Computed Tomography (CT) as a Nondestructive Test Method used for Composite Helicopter Components

Reinhold Oster
MBB, Deutsche Aerospace AG
Helicopter Component Test
Munich, Germany

Abstract

The first components of primary helicopter structures to be made of glass-fiber-reinforced plastics (GFRP) were the main and tail rotor blades of the Bo105 and BK117 helicopters (Bölkow system). These blades are now successfully produced in series.
New developments in rotor components, e.g. the rotor-blade technology of the Bo108 and PAH2 programs, make use of very complex fiber-reinforced structures to achieve simplicity and strength.
Computed tomography has been found to be an outstanding nondestructive test method for examining the internal structure of components. A CT scanner generates x-ray attenuation measurements which are used to produce computer-reconstructed images of any desired part of an object.
The system images a range of flaws in composites in a number of views and planes.
In the past ten years MBB has used conventional medical CT scanners to test composite materials. This paper reports on several CT investigations and their results, taking composite helicopter components as an example.

Computed tomography: a universal nondestructive test method

In recent years the objective of helicopter rotor development has been to simplify rotor design. The result has been that more and more functions have been integrated into rotor blade structure itself (e.g. the Bo108), resulting in ever increasing structural complexity. Such complex structures of composite materials do not lend themselves well, if at all, to the usual nondestructive test methods, such as ultrasonic or conventional x-ray testing. These methods are especially unsuitable for testing the thick-walled composite laminates of rotor-blade structures (blade joint).
Computed tomography (CT) is an imaging method that closes ths gap. CT is especially suitable for applications involving spatial analysis, differentiation, material identification, flaw analysis and structural quantification. This is made possible by the method's good spatial (0,2 mm flaw size) and very good density resolution.

Procedure

CT utilizes the transmission properties of x-rays to produce a tomogram, a crossectional image of objects that are attenuating to x-rays. A tomogram effectively visualizes the density distribution inside the test specimen. Fig. 1 to 3 illustrate the principle of the technique.
A tomogram is produced by moving x-ray tubes ③ and detectors ⑤ around the test object ① in a number of discrete angular steps and measuring the attenuation ⑥ profile in each step. From this series of attenuation profiles, the computer uses a filtered back projection to calculate the distribution of the attenuation coefficients through the cross-section and displays this distribution as a grey-scale image (tomogram) on the screen. Another advantage of CT is that it is not restricted to composite structures. For example, it can also be used to inspect metallic components or rubber-metal compounds (elastomer bearings). However, for such applications a sufficiently powerful x-ray tube is required.
The drawback of CT is that owing to design constrains the object size is limited to a certain diameter, which depends on the field size ② of the scanner. Medical CT scanners, for example, have a field size of 48 cm.

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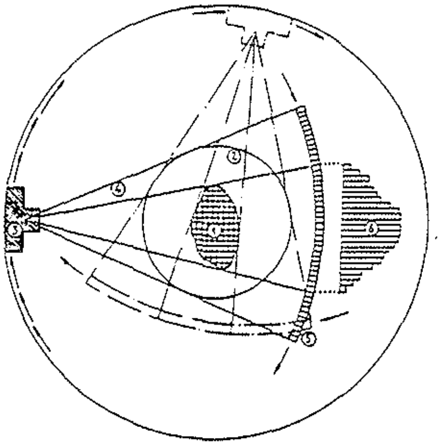


Fig. 1 Measurement principle

Data of the GE 9800 medical rotation scanner (General Electric)	
Field size	9.8 to 48 cm
Slice thickness	1.5, 3, 5, 10 mm
Positioning travel	1.0 m
Scanning times	2, 3, 4, 8 sec.
Cycle times	20 sec (with 2 sec scan)
Image matrix	512^2
Reconstruction	From 100 layers
Other levels	
High voltage	00, 120, 140 kV
Tube current	10 - 300 mA
Focal point	1.0 mm
Detectors	864 (solid state)
Grey-scale display of attenuation	CT units: -1000 to 4000 water 0, air: -1000, GFRP: - 1000 - 1300, CFRP: 300 - 500
High-contrast resolution (2 sec scan / 120 kV / 200 mA)	0.35 mm

Fig. 2 Technical data

Fig. 3 Tomogram of the rotor-blade neck of the Bo105 helicopter (Bölkow system)

Scan data:

- Upper left: Position, image number, field size algorithm
- Upper right: Location, specimen data
- Lower left: Tube voltage, tube current, slice thickness, scanning time (in this case 2 sec.)
- Lower right: Grey-scale spread (CT units)

CT inspection of helicopter rotor blades

The distinguishing feature of composite materials is that the strength and structural shape and thus the component itself - are not determined until the curing stage.

The primary aim of a nondestructive test method is to obtain test results from which conclusions can be drawn regarding any anomalies in the rotor blade. Anomalies may be production flaws or changes produced by operational loads and may lead to considerable strength losses, thus significantly reducing the blade's useful life.

CT provides thorough a nondestructive means of testing composite structures. The most important flaw types and the analytic possibilities are listed in Figs. 4 and 5.

Fig. 4 Flaw types

- Buckling of the laminate (longitudinal, transverse)
- Curing cracks
- Fiber cracks
- Delaminations (up to 0.2 mm)
- Air inclusions
- Nonuniform resin/glass distribution
- Resin pockets/accumulations
- Shifting of structural parts
- Scale detachment
- Bonding flaws between skin and laminate
- Bonding quality of sandwich structures
- Bonding of foam cores
- Foam fractures
- Foam deformations
- Separating films (only very limited)

Fig. 5 Analytic possibilities

- Imaging (cross-section and 3 D)
- Display of structures with large density differences
- Density measurements of composite structures
- Flaw identification (e.g. air or resin)
- Material identification (e.g. glass, carbon, resin, foam)
- Mold closure problems (laminate gaps)
- Flaw size (volume, length, shape)
- Flaw location
- Strength analysis
- Determination of degree and nature of damage
- Crack propagation measurements
- Damage cataloging
- Comparative analysis of structural makeup and density
- Component documentation/error tracking

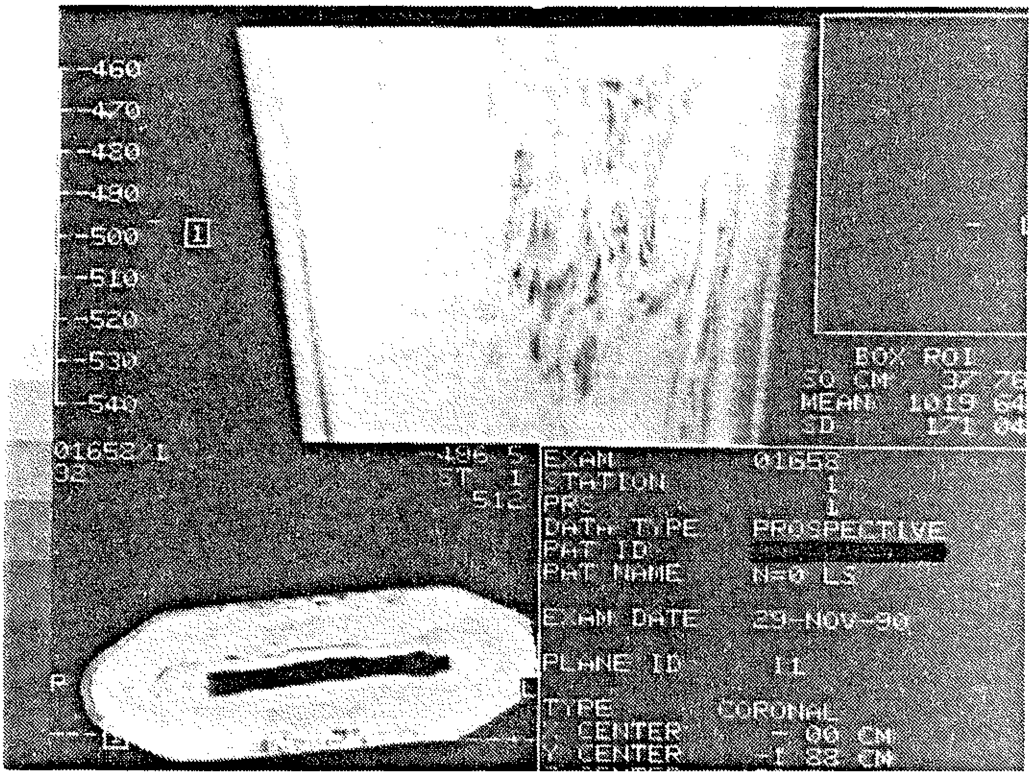


Fig. 6 GFRP prepreg structure with buckling.
CT image obtained by scanning a block 99 mm in length
(66 cross-sections, 1.5 mm slice thickness)

Sample Tomograms

The following pages show sample tomograms of various rotor-blade structures (design studies).

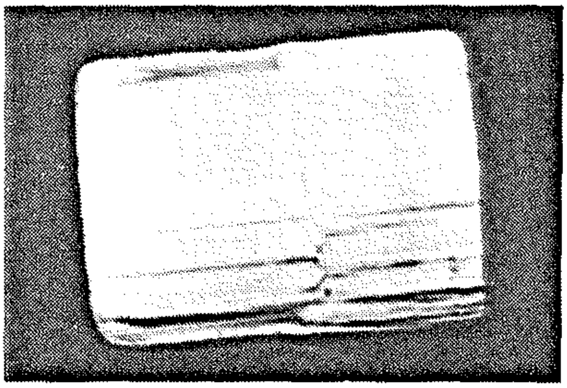


Fig. 7 CT image
Cross-section of a dynamically loaded original GFR prepreg laminate. Note the interlaminar and intralaminar delaminations. Delaminations as small as 0.2 mm can be detected with CT.

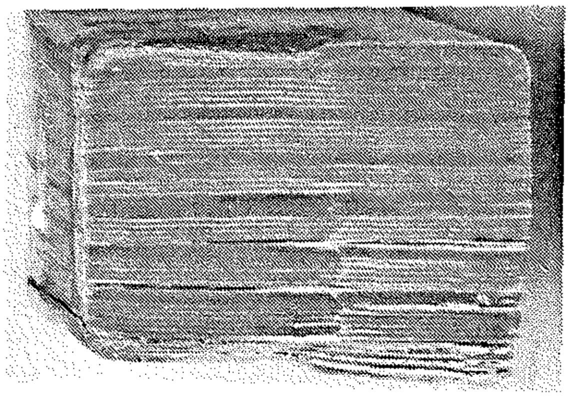


Fig. 8
Comparative image of the original cross-section from Fig. 7

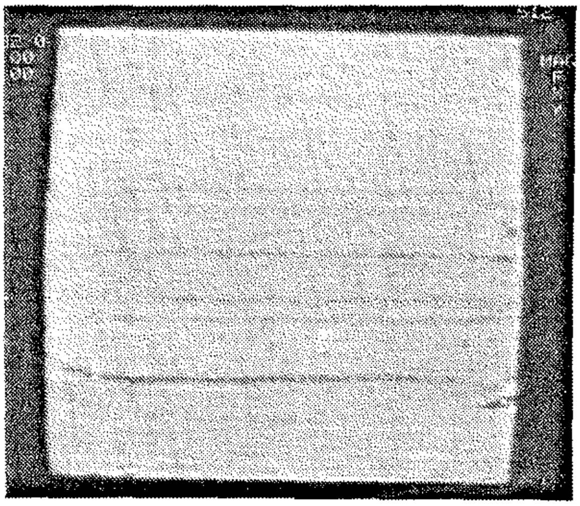


Fig. 9
Interlaminar delamination in a homogeneous prepreg laminate (with uniform distribution of resin and glass).

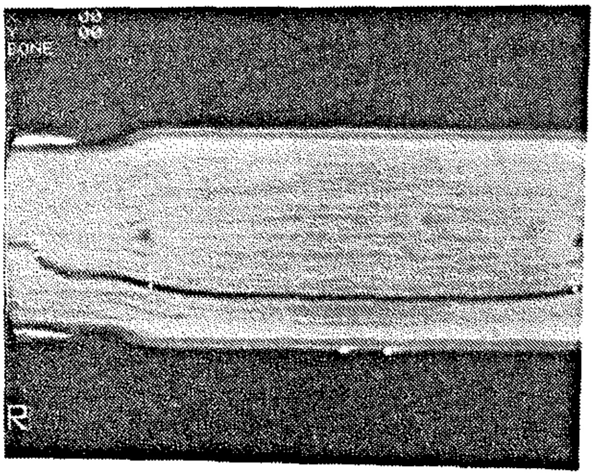


Fig. 10
Interlaminar delaminations in a multiple-ply GFRP section composed of various prepreg laminates.

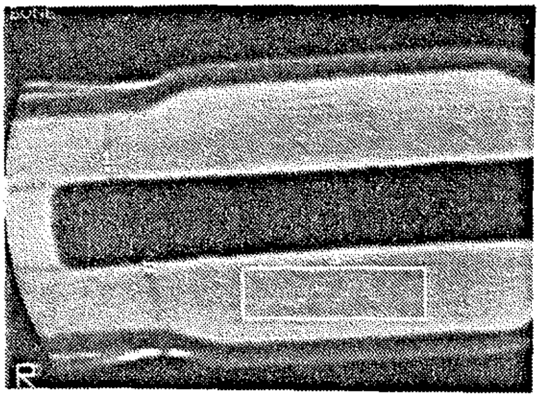


Fig. 11
Curing cracks in thick-walled prepreg composite laminates with different coefficients of thermal expansion (GFRP/CFRP combination)

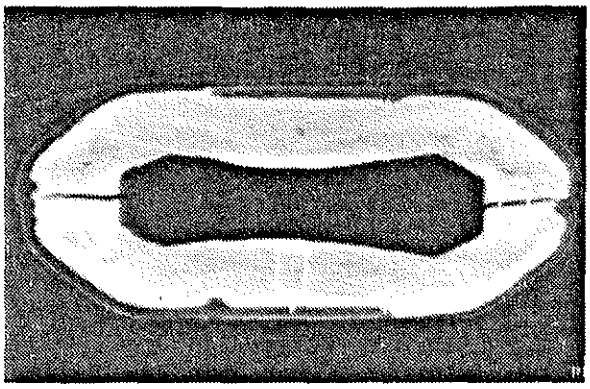


Fig. 12
Curing cracks in a GFRP/CFRP composite laminates

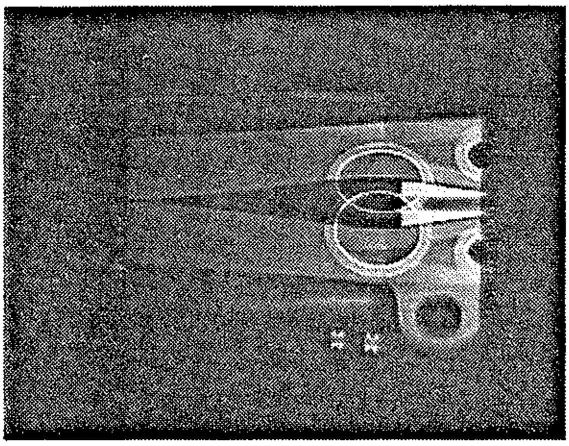


Fig. 13
Shadow image of a rotor-blade joint.

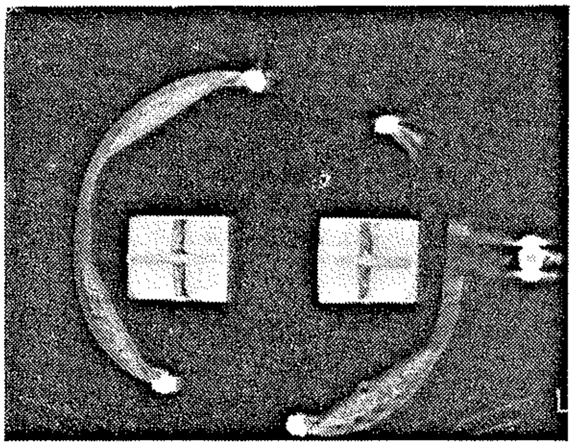


Fig. 14
CT image of a rotor-blade attachment
Inside: GFR structure
Outside: CFR torque tube

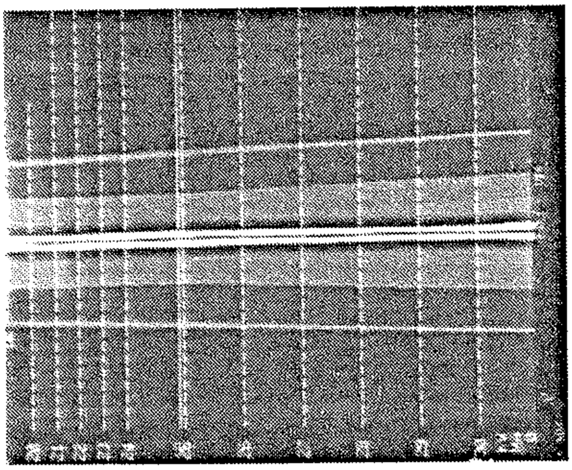


Fig. 15
Shadow image of rotor attachment with twist element.

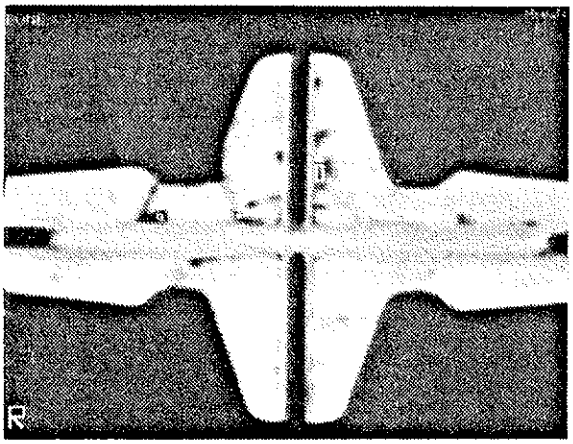


Fig. 16
Cross-shaped twist element of a unidirectional GFR element. Air inclusions, resin pockets

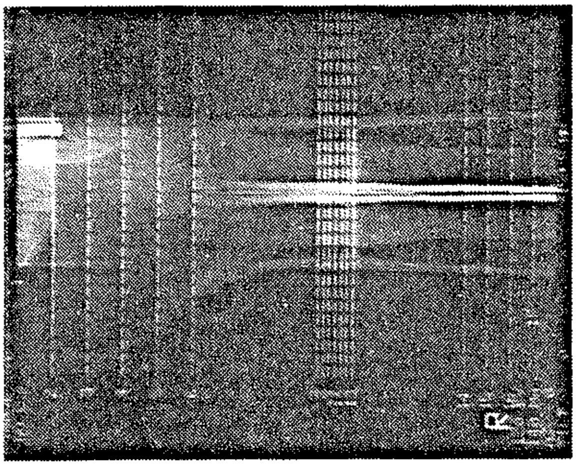


Fig. 17
Shadow image of the transitional area between the rotor twist element and the blade section.

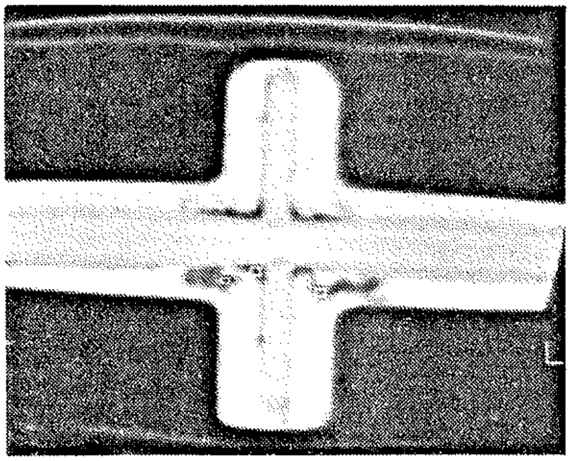
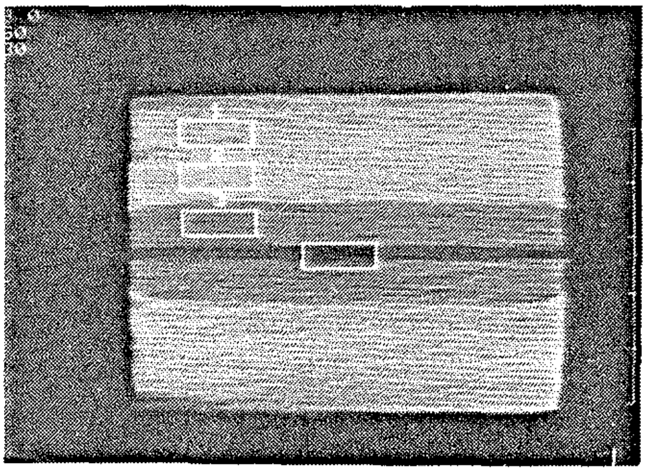


Fig. 18
CT image of twist-element transition.
Inside: Cross-shaped twist element
Outside: CFRP envelope (sandwich construction). Air inclusions have CT values less than 0.

Density measurements

A good way to test the quality of a laminate is to determine the composite structure by means of CT density measurements. The laminate type as well as the uniformity of the resin-fiber distribution can be readily demonstrated.



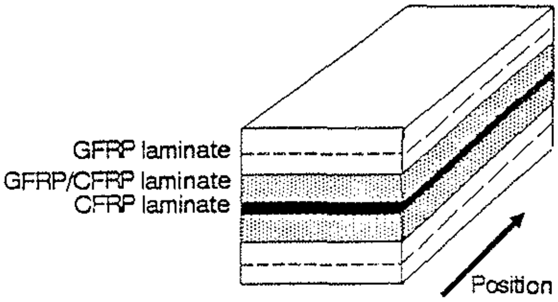
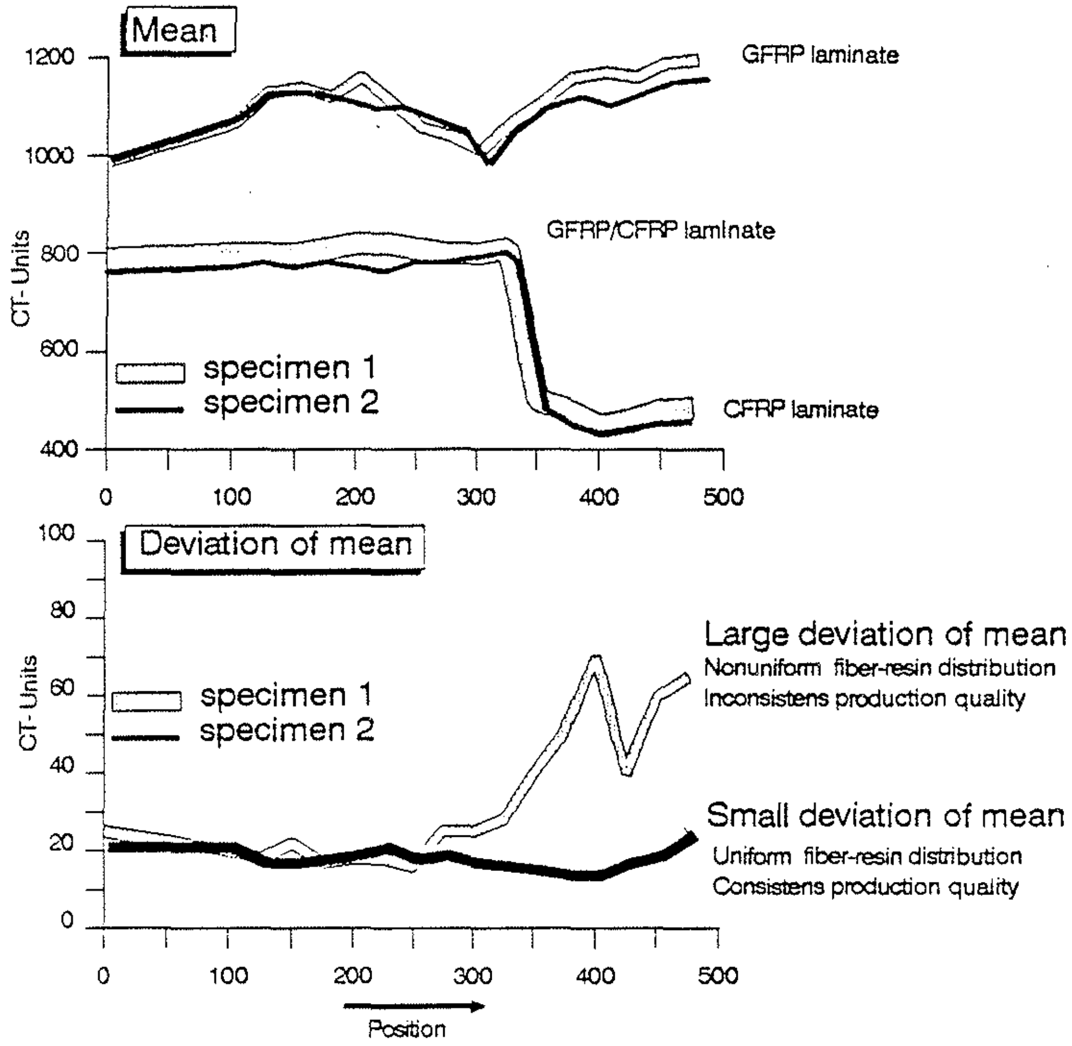


Fig. 19
shows sample results of density measurements on two different test objects. A uniform resin-glass distribution produced, for example, by buckled laminates, can also increase the deviation of mean of the density values.



Correlation strength/CT

As an imaging technique, CT has the advantage of providing a very precise insight into the nature of the composite structure. The difficulty in interpreting tomograms lies in finding a correlation between the image and the structural strength of the component. To this end a reference must be created which relates the tomogram to strength. This can be accomplished very early in the development of a rotor blade. Every new composite structure of a rotor blade must undergo destructive testing for strength and life before it can be flight-tested on a helicopter. It is possible to qualify CT by using it as a complementary nondestructive test method in this application. It was thus possible at a very early point to compile a flaw catalog which can and should be continuously added to during production and operation.

The possibilities of assessing composite structures for flaws and damage tolerance have thus been greatly extended. An example should illustrate this Figs. 20, 21, 22 and 23 shows a CT images of the composite structure of a dynamically tested rotor-blade design study.

The tomogram clearly shows buckled laminates which undergo delamination during the dynamic fatigue test. The optimized composite structure, as shown in Figs. 22 and 23, has a much more uniform laminate structure and no buckling. In the dynamic fatigue test this component had a manifold useful life.

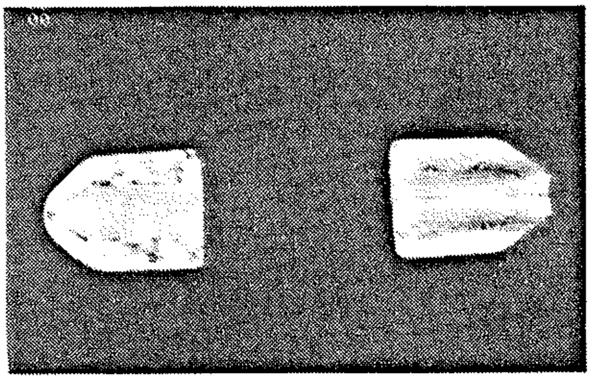


Fig. 20
CT image of a multidirectional glass-fiber-reinforced component with marked buckling of the prepreg layers.

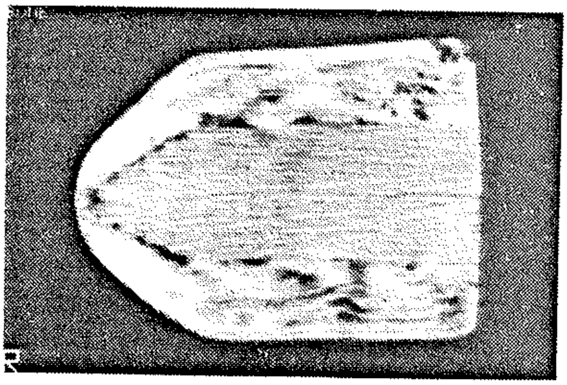


Fig. 21
Enlarged image of the left cross-section.

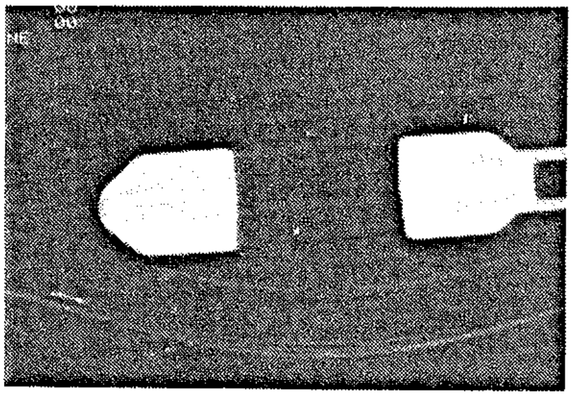


Fig. 22
CT image of the optimized cross-section (Figs. 20, 21).
Less buckling means a manifold longer useful life of the composite structure

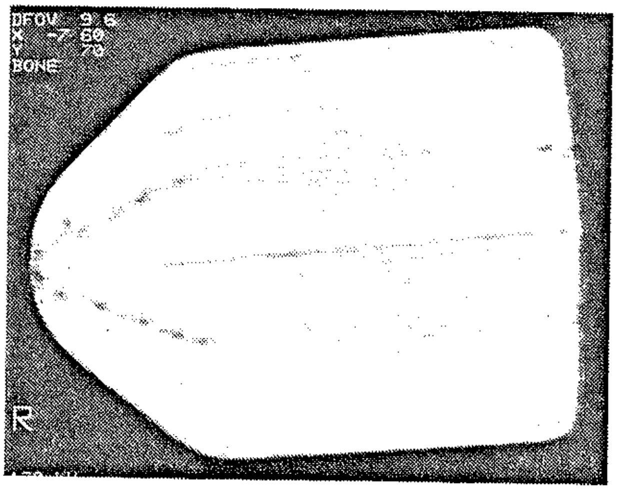


Fig. 23
Enlarged image of the left cross-section

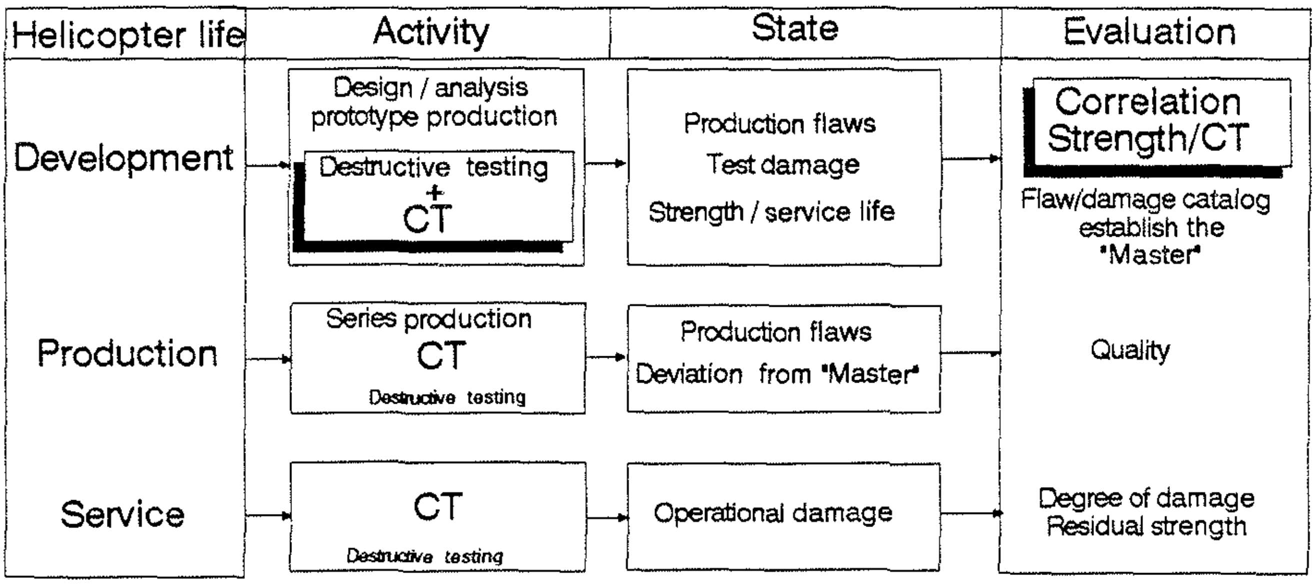
Another application of CT is as a monitoring aid during the operational life of helicopter blades. Helicopter blades with a long service history (5000 to 10,000 hours) can be bought back from customers and their residual strength can be determined with the help of destructive testing.
CT inspections are performed at the same time. Initial results have already shown that assessment of these aged blades can be substantially improved by means of CT. It is even possible, within certain limits, to draw conclusions about the residual strength of the blades without destructive testing.
The Fig. 24 are meant to illustrate that CT can be used at the beginning of a component's life - from development to certification of the helicopter model - in parallel with destructive testing. In this way the CT image can be correlated with the strength of the component. During the later life of the component type, destructive testing plays a subsidiary role. Only in exceptional cases is an additional destructive test of the component necessary.

Conclusion

It has been shown that computed tomography can meet the need for a nondestructive test method of thick-walled composite structures. This imaging test method permits detailed nondestructive testing of dynamic helicopter components such as main and tail rotors.

If used consistently throughout the development, production and operation stages, CT can help raise the quality and safety of dynamic helicopter components of composite materials.

Fig. 24 Computed tomography (CT) on helicopter rotors



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