Proceedings of the International Conference on Aerospace Science and Technology
26 -28 June 2008, Bangalore, India

INCAST 2008-024

Non-Destructive Evaluation of Co-cured Wing for SARAS

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Abstract

After considerable experience with the development of pre-preg based (mostly Fiberdux T300-914C) autoclave moulded carbon epoxy composite airworthy components for both Tejas (LCA) and SARAS programmes, the Advanced Composites Division (ACD) has now come out with an ingenious Vacuum Enhanced Resin Infusion Technology (VERITy) route for the development of Co-cured Carbon Wing for the SARAS aircraft using Carbon Fabric and Epoxy resin. Non-Destructive Evaluation (NDE) has played a crucial role in the formulation of the VERITy process. Also, NDE will be used in the qualification of the wing components and an approach has been evolved.

1.0 Introduction

Composite materials are increasingly being used for the fabrication of composite structural components for both civilian and military aircrafts. The conventional manufacturing technology employs either fastening or adhesively bonding processes of a number of individual components, fabricated separately, in realizing the structural assemblies [1-4]. However, there is an ever increasing demand for the designer to reduce the weight of the structure with improved performance and at reduced manufacturing costs. A number of approaches are available to achieve and one such approach is through co-curing. ACD has been vigorously pursuing co-curing technology and a number of composite components / assemblies have been developed for both Tejas (LCA) and SARAS aircrafts[5]. Co-curing technology has a number of advantages which include consolidation of a number of parts to form an assembly in a single cure cycle. This minimizes the use of fasteners, eliminates stress concentration due to drilled holes, reduces assembly time and costs and enhances the production rate.

In view of the advantages of co-curing technology, the SARAS wing has been designed to achieve both cost and weight benefits. Further, the manufacturing technologies have been carefully looked into keeping the low speed civilian aircraft requirements in mind and an appropriate technology has been developed for the SARAS wing. The manufacturing technology developed is based on Resin infusion technology with process modifications to realize a quality end product.

In view of the new VERITy process proposed for SARAS wing, there is a need to establish various parameters for a stabilized manufacturing process which would give components of consistent acceptable quality and repeatability. NDE plays a crucial role in achieving the above goals. In this wing programme these goals have been achieved through extensive NDE studies on specially prepared test laminates. The feedback from NDE studies has helped to fine tune the process parameters to establish well defined fabrication procedure which would ultimately meet the NDE requirements as defined for the Tejas (LCA) components fabricated using pre-pregs[8]. Hence, the acceptance criteria regarding the quality and defects for the SARAS wing employing VERITy process will be the same as that of the LCA and SARAS components fabricated using pre-pregs[5].

2.0 VERITy Process

The Vacuum Assisted Resin Transfer Moulding (VARTM) is widely used technique. However, the VERITy process has many improvement over the VARTM process. The fiber used is Carbon UD Fabric and the resin system is Epoxy Resin RTM 120 and Hardner HY 2954. These are the material system followed. In this process at the time of infusion, the resin is warmed to a temperature of about 45^0 C., and the mould is heated to a temperature of 50^0 C. The carbon layers are stacked for the appropriate thickness and vacuum bagged before resin infusion. At one end of the vacuum bag resin is infused and at the other end vacuum is applied. After the resin infusion is completed, the part is cured in autoclave at 80^0 C under 1 bar pressure[6,7]. The advantage of this process is that it gives better consolidation of the layers in the laminates. This has been established through a number of trials on test laminates and the feedback from NDE on its quality.

3.0 Non-Destructive Evaluation

Non-Destructive Evaluation for process proving and stabilization has been carried out on a number of specially prepared test laminates. As described earlier the NDE reference values established for LCA components[8] have been used for comparison purposes for the VERITy process.

Visual inspection was carried out on all components for surface defects like dents, deep scratches, pits etc. Doubtful areas were further inspected, at magnification 5. The NDE studies have been carried out in many stages namely, firstly on test laminates and secondly stringer panels thirdly spars / J joints and finally on the test box. These are discussed below :

3.1 Test Laminates

A number of test laminates have been made at each stage of the development programme and all of them have been inspected at 5 MHz using Automated Ultrasonic Through Transmission Squirter C-scan System. The material system used for these laminates is same as that would be used for the wing. In the initial stages, the laminates had unacceptable levels of porosity (>1%) resulting in wide variation in the measured ultrasonic attenuation levels in the range of 18-25 dB (Figure-1). Also, there were regions with resin starvation due to poor process control resulting in very high attenuation levels beyond the system dynamic range of 50dB (Figure-1). The higher attenuation levels noticed are due to the scattering of ultrasonic waves within the laminate due to higher degree of porosity.

Based on the feedback from NDE, process modifications were carried out. After a number of iterations we could achieve good laminate consolidation which had acceptable level of porosity (<1%), uniform attenuation distribution over the entire laminate (2.72 thick) dominantly in the range of 6-8 dB (Figure-2). The measured attenuation levels and their distribution are comparable with the levels established on autoclave cured pre-preg laminates having the same thickness. Once the process was stabilized, it was extended further beyond 6.8 mm thickness, to fabricate laminates for NDE studies. A range of thicknesses were identified keeping the actual thickness in the wing component which was in the range of 6.8 – 12mm. Similar inspection parameters and inspection frequency of 5MHz was employed for NDE studies. Figure-3 shows the attenuation distribution across the laminate having 12 mm thickness.

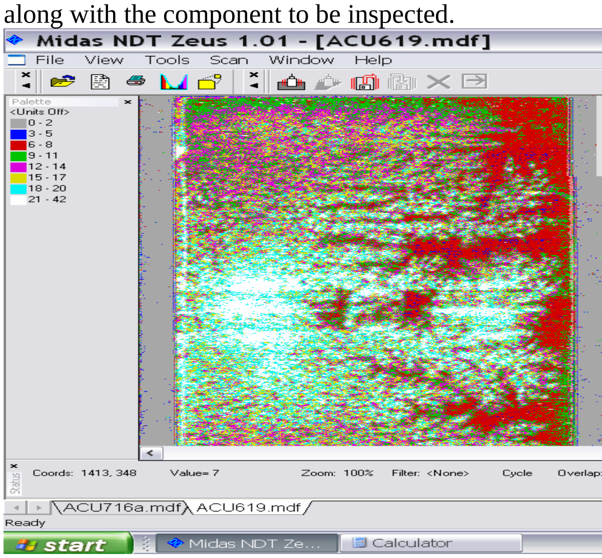
Figure-4, giving plot of attenuation versus thickness, shows the attenuation levels measured on a number of test laminates having a range of thicknesses from 2 – 12mm. The distribution is linear over the entire range. These results indicate the process consistency, acceptable levels of porosity and the repeatability in the inspection parameters and frequency as that of the procedures being followed for LCA components.

The manufacturing process and NDE procedures established were further verified through a variety of destructive testing on coupons namely Tensile strength, Compression Strength, Flexural Strength, Inter Laminar Shear Strength (ILSS), Multi-angular test and Open Hole & Closed Hole Shear tests. These test results are comparable with those of pre-preg test specimen. Also, the void content was well within 1% and Fiber volume fraction was about 58 – 60%.

With this background the NDE procedures were extended to the sub-structure and wing test box specially designed for structural testing.

3.2 Reference Laminate

Suitable reference standards with artificially induced defects of different sizes located at various depths in the form of Teflon inserts and other fabrication process materials were fabricated to the requirements defined in the acceptance criteria. These reference standards having intentionally introduced defects were used in each scan along with the component to be inspected.



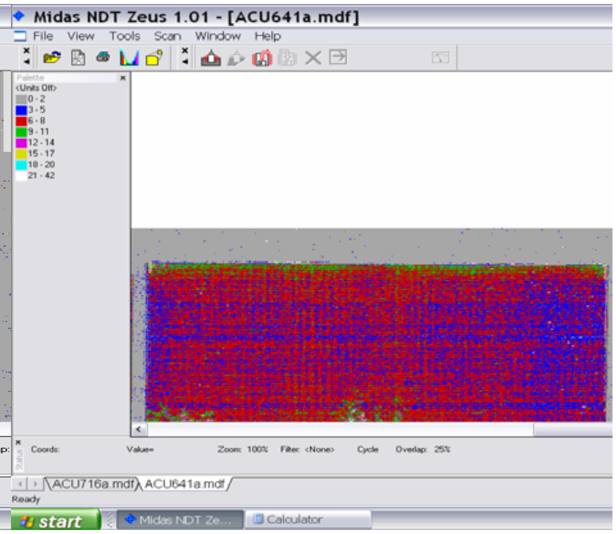


Figure-1 C-scan plot of 2.72mm thick Bad laminate

Figure-2 C-scan plot of 2.72mm thick Good laminate

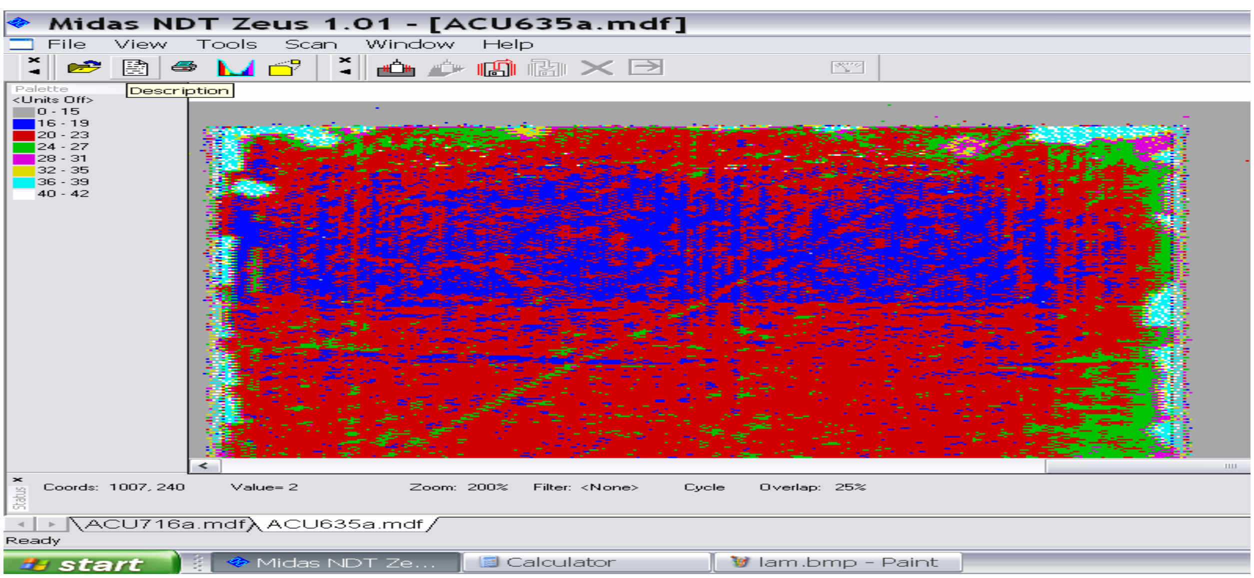


Figure-3 C-scan plot of 12mm thick Good laminate

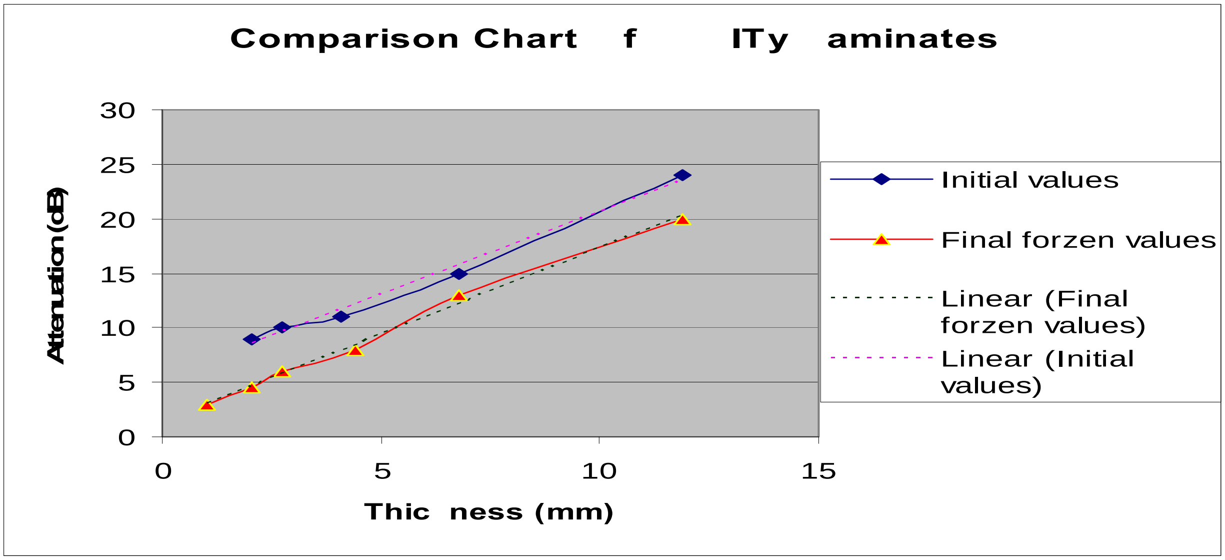


Figure-4 Chart

3.3 NDE of Stringer panel & Substructure

In the second stage the stringer panels were fabricated, this is a portion of the top and bottom skin structure of the Wing skin. This stringer panel construction is the flat panel having stringer on the inner side and the stringer are filled with foam inside. Before making the larger structure the substructures were fabricated and these are the structures connecting the top and bottom skins. The rear beam is an I-sectional construction having web and two flange regions and are critical for inspection on all the segments. NDE (Figure-5) was carried out on the above components and the quality has been stabilized.

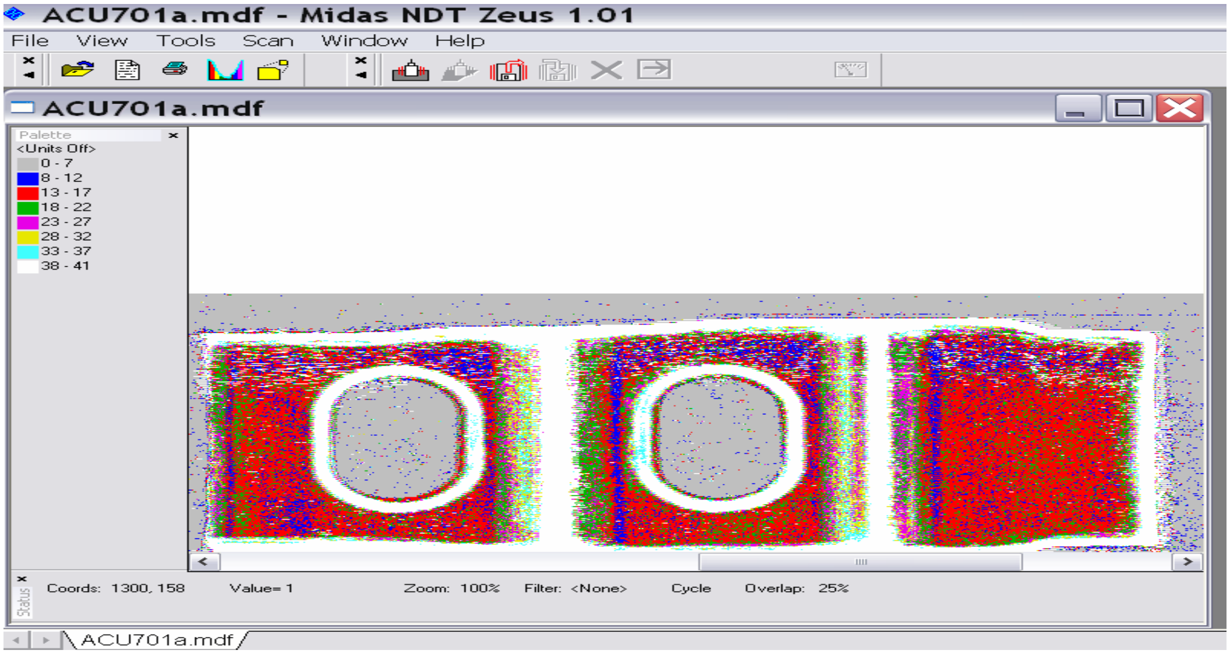


Figure-5 C-scan plot of Sub-structure

4.0 Wing Test Box

After the VERITy fabrication process got proved at the laminate level, the process was extended to a larger component representing the region of the SARAS wing. This test box was fabricated using the same concepts that are to be employed for the actual wing. The bottom skin was co-cured with ribs, spars and gussets (Figure-6). The top skin was co-cured with the stringers. The top skin was mechanically fastened to the bottom skin using fasteners.

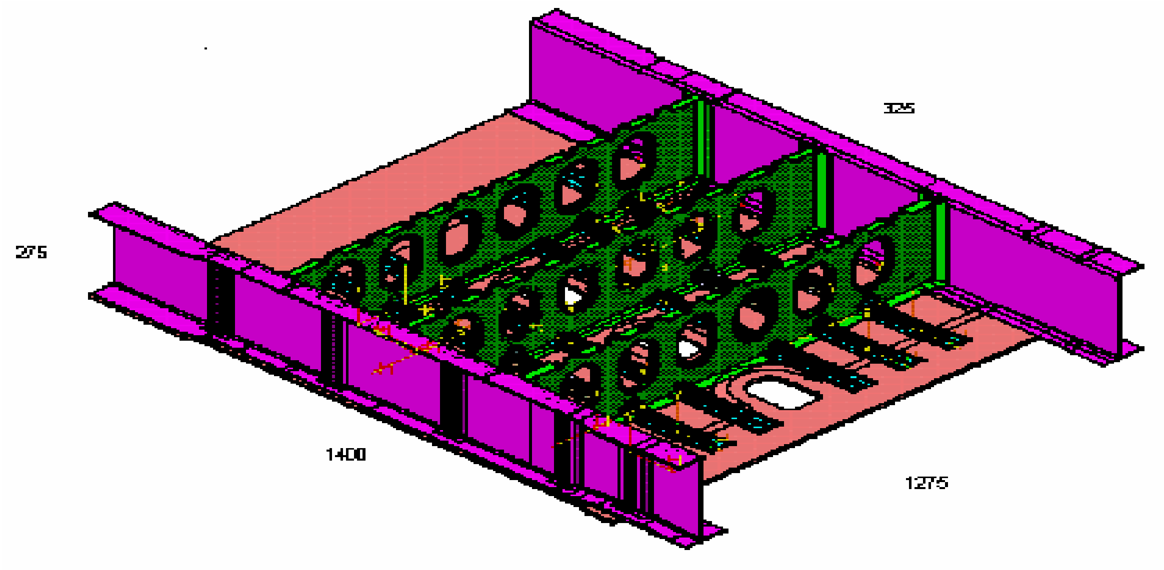


Figure-6 Co-cured wing test box

4.1 NDE of test box

The inspection of the part is a mammoth task and the existing attachments were inadequate to meet the inspection requirements. In view of the co-curing of the bottom skin with the substructure it is not possible to inspect the entire box in one setting. Hence, the inspection was carried out in a number of segments. To have access for inspection we had to design special fixtures for probe movement, component handling etc. The various segments that have been inspected with the specially designed attachments are shown in Figures 7-8. Also, the inspection of the top skin with stringers has been carried out in through transmission technique.

Figure-7 shows the automated ultrasonic through transmission inspection of the rib. In one setting one rib can be inspected. The procedure is to be repeated for the remaining ribs.

Figure-8 shows the automated ultrasonic through transmission inspection of a segment of the bottom skin. Here again, the procedure has to be repeated for the remaining segments.

The automated inspection could not be carried out completely on the test box. There are a few areas not accessible for automated inspection and these are inspected manually using ultrasonic contact pulse echo technique at 5 MHz. Nearly 90% of the area of the test box is accessible for the automated inspection.

Figure-9 shows the ultrasonic through transmission attenuation distribution across the bottom skin with thickness ranging from 4.08 to 10.2mm. The attenuation distribution varies in the range of 9 -16 dB and is in agreement with the thickness (Figure – 4).

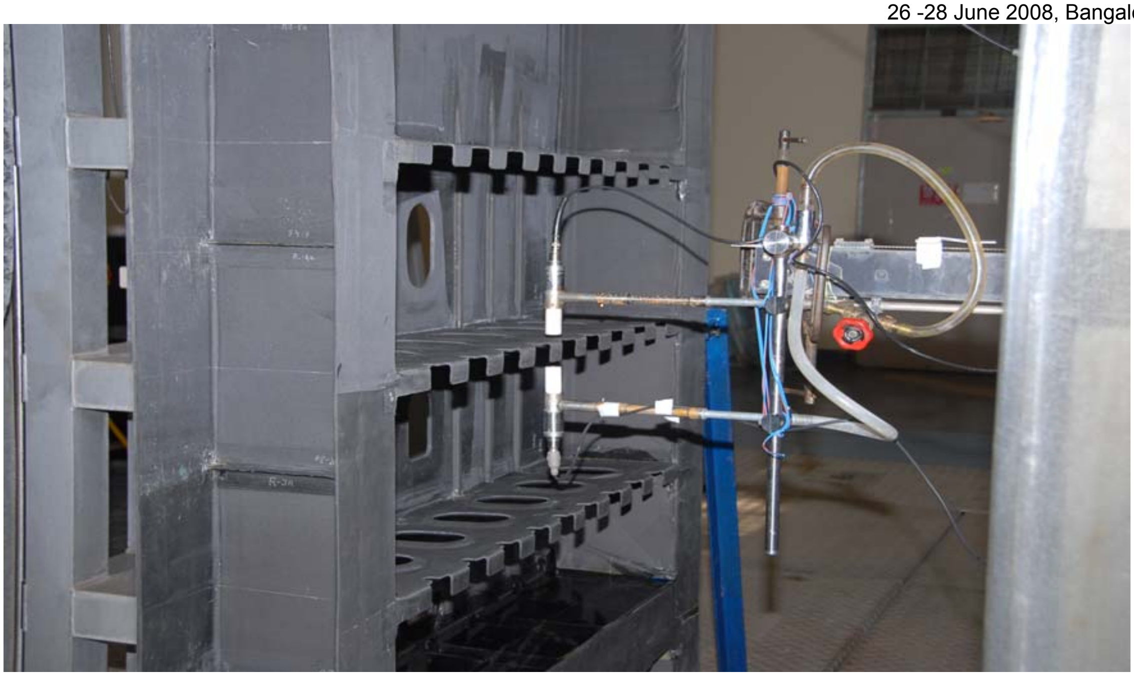


Figure-7 Test box Rib inspection

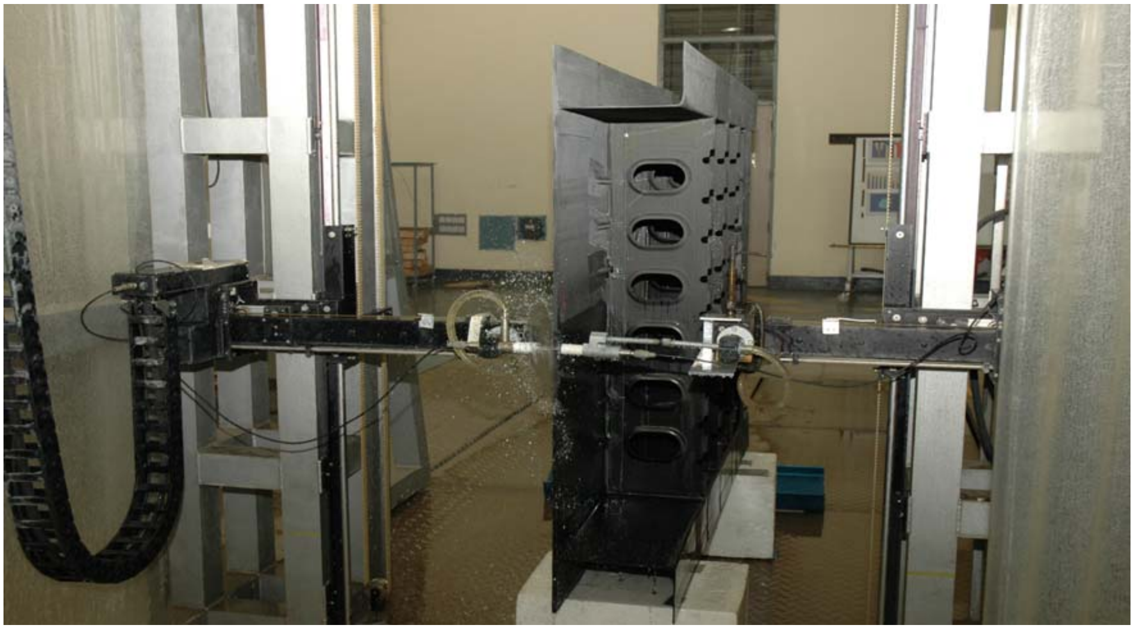


Figure -8 Test box Bottom Skin inspection

4.2 NDE of Saras Wing

The inspection procedures established for the wing test box will also be implemented for the inspection of the actual wing assembly having bottom skin with substructure. The difference between the wing test box and the actual wing is mainly in the dimensions, other construction and process are similar. There are no inspection issues for the top skin.

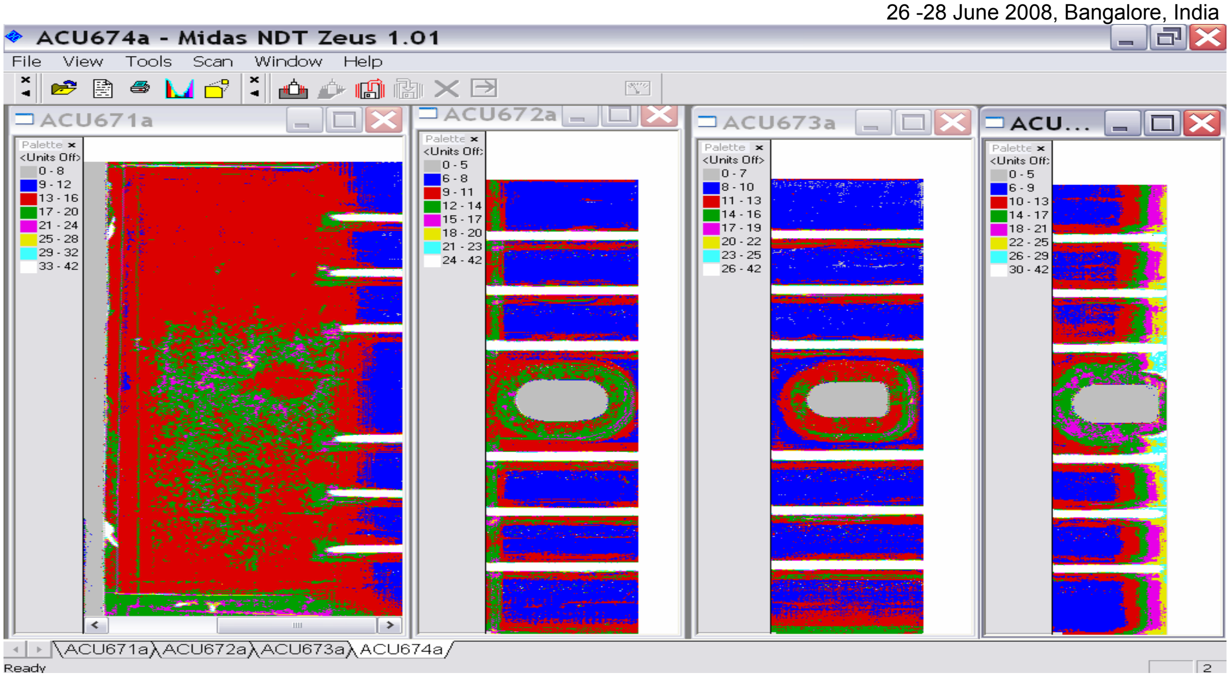


Figure-9 C-scan image of the Wing test box Bottom skin

5.0 Conclusion

In conclusion, the NDE experiments helped in establishing a VERITy process that gives components of quality and consistency similar to that of pre-preg based LCA airframe components developed earlier. It also helped in formulating the NDE approach in terms of fixing of inspection parameters and methodologies for VERITy fabricated components with the same acceptance criteria established earlier for pre-preg based SARAS components.

Acknowledgment

Thanks are due to Mr. MC Devaiah, Mr. S. Sanjeev Kumar and Mr. S. Kali Kiran, for the extensive support during the work. We are also grateful to Dr. Ramesh Sundaram and Mr. Kundan Kumar Verma for many useful discussions.

References

[1] Quality Assurance of LCA Composite Rudder, NAL PD ST 9424, September 1994.
[2] Quality Assurance of Co-cured Composite Fin for LCA, NAL PD ST 9508, May 1995.
[3] Quality Assurance of LCA Composite Wing Spars, NAL PD ST 9431, December 1994.
[4] Quality Assurance (QA) document for Composite Components of LCA, NAL SP 9810, July 1998
[5] Non-Destructive Evaluation of Composite Components for SARAS : Acceptance Criteria, TB-01, Vol.38, Dec. 2000
[6] Ramesh Sundram, M. Subba Rao. Fabrication of high performance composites by Vacuum Enhanced Resin Infusion Technology (VERITy). INCCOM-3 & 3rd ISAMPE National Conference on Composites, (Oct. 7- 9, 2004)
[7] Ramesh Sundram, Kotresh M. Gaddikeri, Kundan Kumar Verma, Kailash Singh, Dinesh BL, M.Subba Rao. Tooling concepts for the VERITy process. INCCOM-5 & 5th ISAMPE National Conference on Composites (Nov. 24-25, 2006)
[8] Acceptance standard for carbon fibre composite components, ADS 32, December, 1998