A STUDY ON NONDESTRUCTIVE INSPECTION FOR VARTM COMPOSITE WING STRUCTURE

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Keywords: *VaRTM, Composite Wing Structure, NDI, Quality Assurance*

Abstract

Vacuum assisted resin transfer molding (VaRTM) method is one of the candidates to achieve low cost aircraft structure. A development of 6 m span VaRTM wing box project is conducted to demonstrate VaRTM technology and to make clear the certification procedure of VaRTM by Japan Aerospace Exploration Agency (JAXA). The project result will eventually support the policy and guidance procedures of Japan Civil Aviation Bureau (JCAB), and also a certification procedure of aircraft companies in Japan. This 6 m VaRTM made wing box demonstrator is assumed a 30 passenger aircraft and a static test of this wing box is planed in fiscal year of 2007. A 2 m wingspan specimen was made as an experimental production which contains every technical component to be solved before manufacture of 6 m wing box specimen. Technical expertise and the remaining issues were obtained from this 2 m specimen.

1 Introduction

In recent years, low cost manufacturing is a key issue of developing a new aircraft. Vacuum assisted resin transfer molding (VaRTM) method which is a composite manufacturing process, is one of the candidates to achieve this. A dry fiber perform is laid up on one-sided tooling and covered with a vacuum bag. Then the air is evacuated by a vacuum pump and liquid resin from an external reservoir is drawn into the component by vacuum. The liquid resin is infused into the component. VaRTM is expected to reduce the manufacturing cost because the autoclave used for composite structure of conventional prepreg system is not used. There are many other features, for example, one sided tooling, no high strength tooling, cost less than prepreg, non freezing storage, easy to make a large and/or integral composite parts, etc. A development of 6 m span VaRTM wing box project is conducted by Aviation Program Group and Advanced Composite Center of Japan Aerospace Exploration Agency (JAXA) since 2004 [1]. Objectives of this project are to demonstrate VaRTM wing box and to make clear the certification procedure of VaRTM. The project result will eventually support the policy and guidance procedures of Japan Civil Aviation Bureau (JCAB), and also a certification procedure of aircraft companies. This wing box is assumed a 30 passenger aircraft and a static test of this wing box is planed in 2007. Before this static test of wing structure, various tests from coupon specimens to element specimens, and many experimental productions have been being conducted. A 2.1 m wingspan specimen was made as an experimental production which contains every technical component to be solved before manufacture of 6 m wing box specimen. Technical expertise and the remaining issues were obtained from this 2 m specimen and are described here.

2 Fabrication of a Lower Wing Panel as an Experimental Production

A lower wing panel with integral spar and T-shape stringers was fabricated as an experimental production which contains every technical component to be solved before manufacture of 6 m-wing box specimen made by VaRTM. The aims of this experimental production are to confirm moldability, determination of structural type and base materials such as fiber and matrix and to make clear the other technical difficulties. To take advantage of VaRTM, skin, spars and stringers are fabricated as an integral molding except for secondary bonding of intercostals for rib connecting. External size of this panel is 2.1 m-span and 1.4 m-chord, and the skin of lower panel has contour form of radius approximately 7 m in order to simulate

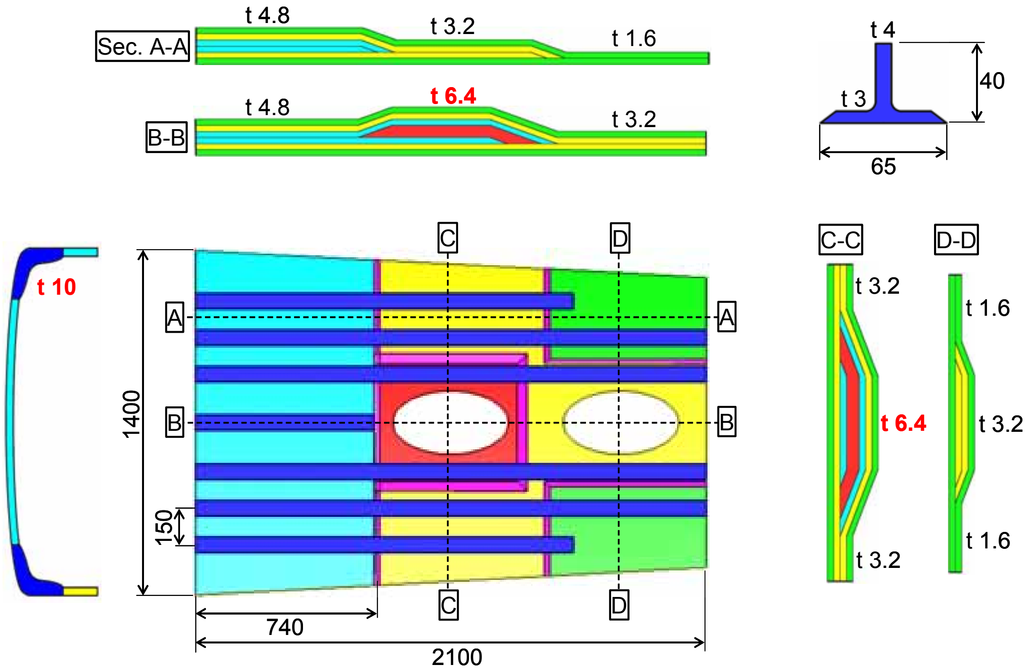


Fig. 1. Schematic illustration of thickness distribution in 2.1 m-span lower wing panel with stringers and maintenance holes.

main wing cross section. Non crimp woven (NCW) of Toray T800SC carbon fiber, and low viscosity and high strength epoxy resin developed for VaRTM process are selected for fabrication of this wing panel. Regarding the stringer section, non crimp fabric (NCF) was applied as a base material to maintain the shape of preform. For the evaluation of resin impregnation, this specimen has three step ply drops off from root to tip, and thick sections with pad of additional plies around the maintenance holes and intersection corners between skin and spar. All angles of ply drop off are designed approximately 2.3 degree. The thickest section is about 10 mm. There are Run-out sections of stringer for evaluating the effect of this discontinuous on the resin impregnation. In addition, an influence of SUS make punching metal for bag side surface to improve the surface quality is also evaluated. A schematic illustration of thickness distribution in 2.1m-span lower wing panel with stringers and maintenance holes and picture of the lower wing panel are shown in Fig. 1 and 2 respectively.

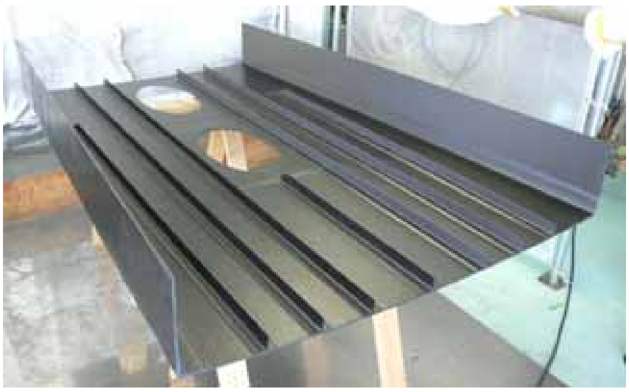


Fig. 2. Picture of an experimental production of lower wing panel integrated with spars and stringers by VaRTM process. (2.1 m X 1.4 m)

3 Inspection Item and Procedure of VaRTM Experimental Production

Visual and nondestructive inspections of the 2.1 m-span lower wing panel were carried out for evaluation of molding quality and manufacturing defect. In the visible inspection, crack, wrinkle, dimple and incomplete resin impregnation region of the surface were evaluated. Then void, delamination and retained foreign material in the subsurface of the specimen were evaluated by NDI. Pulsed thermography was applied to all surface area and ultrasonic C-scan was applied some area of concern. Wrinkle of the surface and fiber waviness in the subsurface were evaluated by mechanical tests of coupon specimens.

Pulsed thermography has a feature of fast, single side and non-contact with wide area. It is also easy to apply to curvature surface and to couple together divided images of wide area in the system [2], [3]. The measured data is a time-series of surface temperature distribution image that is mathematically improved signal to noise. A time-series of first and second derivative images of surface temperature can be calculated from this improved temperature images and these calculated images work for NDI These features offer convenience for in-service and manufacturing applications. It is a NDE device which can detect subsurface damage/defect by acquiring and analyzing temperature image on the object surface after powerful flash. A half of 2m specimen surface was divided in 5 X 11 regions and each region is inspected with this pulsed thermography as shown in Fig. 3.

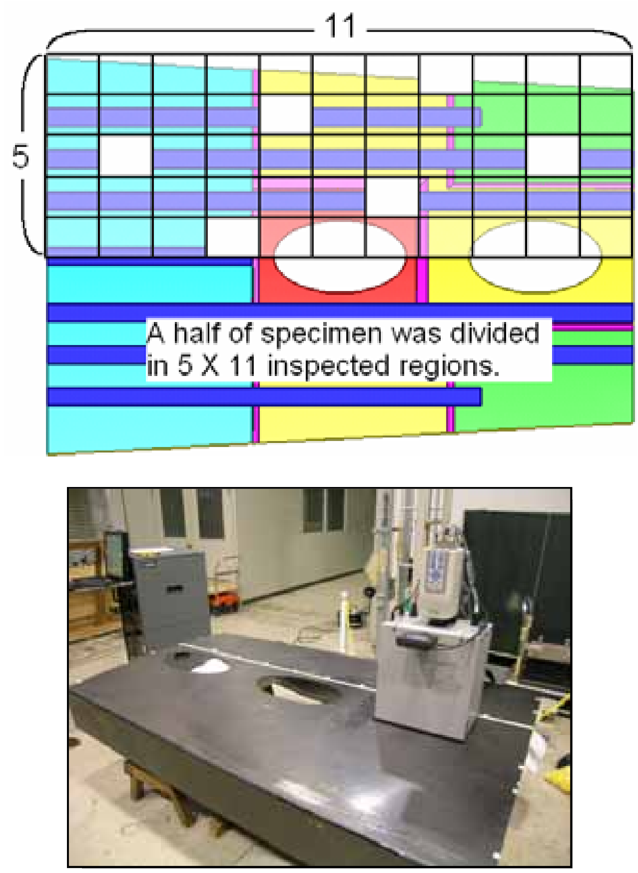
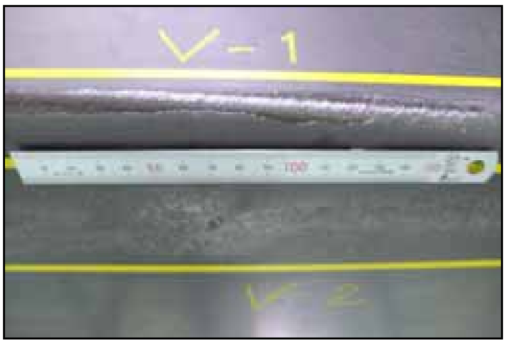


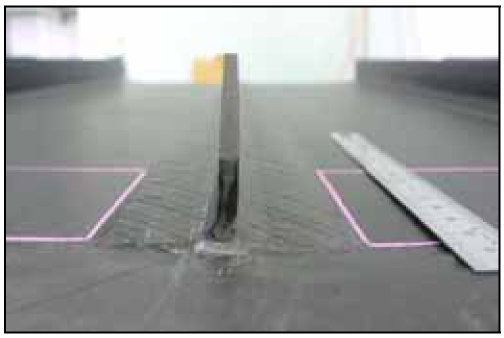
Fig. 3. Picture of inspection of 2 m VaRTM specimen by pulsed thermography.

4 Inspection Result and Discussion

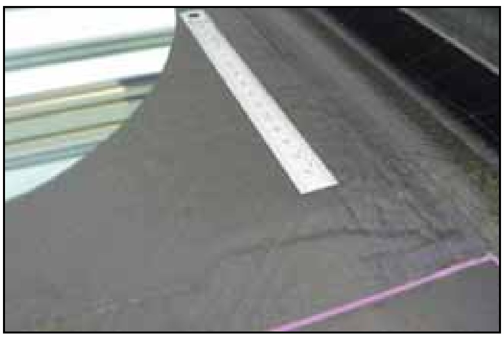
Several quality instabilities in the manufacturing were found by visual inspection, such as incomplete resin impregnation in the thick region of corner where is skin/spar intersection, deformation of stringer web, surface wrinkle in the ply drop region and springing at the spars. These quality instabilities are shown in Fig. 4. It is considered that the dry spots of the thick region in the corner surface are caused by not supposed resin



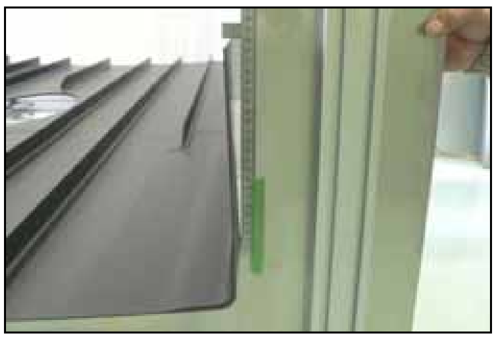
(a) Incomplete resin impregnation



(b) Deformation of stringer web



(c) Wrinkle of bag side surface



(d) Spring-in of spar

Fig. 4. Examples of quality instability in the experimental production made by VaRTM process.

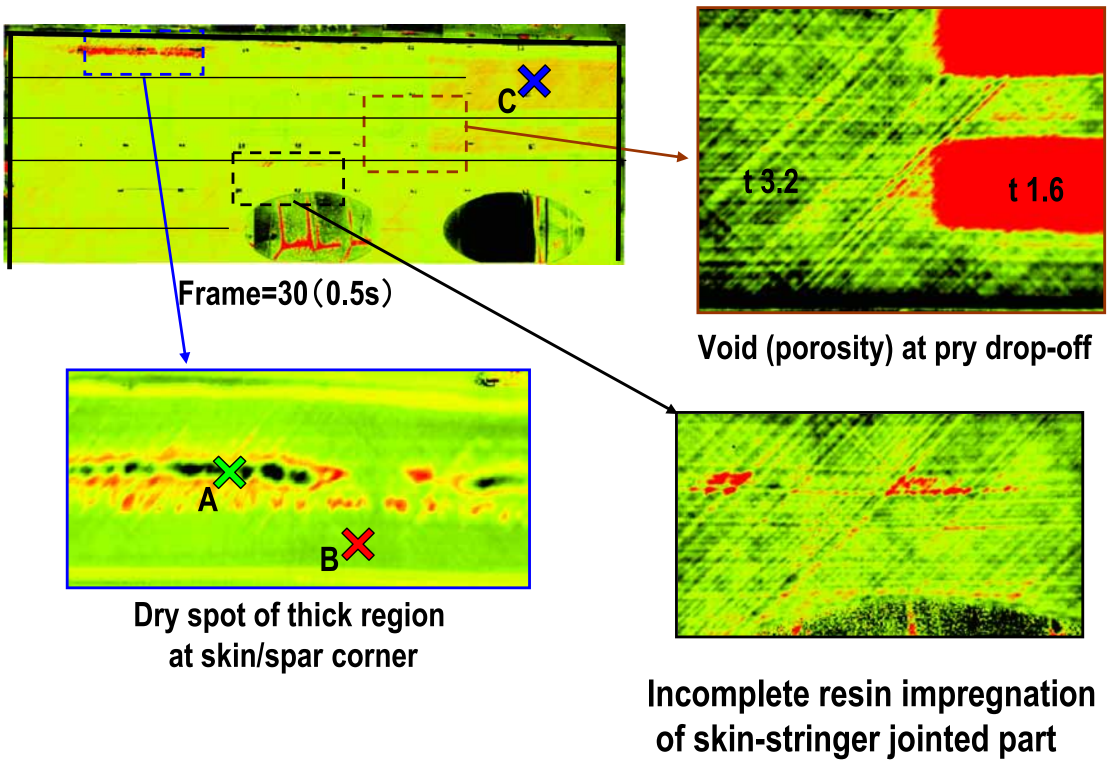


Fig. 5. NDI result of pulsed thermography.

impregnation because these dry spots are the tool side. Resin went around the region and then a dry spot was remained. This problem can be solved by changing of resin impregnation time and location of resin inlet and vacuum outlet points. The deformation of stringer web is caused by moving of inner mold in the process. The surface wrinkle is caused by complex thickness change at the intersectional region between ply drop and stringer. It is considered that this complex change make fiber alignment and/or vacuum pressure disturbance. In addition, spring-in angles of the spar are approximately 1 degree in the wing root and 1.5 degrees in the wing tip. It can be solved by modification of tool angle along spar in consideration of thermal deformation.

NDI result of pulsed thermography is shown in Fig. 5. This result indicates incomplete resin impregnation regions in the corner and under a stringer that were also obtained in the visual inspection. Fig. 6 shows Log-Log plot of surface temperature time history on the specimen at the marked points in Fig. 5. Evaluation of this time history of temperature change provides the incomplete resin impregnation is only several plies from surface. This NDI method is suitable for large area inspection because this method has very fast inspection feature.

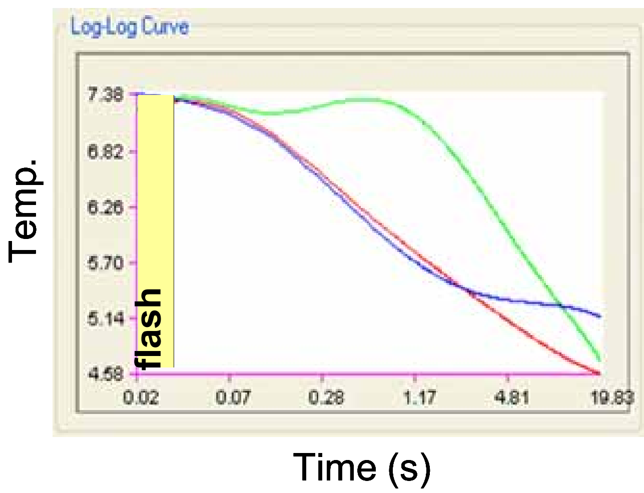


Fig. 6 Log-Log plot of surface temperature time history on the specimen at the marked points in Fig. 5.

Fig. 7 shows NDI result of thickness change region using ultrasonic C-scan. Fig. 7 indicates there are some voids around the ply drop off region and wrinkle on the bag side.

3-D Ultrasonic Scan was also applied to the specimen and a scan result is shown in Fig. 8. This method uses linier or matrix array type probe. Each segment of selected segments of array probe respectively transmits pulses and selected segments receive the echo, and then 3-D scan image is created with aperture synthesis. The scanned part in Fig. 8

(No.2) shows a scan result of thickness change part because of additional plies for corner of between skin and spar. NDI of this part could not be done by conventional ultrasonic inspection. This method is faster and provides better result for thickness change part than conventional ultrasonic inspection.

It is demonstrated that pulsed thermography and ultrasonic C-scan are applicable for the quality assurance of composite wing structure made by VaRTM process. Pulsed thermography is especially suitable for large area inspection because of its fast and easy operation. On the other hand, ultrasonic is suitable for detailed inspection of thick part. 3-D ultrasonic system is especially good from the point of view about applicability for complex shape and gradually thickness change part.

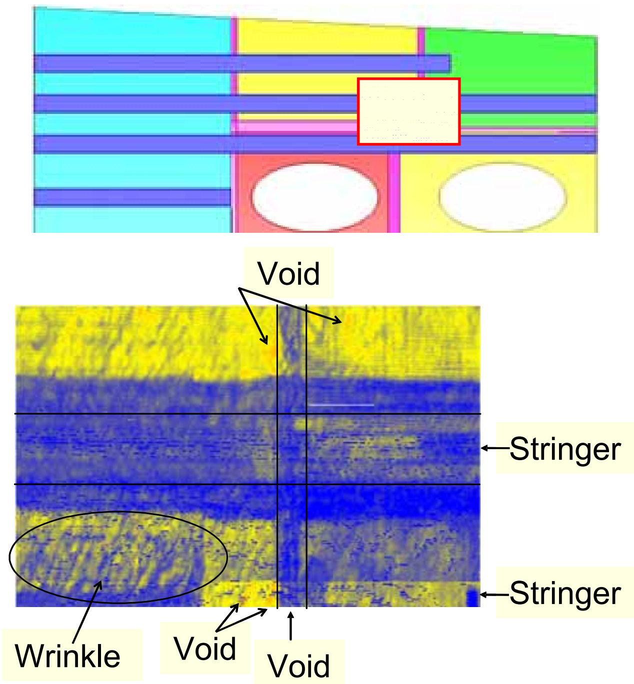


Fig. 7 Result of Ultrasonic C-Scan of thick part.

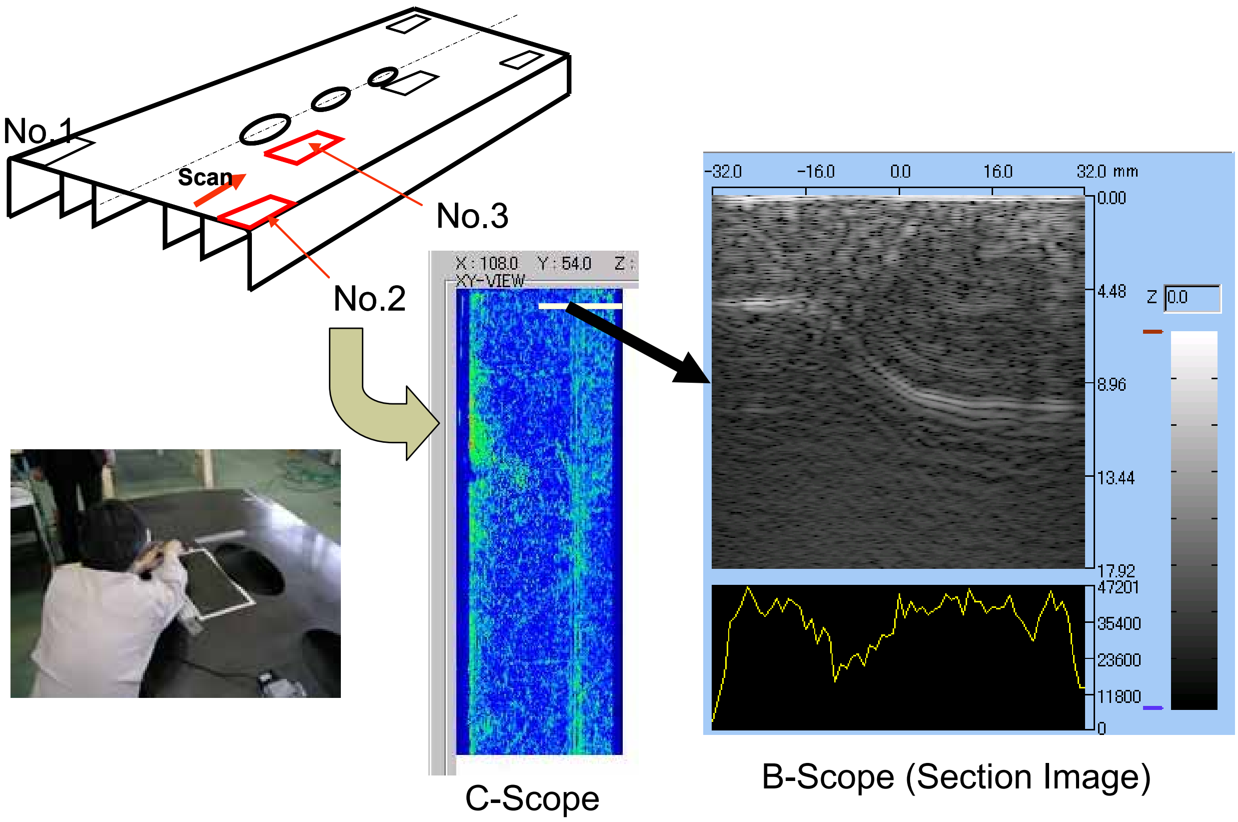


Fig. 8. Results of 3-D Ultrasonic Scan of part No. 2.

5 Conclusions

A project of developing 6 m span VaRTM wing box demonstrator conducted by JAXA since 2004. In this project, a 2.1 m trial specimen was made as an experimental production which contains every technical component to be solved in manufacturing process. Technical expertise and the remaining issues were obtained from this 2.1 m specimen. There were some incomplete resin impregnation part identified by visible inspection and it is clear that the problem is within only some surface layers from both pulsed thermography and ultrasonic C-scan, and this problem was solved by changing of resin impregnation time and location of resin inlet and vacuum outlet points. Some other problems were also obtained from the visible inspection, such as deformation of stringer webs, wrinkle of bag side surface and spring-in of spars.

. It is demonstrated that pulsed thermography, conventional ultrasonic inspection and 3-D (Array) Ultrasonic system are applicable for the inspection of composite wing structure made by VaRTM process. Pulsed thermography is especially suitable for large area inspection because of its fast and easy operation. On the other hand, ultrasonic is suitable for detailed inspection of thick part. 3-D ultrasonic is especially provide good NDI result of thickness change or complex shape part.

References

[1] Yosuke Nagao, Toshiya Nakamura, Jiro Nakamich and Takashi Ishikawa, "*Low-Cost Composite Manufacturing Technology Development Program in JAXA*," Proceedings of the Ninth Japan International SAMPE symposium, Tokyo, Japan, 2005.

[2] Shepard, S.M., "*Advances in Pulsed Thermography*", Proceedings of SPIE Thermosense XXIII, Vol.4360, pp. 511-515, April 2001.

[3] Sunao Sugimoto, Toshio Ogasawara, Yuichiro Aoki and Takashi Ishikawa, "*Damage Detection Of Composites Using Pulsed Thermography*," Proceedings of the 15th International Conference on Composite Materials, Durban, South Africa, 2005.