work with…

Common types of composite materials which need to be inspected.

- Monolithic Carbon/glass reinforced plastic
- Honeycomb cored sandwich
- Foam (or wood) cored sandwich
- Bonded structures

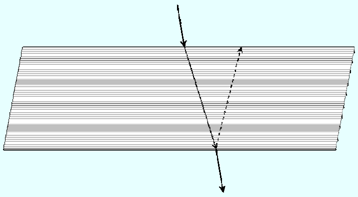
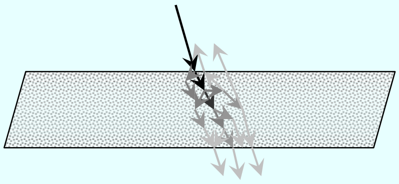
Why are some composites difficult to inspect?

- Inhomogeneous structure
  - Back scatter of sound
  - Lack of sound penetration
  - Extra constraints
    - E.g. porous structure / surface makes use of liquid couplant difficult.

Monolithic reinforced plastic Carbon/glass

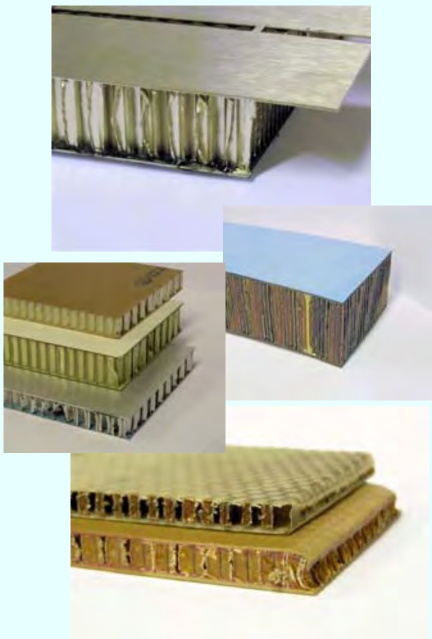
- Plastic matrix bonds Carbon/glass mat together to provide rigidity and prevent fibre movement
- Typically light and strong
- Carbon stronger , easier to test, but much more expensive.
- Curing processes vary

How do they compare ultrasonically?

CFRP (Typical)	GFRP
	
Carbon/Plastic similar Z Minimal scattering Sound travels ‘cleanly’	Glass High Z Lots of scattering Difficult to penetrate Reflections unclear

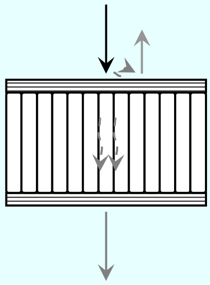
Honeycomb cored sandwich

- Skin typically Monolithic composite or metal sheet.
- Core typically metal foil or Nomex.
- Sometimes made separately and glued together or Sometimes skins cured in situ



Honeycomb cored sandwich

- Ultrasonically complex
- Sound has to get through skins
- Glue layer can have a major effect on sound transmission to core – various mode conversions
- Typically plate wave through core (can get frequency filtering effects)
- Then to second skin
- Minor processing changes can have major effect on sound properties
- Minimal reflected energy from lower skin except at very low frequencies



Foam (or wood) cored sandwich

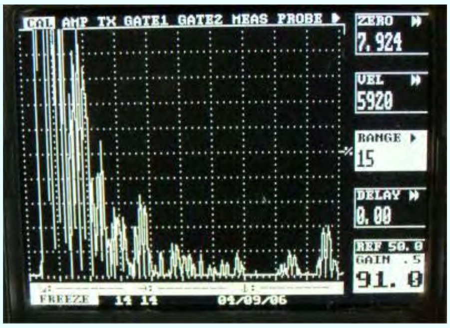
- Skins may be metal, plastic, composite or wood etc.
- Core usually plastic foam or wood
- Lightweight foams very low Z, effectively look like air except in through transmission

What ultrasonic methods are available?

- Pulse echo
- Through transmission
  - Water coupled
  - Air coupled
  - Dry coupled
- Low frequency surface methods
- Resonance methods

Manual Pulse echo

- ‘standard UT’
- Simple to apply
- Single sided, need couplant
- Material scattering often prevents a meaningful reflection pattern
- Manual applications typically only on high quality CFRP etc.



Scanned Pulse-Echo UT

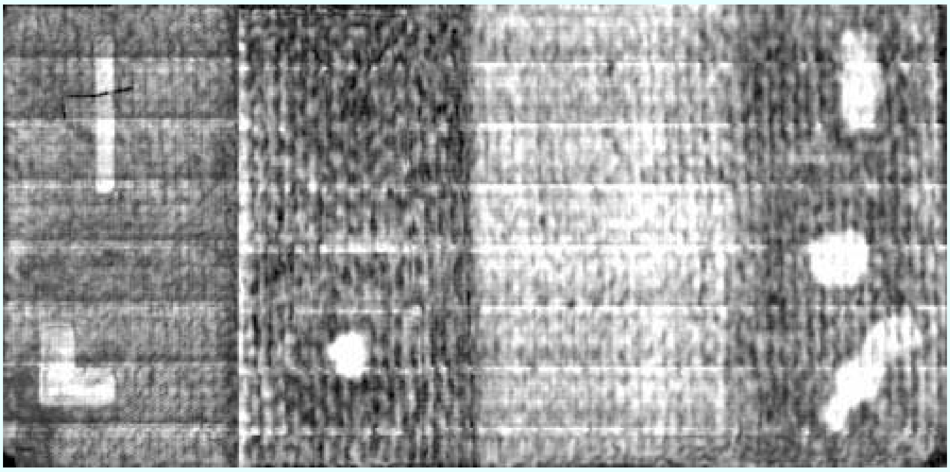
- Immersion tank or arm scanner (AndScan etc)
- Can give very good results on ‘good quality’ carbon and similar materials
- Can use high frequencies (5-10 MHz) – find small defects such as porosity
- Need materials which are non- porous

Array based Pulse Echo UT

- PA systems or “RapidScan”
- Scans much faster than single probe electronics
- Can be rubber coupled – minimal moisture
- Metal sandwiches, monolithic composites,

Array based Pulse Echo UT

- Honeycomb top layer



Through transmission

- Water coupled
- Air coupled
- Dry coupled

Through Transmission

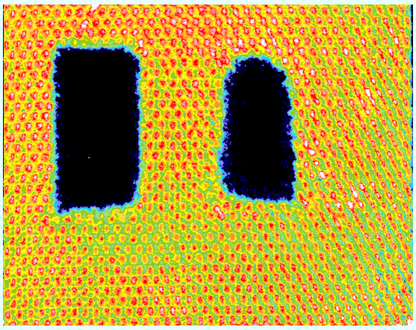
- Works very well in materials where large amounts of scattering – Only transmitted sound is measured, so even if this is a tiny fraction of what is incident changes can still be seen.
- To interrupt beam, defects need to be similar in size to beam diameter, so small defect detection is limited
  - *cf* Pulse echo, where small diameter (relative to beam) defects can be found by reflected energy
  - So need accurate coverage (i.e some kind of scanner) to avoid risk of missing defects
- NEED ACCESS TO BOTH SIDES

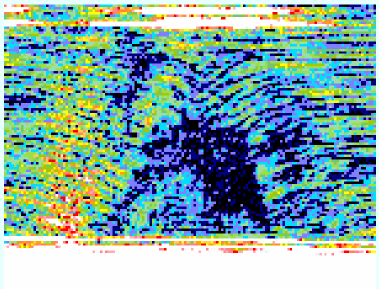
Water coupled TT

- Very widely used.
- Suitable for production inspection of large parts with suitable scanners - Reasonable scan rate
- Squirter systems can be used with care on honeycomb etc where immersions would not be feasible
- Double through transmission (with Glass reflector) often used in immersion tanks for CFRP etc.

Air Coupled TT

- Path losses main issue
  - Worst on high impedance materials (metal, ceramics) better on CFC etc.
  - S/N can be poor
- Use low frequency (50-400 kHz typical)
  - Defect resolution poor at LF
- Non contact – great on porous irregular surfaces
- Slow (PRF limited)
- When applicable can be very reliable and effective





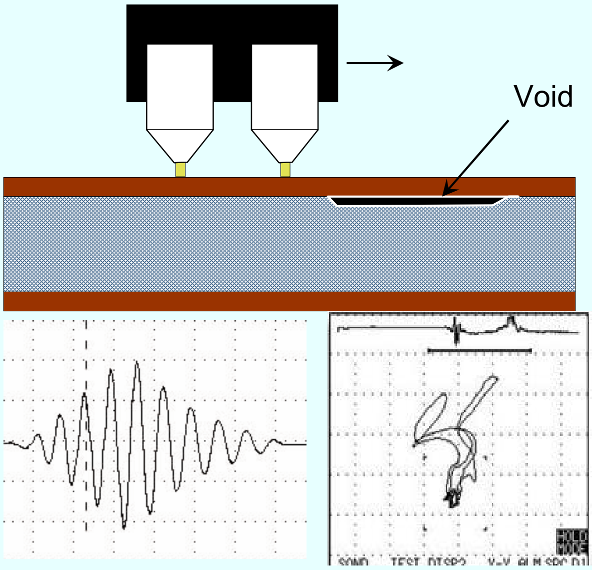
Dry coupled TT

- Easy to apply
  - Standard (or optimised) Flaw Detector
- Rubber coupled probes
- Reasonably sensitive technique
- Standard or roller probes
- Pressure can influence results
  - Both coupling variation and possibility of 'closing defects' especially skin separation...

Low frequency surface methods

“Sondicator”

- Al -> ZETEC / Sonic
- Pitch catch UT
- Typ. ≈ 25kHz
- Variations in surface bonding give variations in transmitted amplitude/phase
- Can use phase plane display and tools like eddy current



Sondicator

- Single sided, no couplant required
- Can give easy / good discrimination of top surface disbonds in honeycomb/ foam cored sandwich, as well as sheet/sheet disbonds
- In favourable circumstance can detect core damage or lower skin disbonds
- Defects defects (on top skin) comparable in size to probe spacing
- Probe spacing needs to be typically 2x cell size to minimise noise
- Rough/ irregular top skins can cause problems

Mechanical impedance

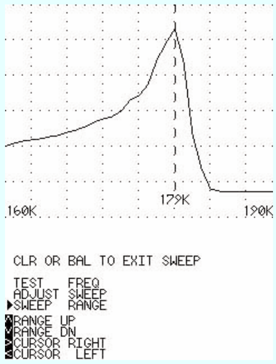
- Staveley MIA
- Very similar performance to Sondicator
- Single probe element, easier to apply / not orientation sensitive
- Can detect smaller disbonds, but more prone to cell noise effects.

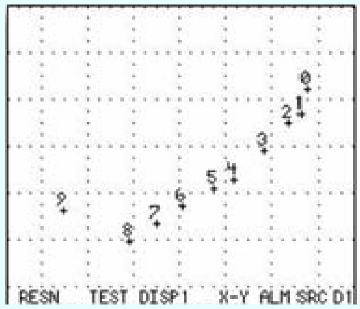
Resonance

- Long Established Method
  - Branson Vidigage 21 (1950's)
  - 700kHz to 25 MHz
  - 140lbs (64kg)
- Gives very good resolution for frequency
- Works for composites too, can get accurate thickness at few 00 kHz

Swept Frequency resonance

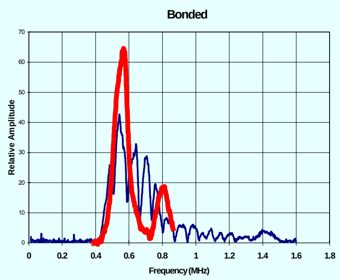
- Zetec/Staveley/Fokker for composite inspection.
- Single sided, Needs couplant
- Typ range 30 – 500 kHz
- Very good for determining thickness/ delamination depth in, e.g CFC
- Relatively slow

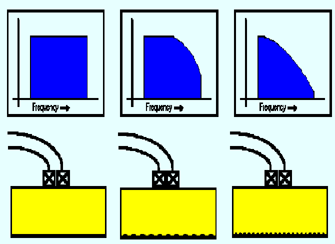




Chirp Resonance Technique

- Ultraspec™
- Use long tone burst (typ 1 ms)
- Typ frequency from 1 – 6 MHz
- Dual element probe
- Multiple FFT Processing
- Good for multiple layer structures and lossy top layers, individual lower layers can resonate separately, strength of different resonances indicates degree of bonding etc
- Frequency response of structure can reveal much about it





So…

- Lots of different issues
- Lots of available tools
- How do we choose…..

Material factors

- Type of material
  - Solid/Foam/Honeycomb
  - Is it consistent (often get inserts, different types of core, etc.
- What defects do we expect to find
- What material properties may interfere with the inspection (e.g 'non-critical' porosity)

Application factors

- Size and Shape of the part to be inspected
  - Is through transmission possible?
- Can we get the material wet/use couplant
- How large a defect can we afford to miss?

- Can't always achieve everything….

Technique Selection

- Can material be penetrated by single sided UT?
- YES
  - Try Pulse echo methods first, remember that C-scanning will often give an effectively 'improved' S/N
- NO

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Technique Selection

- Can we get access to both sides?
- YES
  - Consider Through Transmission approach (Water, Dry or air coupled as appropriate)
- NO

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Technique Selection

- What sort of material are we looking at?
- CORED sandwich (foam or Honeycomb)
  - Try Sondicator or MIA technique
- Monolithic material
  - Try Resonance
- OTHER
  - (maybe Ultraspec?)

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If none of this works

- Think hard
- Consider other methods (Thermography, RT etc..)
- May need to compromise
- Can't always manage these things easily…

Any Questions?