Practical Applications “New” NDT Techniques on Composite Material in the Aerospace Industry

photo: Aviation Week / Airbus

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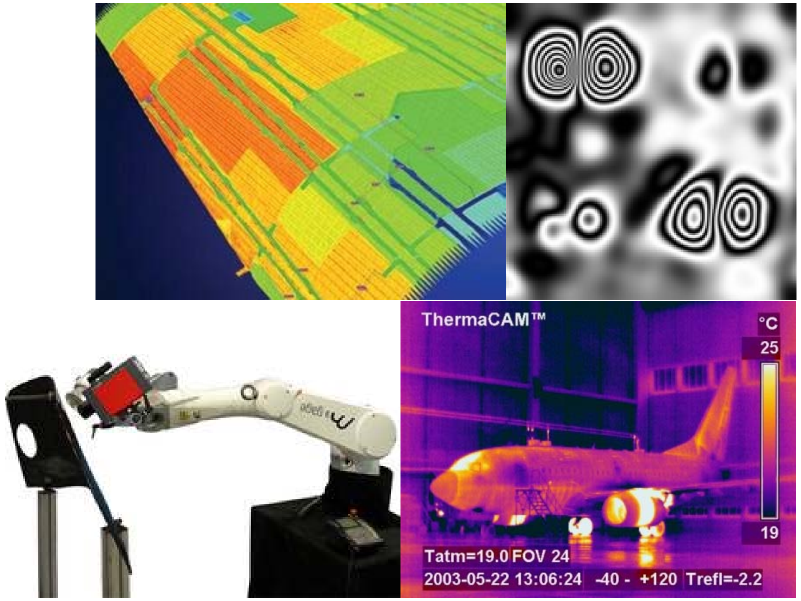
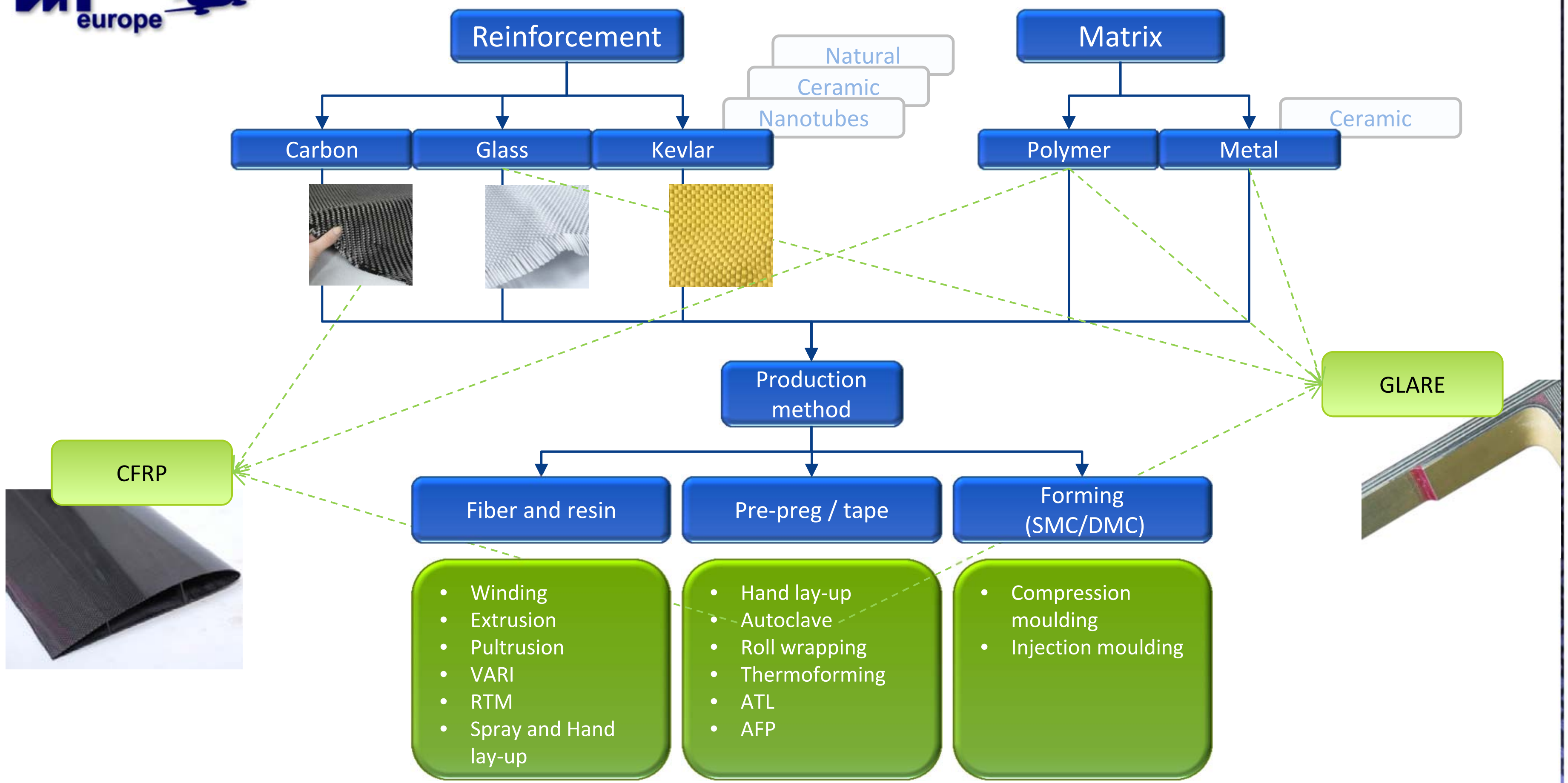
  - Its use in the aerospace industry
  - Type of discontinuities
- NDT methods and techniques
  - General overview
  - In more detail (TT, UT and RT)
- Future developments



COMPOSITE MATERIAL

- Definition: Material built up from (at least 2) different components in which the material (mechanical) properties of the composite is a combination of the best properties of its constituents.
- In the aerospace industry: mostly fiber reinforced plastics are referenced as composite material. However, also fiber-reinforced-aluminum (Glare) and honeycomb/foam sandwich laminates are composite materials.
- Composite material is a true "designer" material; the material can be optimized for the function of the component/structure
- Composite material is being used in many different arrangements or configurations

Composite Fan Blade CFM LEAP
photo: Seattletimes


Reinforcement
Natural
Ceramic
Nanotubes
Matrix
Ceramic
Carbon
Glass
Kevlar
Polymer
Metal
Production method
GLARE
CFRP
Fiber and resin
Pre-preg / tape
Forming (SMC/DMC)
• Winding
• Extrusion
• Pultrusion
• VARI
• RTM
• Spray and Hand lay-up
• Hand lay-up
• Autoclave
• Roll wrapping
• Thermoforming
• ATL
• AFP
• Compression moulding
• Injection moulding

COMPOSITE MATERIAL (SWOT analysis)

Strengths

Mechanical Properties

High strength/weight ration

Corrosion resistant

Fatigue resistant

Complex shapes possible

Opportunities (future)

Automated production

New recycle methods

Legislation

Development of smart and "functional" materials
(self-healing, shape changing, lightning protection)

Weaknesses

High costs

Damage tolerance

Non Destructive Testing

Insufficient design data (compared to metals)

Forecasting/Calculating failure mechanisms

Special repair techniques

Threads

Titanium

Innovation in metals
(machining, super plastic forming, ALM)

Recycling problems

Reputation through (failure-) incidents/events
(delay in production 787)

Shortage in (raw) materials

Legislation (REACH)

COMPOSITE MATERIAL USE

- Composite material is being used for decades in the aerospace industry
- The use of composite material in the aerospace industry is growing; also in primary structures and components

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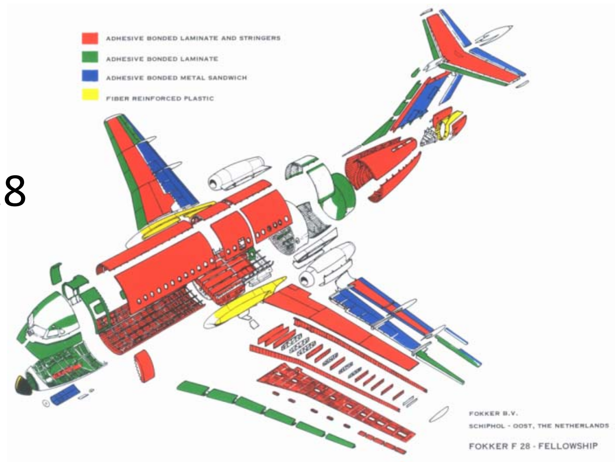
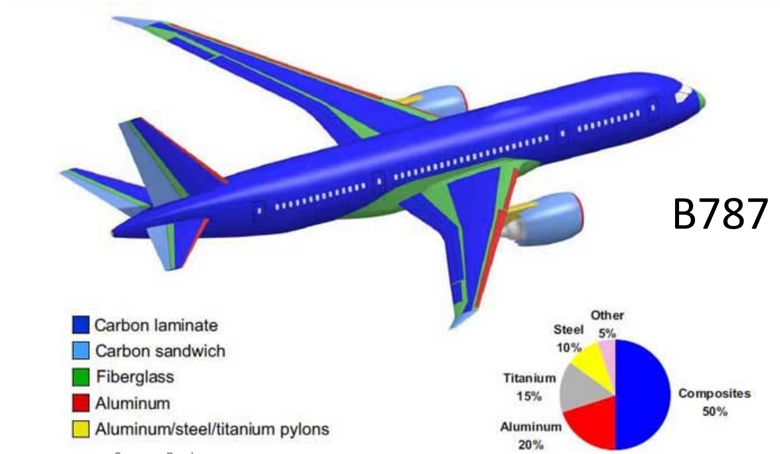
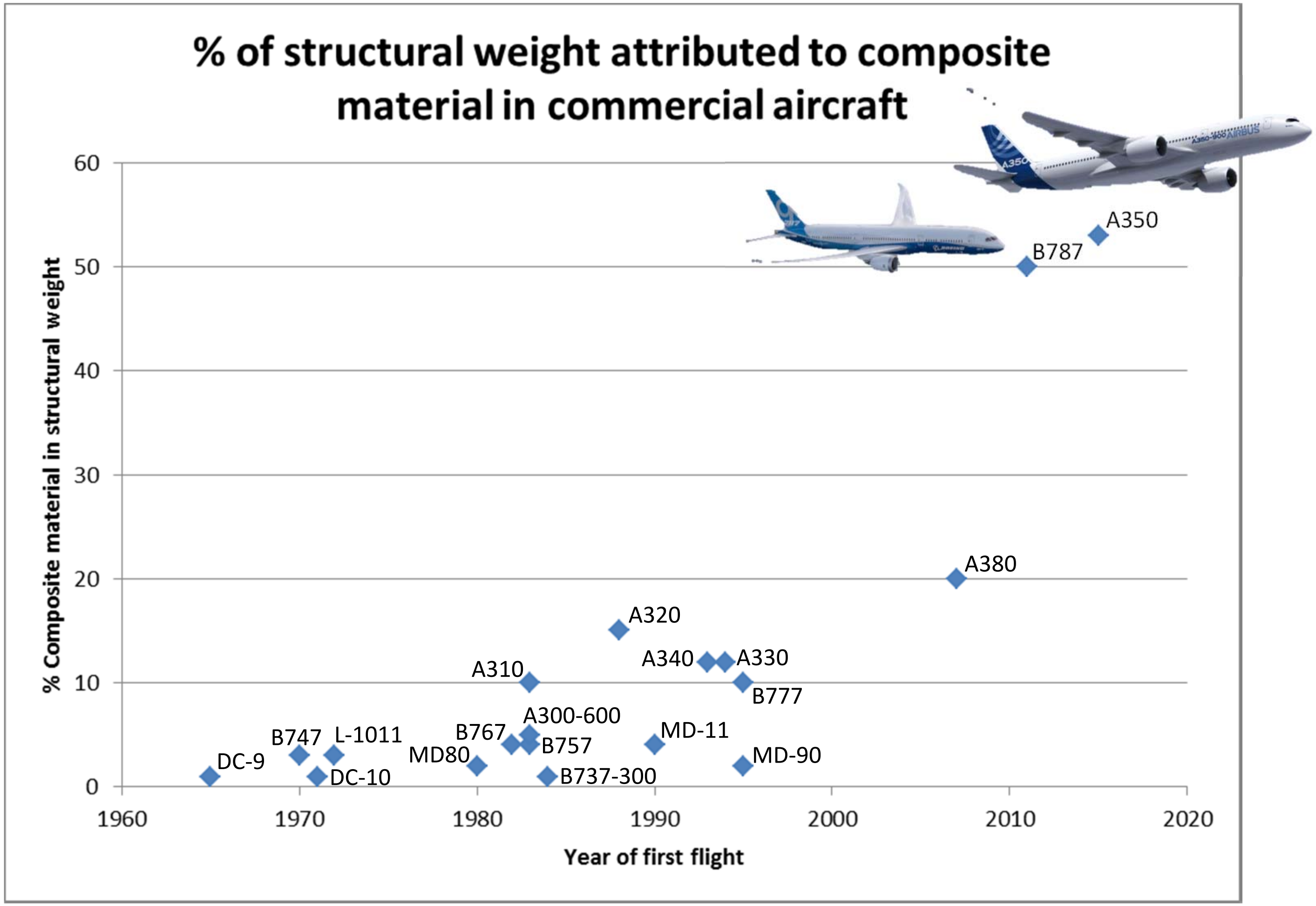


B787



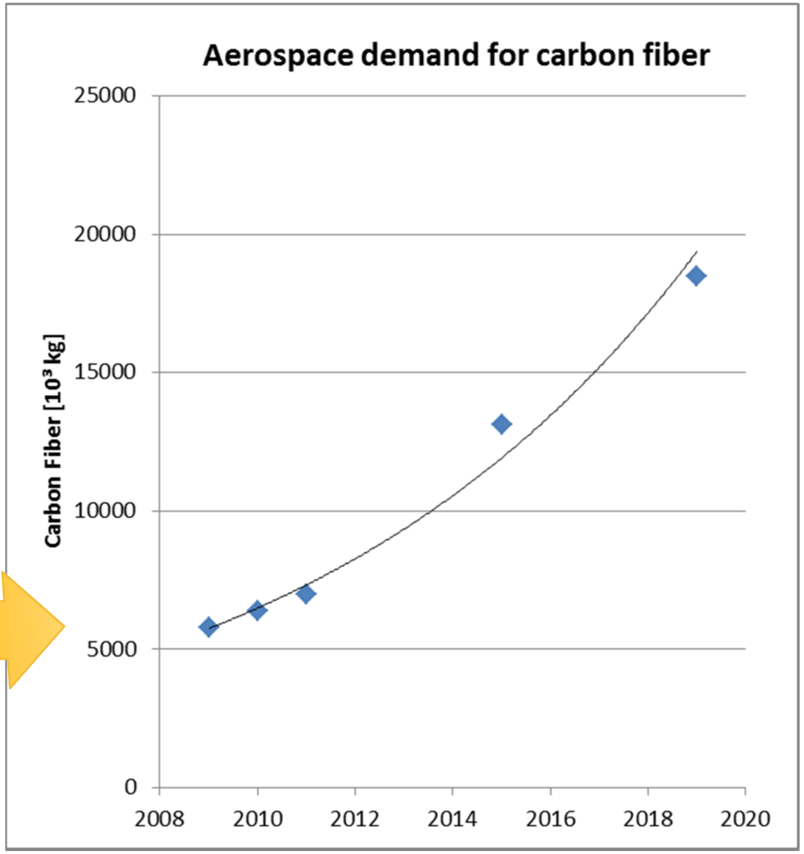
Source: Boeing



Source: Airbus, Boeing

Usage of composite material in the aerospace industry:

- In the commercial sector
  - Percentage of structural weight stabilizes more or less
  - Percentage of structural weight turbofan engines increases strongly
  - Total volume increases progressively; material shortage is a point of concern
  - Demand for carbon fiber:
  - FYI: world wide demand for carbon fiber in 2019 is expected to be 134,280 metric ton, for 2015 this is ± 90,000 metric ton which is more than double the amount of what was ordered in 2009. (source: CompositeWorld)



Reasons for the increase in use of composite material in the aerospace industry:

- Rising oil prices
- More stringent environmental requirements with respect to emissions (CO_2 / NO_x) and noise
- Expected rise in commercial air traffic

- By using composite material, the aircraft weight can be reduced and with that also the fuel consumption and emission (CO_2 / NO_x)
- Design advantages of composite material offer new possibilities *(shape, function, use, maintenance)*

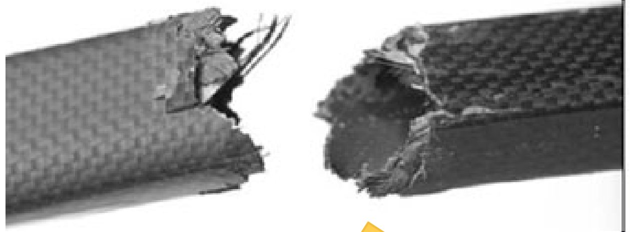
Consequences (or points of concern) by the growing use of composite material in the aerospace industry:

- Design:
  - Increase/expand knowledge/data/methods, calculation & simulation modelling, sharing information (make available), standardization
- Production:
  - Improvement in manufacturing methods in order to answer the growing demand through increasing production quantity and speed
- Quality Assurance:
  - Process control and inspection (including **NDT**)
- Operation/Maintenance:
  - Inspection (including **NDT**) and repair procedures
- Personnel:
  - Specific education, training, certification

FAA (2010): "Composite applications are expanding faster than the qualified workforce involved in structural engineering, manufacturing and maintenance functions."

NDT of Composite material:

Typical Discontinuities (Defects)

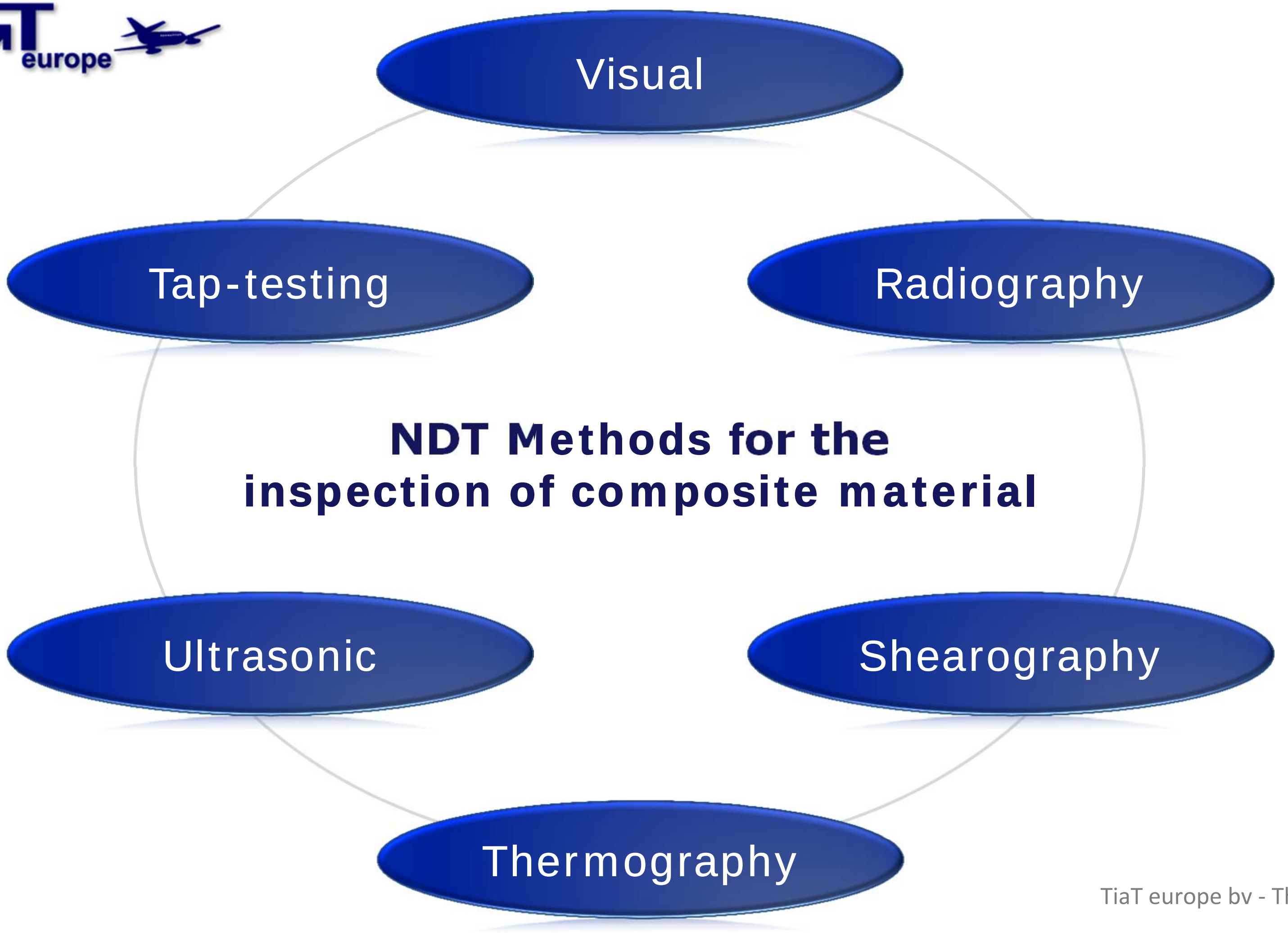


Manufacturing

- Delamination
- Fiber misalignment
- Resin starved or rich areas
- Blisters, air bubbles
- Wrinkles
- Voids or porosity
- Thermal decomposition
- Uneven, insufficient or over curing
- Insufficient fiber volume
- Inclusions

In-Service

- Environmental degradation
- Impact damage
- Moisture ingression
- Fatigue
- Cracks from (local) overload
- Debonding, Delamination
- Fiber fracturing
- Erosion or abrasion
- UV damage, weathering
- Chemical attack

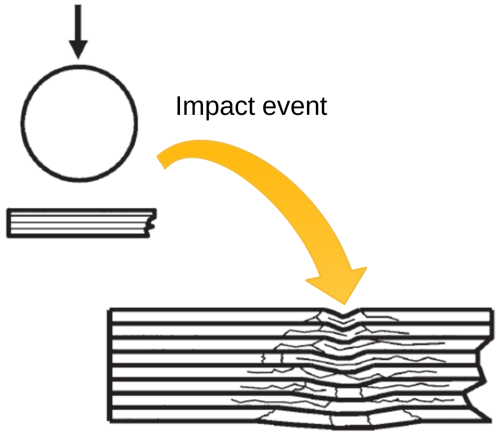

Visual
Tap-testing
Radiography
NDT Methods for the
inspection of composite material
Ultrasonic
Shearography
Thermography

“Conventional” methods for NDT of composite materials:

- Visual Testing
- Tap Testing
- Ultrasonic Testing
- Radiography

Visual Testing:

- First inspection (especially during in-service inspection)
- Restricted to the detection of surface breaking defects
- Relative straight forward, simple, effective method
- Points of concern: inspection conditions (especially illumination) and inspector training
- Defects can be missed: Impact may result is major internal structural damage which is hardly visible at the surface



Tap Testing:

- Audible Sonic Testing (Coin Tapping), 10-20Hz
- Detection of disbonds and delamination
- The simple version relies on the well practiced hearing of the inspector
- Automated "tap testers" are more sophisticated and do not rely on the practiced hearing (Wood pecker, RD[3])
- Method performs better on the thinner sheet thicknesses

Photo: WichiTech Industries, Inc.

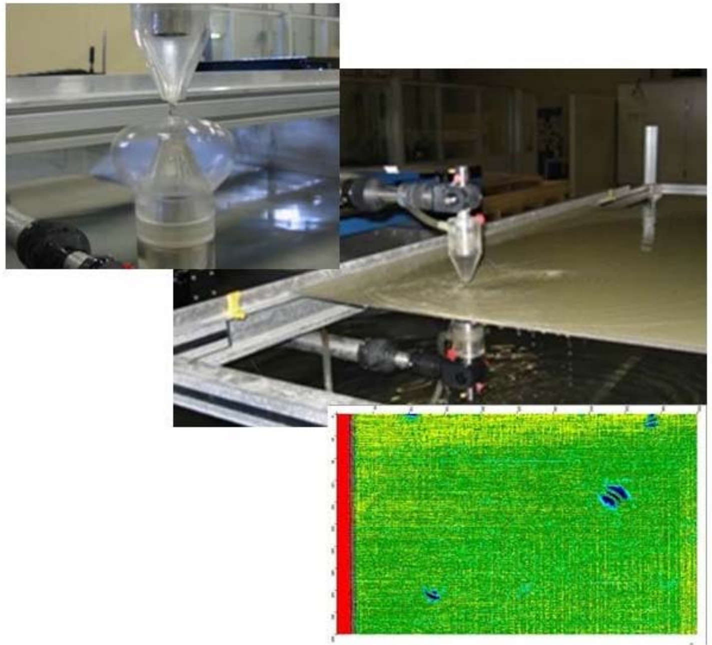
Ultrasonic Testing:

- Widely used for the inspection of composite materials, utilized in both manufacturing as in-service situations, manual and automated inspection systems
- Suitable for detection of most common defects such as internal delaminations, disbonds, voids, or inconsistencies in composite components
- Uses “ultrasonic” (high frequency) sound wave energy
- Several techniques are utilized:
  - **Through Transmission**
  - **Pulse-Echo**
  - **“Bondtester”**
  - **Phased Array**
- Combining the ultrasonic inspection with scanners enables the recording of inspection results in “C-scan” form

Roller Probe UT Inspetion, photo: Sonatest.

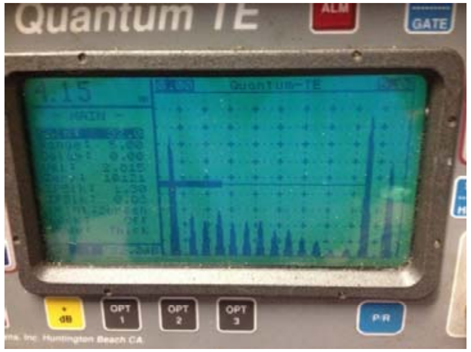
Trough Transmission Ultrasonic Testing:

- Requires accessibility from 2 sides (transmitter on one side, receiver on the other side of the product)
- In scanner systems: immersion or using squirters (water is the couplant)
- Air-coupled ultrasonics
- No “depth” information about the discontinuities found
- Proven technology for a wide range of applications in automated systems
- Scanner systems are less practical for onsite in-service inspections

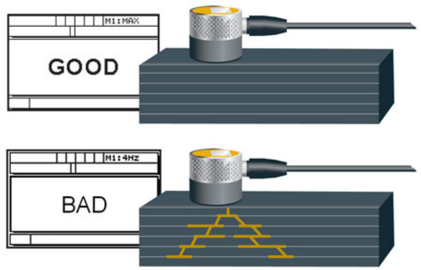


Pulse Echo Ultrasonic Testing:

- Widely used for the inspection of composite materials, utilized in both manufacturing as in-service situations
- In manual and automated systems
- Penetration depth restricted in composite material (compared to metals) because of damping, absorption and dispersion
- Proven technology for a wide range of applications in automated systems and manual uses
- Simplified, go/no-go versions available
  (example: 35RDC is incorporated in Boeing procedures, it is designed to detect subsurface defects caused by impact damage on aircraft composite structures)



35RDC. Photo: Olympus



"Bondtester" Ultrasonic Testing:

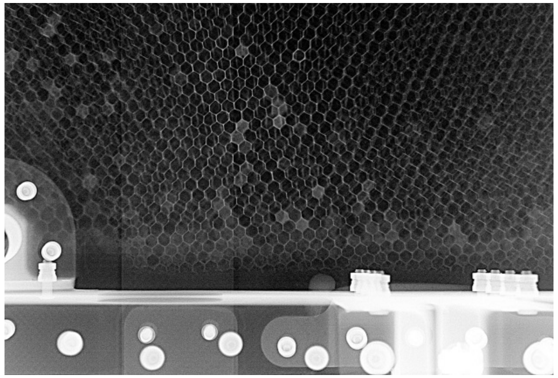
- Special equipment designed for the detection of delamination and disbonds in composite laminates
- The instruments utilize techniques as:
  - Pitch-Catch (RF, Impulse Mode, Swept Frequency)
  - MIA (fixed and swept frequency)
  - Resonance
  - Resonance-Impedance
- Examples:
  - Bondmaster (Olympus)
  - Bondascope (NDT Systems)
  - Sondicator (Zetec)
  - Fokker Bondtester (Servicing Europe)
- For local, manual inspections

Bondmaster. Photo: Olympus

Bondascope. Photo: NDT Systems

Radiography:

- Not the preferred method for detecting defects such as delaminations that are in a plane that is normal to the ray direction
- Most effective method, however, for detecting flaws parallel to the X-ray beam's centerline
- Internal anomalies, such as delaminations in the corners, crushed core, blown core, water in core cells, voids in foam adhesive joints, and relative position of internal details, can readily be seen via radiography.



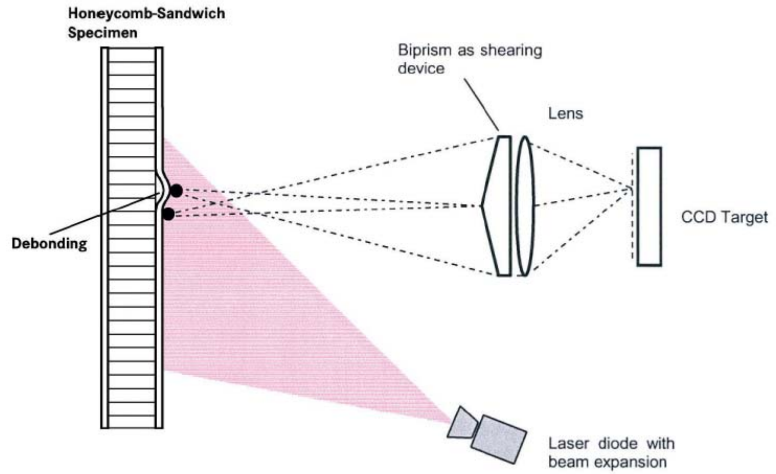
Relative “new” NDT methods for the inspection of composite materials:

- Shearography
- Infrared Thermography
- Phased Array Ultrasonic techniques
- Digital radiography

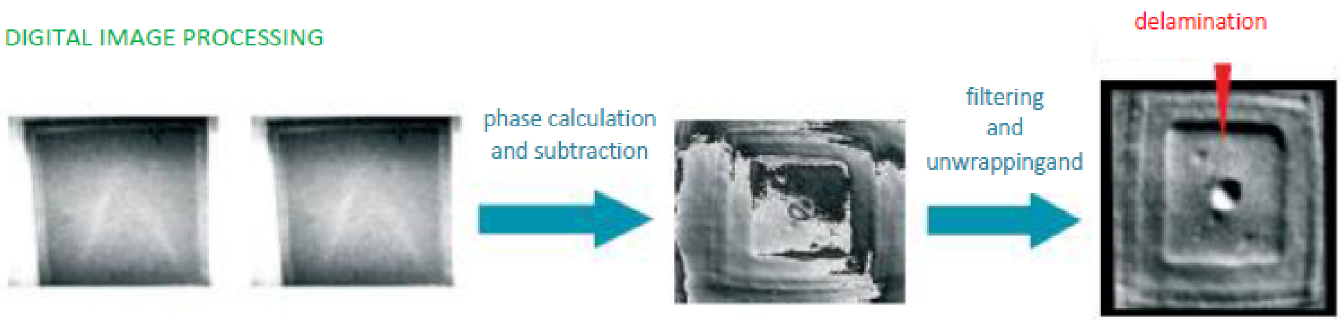
Shearography:

- Using laser light, a shearing interferometer is able to detect extremely small (sub-micrometer) changes in surface deformation. When a test object is subjected to an appropriate change in load, a proportional strain is induced on the test surface. If underlying surface discontinuities are present, the surface will deform unevenly which is interpreted through the interferometer as a shearographic image
- Shearograpy allows users to measure and qualify large surfaces quickly and efficiently, yielding near real-time results.


Photos: Dantec Dynamics



DIGITAL IMAGE PROCESSING



video images (loaded/unloaded state)

phase image

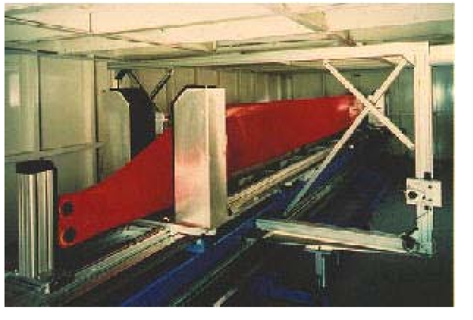
result image

Images: Steinbichler

Shearography :

- Fast optical method
- No contact with the part
- No couplant needed
- Single side access
- Interpretation of results is easier (compared to thermography); the deformation of the surface caused by stress/loading is measured, so defects are detected only by their mechanical response
- Robotic shearography
- Applications: Sandwich panels; detection of disbonds, delaminations shared core etc., impact damage

- Interpretation of results required special trained inspectors
- Requires special inspection conditions (surface condition, illumination)
- Loading of the part may cause damage
- Delicate equipment



Shearography inspection of helicopter blade
Photo: NDT.NET

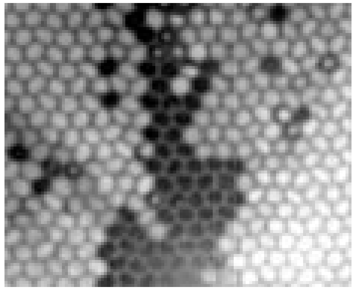
Infrared Thermography:

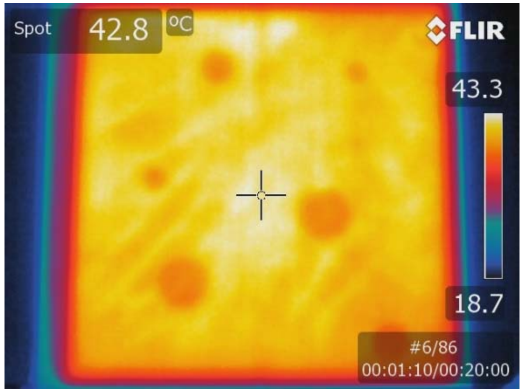
- Infrared Thermography is defined as the non-contact mapping and analysis of thermal patters emitted from the surface on an object
- Passive and Active thermography: for NDT on composite materials mostly **ACTIVE**
- In the past Liquid Crystal Sheets were used
- Infrared Thermography Cameras have become available for NDT

Infrared Thermography (cont.):

"Conventional" active thermography

- Heat input with simple hot-air blowers, or heat removal by cooling in a refrigerator
- Best suitable for applications were there is a relative large difference in temperature between areas without discontinuities and the discontinuities.
  Examples:
  - Detection of moisture ingress (especially in honeycomb laminates)
  - Detection of delaminations (in the carbon top sheet) in a carbon-foam laminate
- Developments: microwave excitation for improved water ingress detection (only water gets heated)

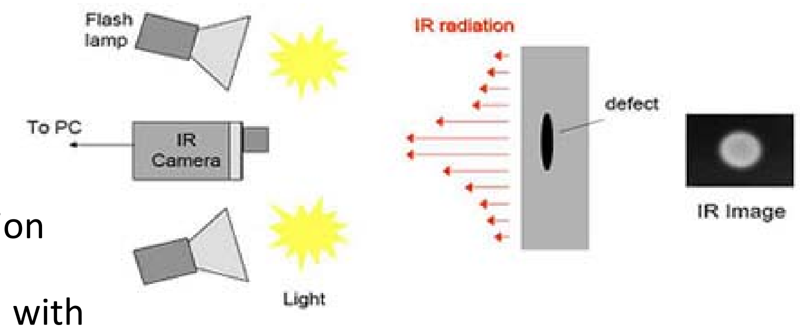


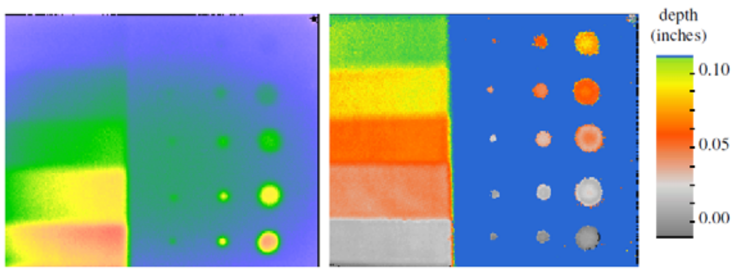


Infrared Thermography (cont.):

"Advanced" active thermography

- The heat input is more controlled (duration)(flash lamps, or other), creating a "heat wave" progression through the material
- The images taken by the camera are synchronized with the heat input and analyzed (requires "faster" cameras and signal processing software)
- Analyzing focusses on speed of changes in surface temperatures *(1st, 2nd derivatives)*
- Techniques:
  - Flash Thermography
  - Pulsed Thermography
  - Lock-in Thermography
  - Transient Thermography
- Advantages: better detection of internal discontinuities (delaminations etc.), depth information of defects





Source: Flash Thermography of Aerospace Composites Steven M. Shepard

Infrared Thermography (cont.):

Advantages:

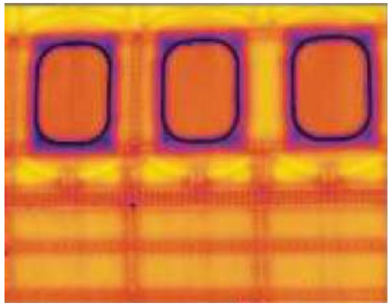
- Can be used for testing of large areas for delaminations, water inclusions and bad bondings
- Non-contact
- Short measurement time
- Suitable for a great variety of metals, plastics and composite materials (aluminium, steel, palstics, CRP, GRP, Honeycomb)
- Economically advantageous solution for 100% testing

Source: Automation Technology GmbH

Infrared Thermography (cont.):

"Advanced" active thermography

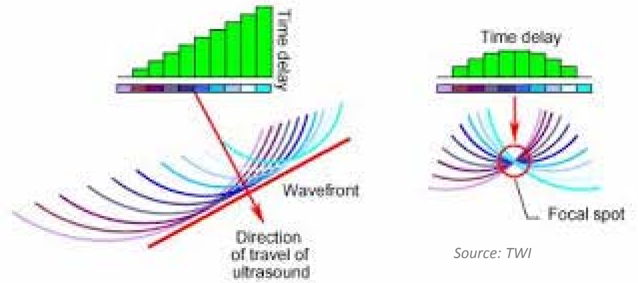
- More and more used in the aerospace industry for both manufacturing as maintenance applications
- Improved signal processing and analysis software (early versions were based on analysis of contrast in the post-heating image data sequence, modern systems treat each pixel as an independent time series, so that information about the state of a sample can be acquired from a single pixel)
- Improved Infrared cameras
  (frame rate / image capture frequency up to 4500Hz)
  (thermal sensitivity: up to 1mK)
- Automated inspection systems (using robots)



Source: Automation Technology GmbH

Phased Array Ultrasonic Testing:

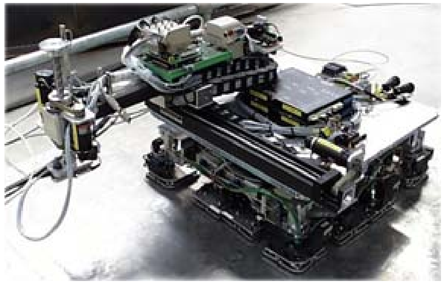
- 0-deg longitudinal ultrasonic pulse echo is mostly used when testing composite material; the array type transducer utilizes multiple probe elements *(upto 128 elements supported in the Olympus Omniscan)* increasing inspection track width
- Phased array is being used in both manufacturing and onsite in-service inspections situations
- Combined with encoders/scanners/software; phased array inspection provides c-scan images combined with a-scan information of each point of the inspected surface
- Phased array techniques can be used to optimize the focusing of the signal
- Phased array probes are available in different shapes to optimize for focusing and/or surface contour



Phased Array Ultrasonic Testing Developments:

- Following complex shapes
- Using automated systems (robots)
- Phased Array Roller probes (combining easy surface scanning and c-scan recording capabilities)
- Presentation of the inspection results: further development of software to combine scanner and ultrasonic information into 3d reconstruction of the component with discontinuities (location, orientation, size etc.)

Roller probe. Photo: Sonatest

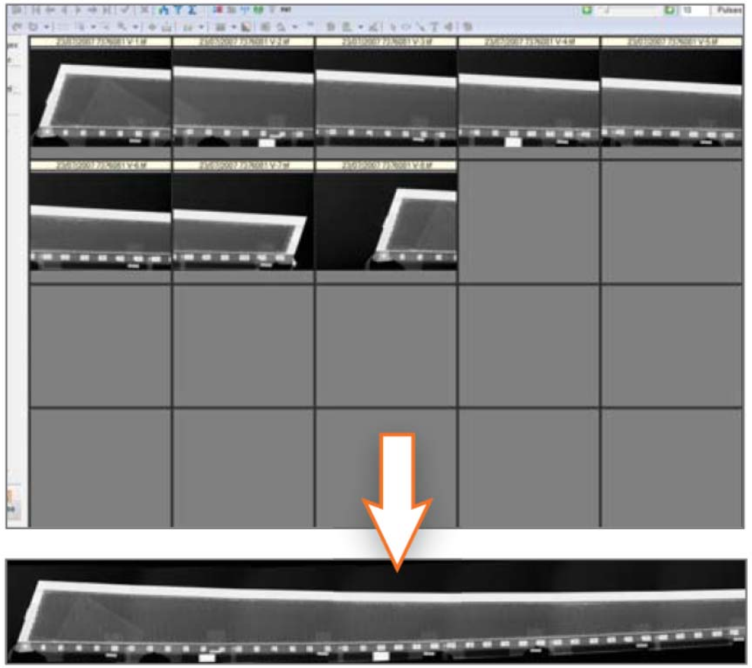


RobAir Project. Photo: NDT Consultants Ltd.

Digital Radiography:

- Image management, reporting possibilities (image enhancement, image stitching etc.)
- Image analysis
- Increase inspection speed
- Automated systems are considered
- Computed Tomography (3D image processing)

Photo: Vidisco

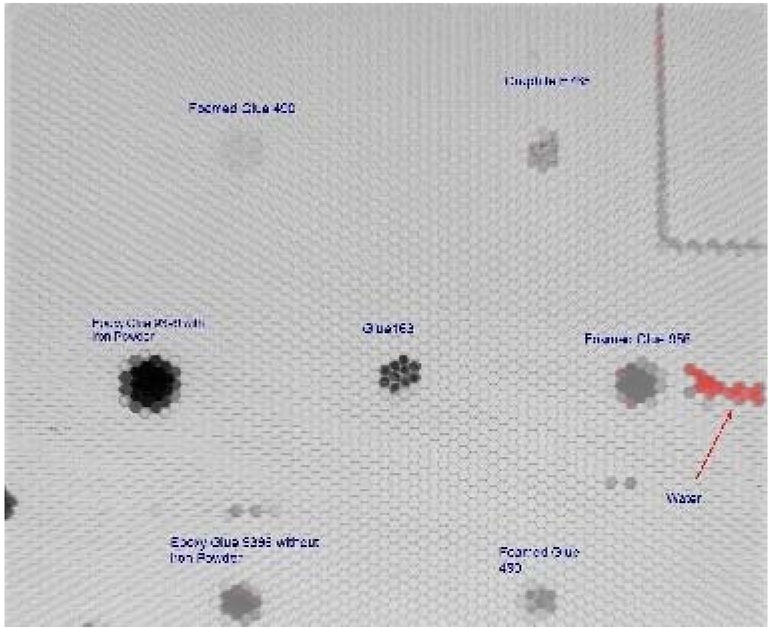


Automatic Stitching

Photo: Vidisco

Digital Radiography (cont.):

- Dual Energy Detection. With this technique a differentiation is made between organic substances and inorganic substances (and light inorganic materials and hard inorganic materials such as metals).
  This differentiation is enabled by taking X-ray images at various energy levels (at least two, hence the name “Dual Energy”), and comparing density in order to deduct if a material seen in an X-ray image is organic or inorganic. An example of this technique used the NDT field is to positively distinguish water in honeycomb sandwich structure from resin and filler.
  Other application are under development



Water in dual energy. Photo: Vidisco

General remarks:

- In the new NDT methods and techniques, analysis of inspection measurements and imaging and visualization of the results are strongly integrated
- Because of the wide variety of composite material, qualification of inspections need special attention (and need to be performed for (almost) each separate configuration*) (result in the past are no guarantee for the future)*
- With the continuous development in composite materials, it is likely that methods as shearography and thermography NDT techniques will become more prevalent over traditional NDT techniques.

Considerations:

- Further develop and fine tune the available NDT methods and techniques to cope with the special and diverse conditions/configurations when inspecting composite materials.
  A significant move forward is needed to catch up with and prepare for the growing use of composite material in the aerospace industry. Including the training and certification aspects

FAA (2010): "Composite applications are expanding faster than the qualified workforce involved in structural engineering, manufacturing and maintenance functions."

Considerations (cont.):

- Standardization (development of codes, standards, and procedures) with respect to NDT, will require a different approach (compared to metals)
- Sharing knowledge, teaming-up in projects and research and development programs is invaluable in achieving the goals for efficient NDT of composite materials.

Developments at TiaT europe:

- Special training programs for non-destructive testing of composite materials are developed and implemented.
- Participating in several projects regarding composite materials
- Teaming up with other companies, authorities and parties in order to solve specific inspection challenges with composite materials

Thank you for your attention