INVESTIGATION OF MICROSCOPIC DEFECTS IN AIRCRAFT WINGS WITH THE HELP OF VIRTUAL TOOLS

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Abstract. *There are various types of defects in aircraft wings and a wide range of non-destructive tests (NDT) is available for detecting them. These cracks are mainly caused by either fatigue loading or corrosion. Varying loads and stress cycles may cause the structural cracking or fatigue cracking. In some situations these fatigue cracks may obstruct airworthiness of the aircraft and make it unsuitable for flying. Some environments factors like saltwater, humid air, and sump water can also produce cracks due to corrosion. Among the NDT approaches for detecting defects, the most commonly used today are: ultrasonic method, visual methods, radiography, liquid penetrant method, and Eddy current method. Despite the NDT chosen, if microscopic cracks are being investigated it becomes harder to both detect and visualize them. Therefore, this work aims to design and develop a combined CAD/FEM/Virtual application to help on the investigation of microscopic defects in aircrafts wings. The CrackView system improves the 3D visualization of the microscopic cracks by automatically generating a magnified virtual model of the cracked wing that is later displayed through a VRML-based CAVE-like immersive projection system.*

Keywords*: Microscopic defects in aircrafts wings, Virtual Engineering, CAD/FEM applications, Virtual Reality.*

1. Introduction

Some current approaches for detecting microscopic cracks in airplane wings are destructive. The wing is cut into thin slices that can be studied under a microscope. Whether or not the wing had a defect, it is destroyed in the process of looking for a defect.

Non-destructive testing (NDT) approaches can be used to discover cracks without damaging the wing of an aircraft. The major goal of the scientific community devoted to this field has been to identify defects in aging aircraft structures (Bucci *et al*, 2000, Wenk *et al*, 1987). Among the NDT approaches for detecting defects, the most commonly used today are: ultrasonic method, visual methods, radiography, liquid penetrant method, and Eddy current method (Geetha, 2004). These NDT techniques have been mainly applied for the detection of cracks emanating from the sides or edges of rivet holes (Wincheski and Namkung, 1999 , Xiong and Bedair, 1999).

Even assuming that a particular NDT mechanism was chosen for an inspection, some other difficulties remains. There are important challenges to be faced when dealing with microscopic cracks. Firstly, there is a need to display the model details at varying scales.

For example, if we are displaying an entire airplane wing on a 5' x 4' screen, the wing must be displayed at a scale smaller than real-life. However, in order to display a microscopic crack we must display it at a scale much larger than real-life. Both scales must be used in a single display.

When microscopic cracks or even small cracks (1.1 to 5.7mm in size) are being investigated it becomes harder to both detect and visualize them. One possible solution to overcome the above mentioned problem is to combine virtual reality (VR) and finite element modeling (FEM) techniques.

Virtual reality applications allow us to build models of systems whose size or time scale (such a galaxy or a crystal) or nature (nuclear reaction) would not normally permit direct human observation (VanScoy *et al*, 2004). We can present attributes of such systems in ways that multiple human senses, sight, sound, touch, and smell, can experience them

Within this context, the objective of this project consisted in developing an object-oriented system for displaying to multiple human senses information about the location of microscopic cracks in airplane wings.

The CrackView system is an integrated CAD, CAE and Virtual environment for displaying an exaggerated crack in a visual representation of the wing. These tools were developed for use in a VRML-based CAVE-like 3 walled immersive projection system.

2. Non-destructive tests (NDT)

There are several non-destructive mechanisms used for detecting defects in aircraft structures. Examples of defects that can be identified are: porosity, inclusions, voids and cracks. Structural cracking occurs due to aircraft flight operation and aging. Furthermore, corrosion and fatigue cracks are always expected in aging aircraft. These imperfections may expand under suitable fatigue loading condition and, sometimes, reach an undesirable degree that could affect the reliability of an aircraft.

The various NDT methods widely used today are ultrasonic method, visual methods, radiography, Dye penetrant method, and Eddy current method [3]. In the following sub-sections, some of these NDT mechanisms are summarized.

2.1. Ultrasonic testing

An ultrasonic inspection technique commonly used for the aircraft structures is based on ultrasonic spectroscopy. Commercially available instruments (bond testers) used for this test operate on the principle of mechanical resonance in a multilayer structure. A piezo-electric probe excited by a variable frequency sine signal is placed on the surface of the inspected structure. The instrument acquires a frequency spectrum in the range of some tens of kHz to several MHz.

A resonance in the layered structure occurs when echoes between two boundaries travel back and forth due to differences in acoustic impedances at the boundaries. For multilayer structures a number of resonances can be observed depending on their geometry and condition. For each particular defect-free structure and given transducer we obtain a characteristic resonance pattern, an ultrasonic signature, which can be used as a reference.

During the inspection of an unknown object the probe scans its surface and ultrasonic spectra are acquired for many discrete points. Detection is performed by the operator looking at some simple features of the acquired spectra, such as, center frequency and amplitude of the highest peak in a pre-selected frequency range.

The ultrasonic principle is based on the fact that solid materials are good conductors of sound waves. This pulse of waves travels through the metal with some spreading and some attenuation and will be reflected or scattered at any surface or internal discontinuity such as an internal flaw in the specimen. This reflected or scattered energy can be detected by a suitably placed second piezoelectric disc on the metal surface and will generate a pulse of electrical energy in that disc.

The time- interval between the transmitted and reflected pulse is a measure of the distance of the discontinuity from the surface, and the size of the return pulse can be a measure of the size of the flaw. This is the simple principle of the ultrasonic flaw detector and the ultrasonic thickness gauge.

2.2 Radiography

This process involves transmitting X-rays or gamma rays through aircraft structures to a film on the opposite side of the piece being tested, thereby detecting the discontinuities on the inside of structure.

The mobile units are equipped with 200 or 300 kilovolt X-ray machines. These X-ray units have, only a maximum thickness penetration of 2.5 inches of steel but has a higher thickness penetration when inspecting aluminum, plastics, ceramics, and certain other materials, depending on density.

Most of the aircraft structures are made of aluminum and thus, X-rays penetrate the metal and affect the X-ray film, which provides the image. X- rays pass through the cracks (cracks have lesser density than un-deformed portion) and thus produce a darker image on the X-ray film.

2.3 Liquid penetrant

This process is a surface testing mechanism and therefore it is not capable to detect deeply buried flaws in aircraft structures. In this mechanism, the aircraft surface to be inspected is cleaned thoroughly to remove all traces of dirt and grease. A brightly colored or fluorescent liquid is then applied liberally to the component surface and allowed to penetrate any surface-breaking cracks or cavities.

The time the liquid is allowed to soak into the material’s surface is normally about 20 minutes. After soaking, the excess liquid penetrant is wiped from the surface and a developer applied. The developer is usually a dry white powder, which draws penetrant out of any cracks by reverse capillary action to produce indications on the surface. These (colored) indications are broader than the actual flaw and are therefore more easily visible.

Liquid penetrant testing offers a fast, cheap and relatively simple means of surface inspection, making it attractive to a number of industries. The aerospace industry use automated fluorescent penetrant testing to look for fatigue cracking in turbine blades.

2.4 Eddy current testing

Eddy current testing is an electromagnetic technique and can only be used on conductive materials. Its applications range from crack detection, to the rapid sorting of small components for flaws, size variation, or material variation. Commonly it is used in the aerospace, automotive, marine and manufacturing industries.

When an energized coil is brought near to the surface of a metal component, Eddy currents are induced into the specimen. These currents set up magnetic fields that tend to oppose the original magnetic field. The impedance of coil in close proximity to the specimen is affected by the presence of the induced Eddy currents in the specimen.

In case the Eddy currents in the specimen are distorted by the presence of the flaws or material variations, the impedance in the coil is altered. This change is measured and displayed in a manner that indicates the type of flaw or material condition.

This method includes a system, which involves a rotating probe system designed specifically for the detection of deeply buried flaws in multilayer conductors. The design change incorporates a giant magneto resistive (GMR) sensor as the pickup device to improve the low frequency performance of the probe.

3. The CrackView system

The CrackView project consists of an object-oriented system for displaying to multiple human senses information about the location of microscopic cracks in airplane wings. By assuming an existing electronic output file produced either from ultrasonic inspection or Eddy current testing technique, the digital data is, firstly, converted to a solid modeling representation of mechanical part being inspected.

The section of interest of the cracked wing (or all of it) is stored in CAD B-Rep format (i.e. Boundary Representation). Next a 3D mesh is generated through the CrackView's CAE interface. In case of an easily visible crack has been detected, one may simply use the available zooming facility and be quite happy with the results. However, the real advantages of CrackView are better noticed if a microscopic crack has been detected. In this particular case the user can take advantage of the facilities available in CAD/CAE and Virtual modules.

The user may start by adding forces, loads and boundary conditions to the model. Next he will process a job in order to expand the microscopic crack. By using this tool the user would be simultaneously visualizing and evaluating the microscopic crack. But the benefits offered by this application go one step further. There is a virtual module that automatically generates a virtual representation for displaying an exaggerated crack in a visual representation of the wing. Finally the user may visualize the microscopic crack in a VRML-based CAVE-like 3 walled immersive projection system. Figure 1 illustrates CrackView's main screen.

The complete CrackView system works as a hybrid CAD, CAE and Virtual environment interface. Although it is out of the scope of this paper to describe the functionality and purpose of every available facility in CrackView, the following sub-sections will cover the essential parts of some basic modules.

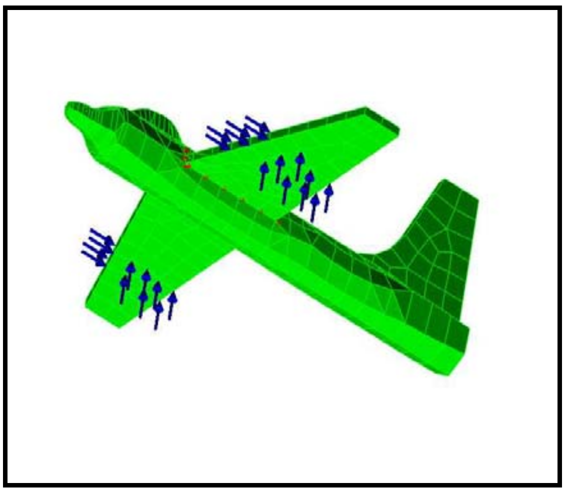

Figure 1a. Airplane and some applied forces.

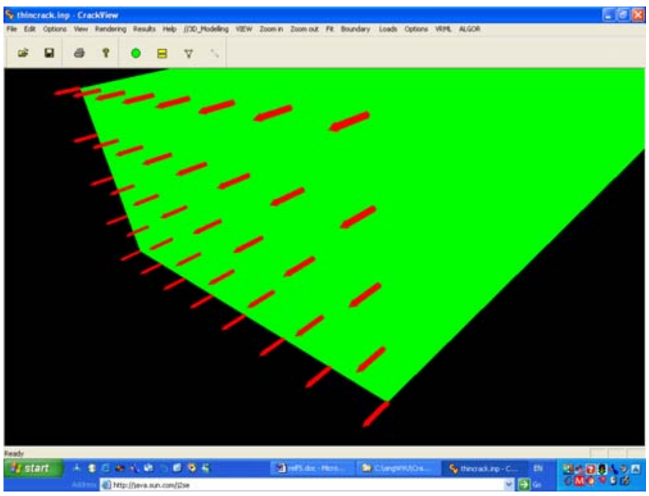

Figure 1b. Forces displayed within the CAD module

3.1 – The CAD display module

Among the various features and abilities of CrackView there are some ordinary tools facilities capable of both displaying and editing: forces, loads, boundary conditions, units (including metric system) and node coordinates. For instance, the arrows displayed in figures 1a and 1b illustrate some applied forces. It also provides various options that allow the user to change the visual appearance of the CrackView system, making for a more friendly working experience.

The application also provides some standard viewing facilities such as: changing node size, background color, zooming, translation, rotation and rendering. These rendering functions include: displaying of the nodes on the screen displaying of the wire frame mesh of the model and displaying of the solid rendering.

3.2 The CAE module

Beyond providing its own electronic FEM format, CrackView allows for the visualization of data obtained from some commercial finite element modeling packages such as ABAQUS and ALGOR. Currently, the interface supports ABAQUS input files and ABAQUS output files generated by version 5.8. Figures 3 and 4 illustrate two frames of a wing cell before and after an expanded crack has been calculated.

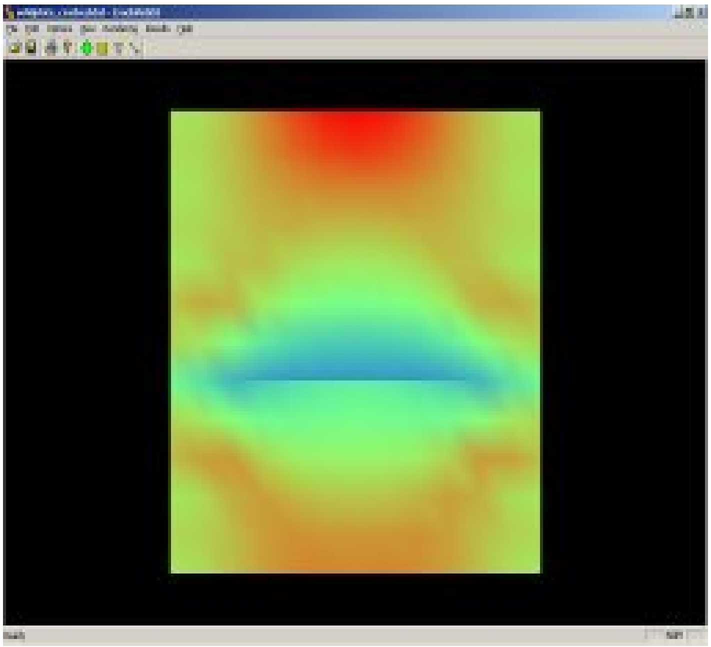

Figure 2. Cell of an airplane wing (Before displacement)

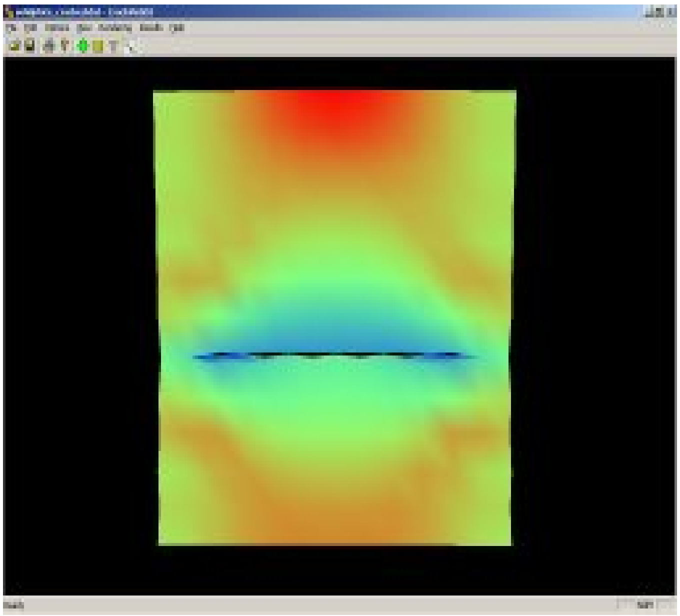

Figure 3. Cell after displacement and magnified (x 100.0)

Furthermore, this module also provides an on-line interface between the CrackView System and **AGSDB** (Algor General Simulation Database). The **AGSDB** system functions as a data bus for all finite element model data within the ALGOR FEA software. This offers an alternative FEA evaluation via ALGOR version 13.12-WIN. It must be emphasized here the importance of this module once the **AGSDB** tool does not include CAD data, finite element analysis results, such as stresses, displacements, etc. Figure 4. shows a frame from an AVI file that illustrates a magnified displacement of a cracked wing.

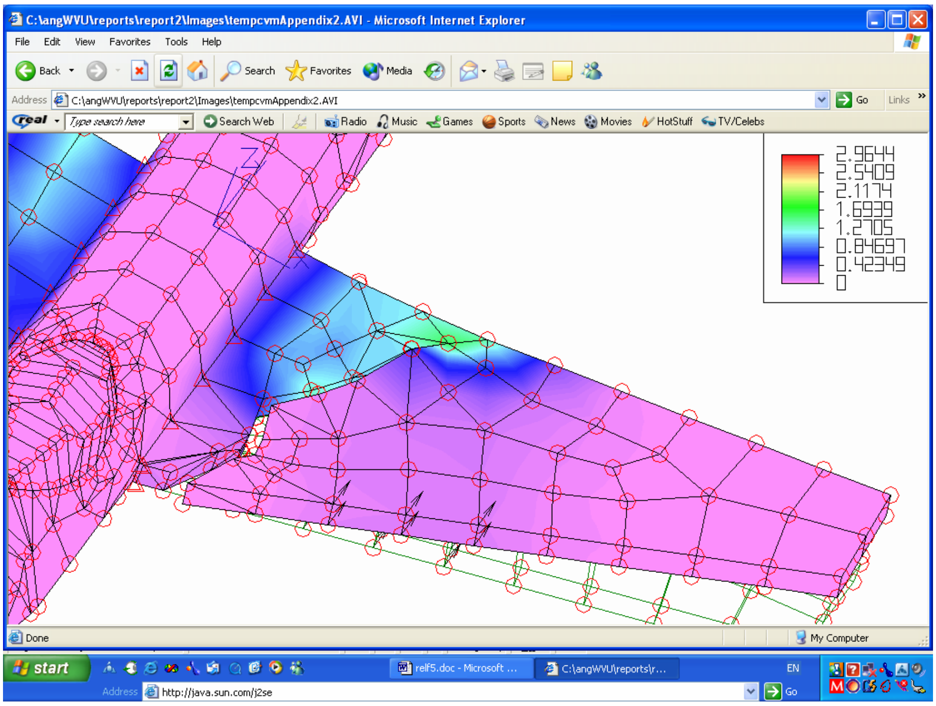

Figure 4. Magnified cracked wing (x 1e07)

Finally, within the CAE module, CrackView provides access to loading and modifying material (aluminum, steel, etc) library properties. Figure 4 illustrates the integration between CrackView and ALGOR FEA software.

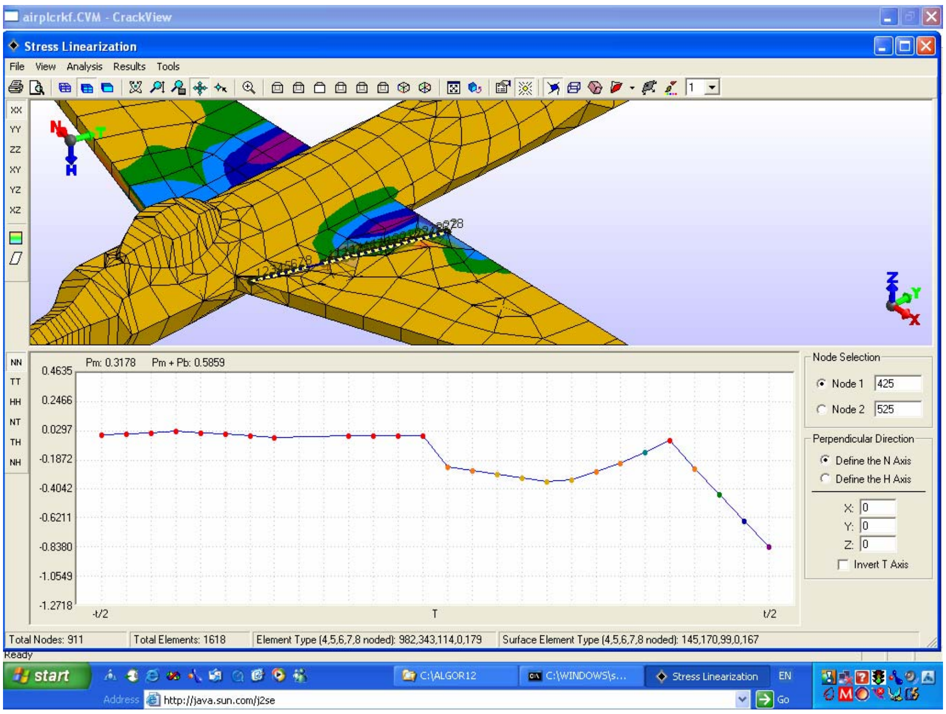

Figure 5. Stress linearization shown via Crackview’s CAE module integrated with ALGOR commercial software.

3.3 The crack insertion module

This module allows for the viewing of internal representations of the models as well as the insertion of horizontal, elliptical cracks into the mesh of a mechanical part.

In order to provide this facility CrackView has implemented an abstract geometric entity namely “split face”. Each element in a FEA model is made up of faces, which are defined by the node ordering in the face. Each face, in turn, may have a corresponding face in the model that contains the same nodes, but is located in a different element. When inserting a crack into the model, this “split” face is the only face that the current face can separate from. Therefore the “split” face supports the crack insertion procedure.

It is important to mention that the functionality of this module is not limited to the insertion of elliptical shape cracks. It also provides some extra tools to allow the insertion of variable, user-defined cracks into the mesh of the model (see figure 6).

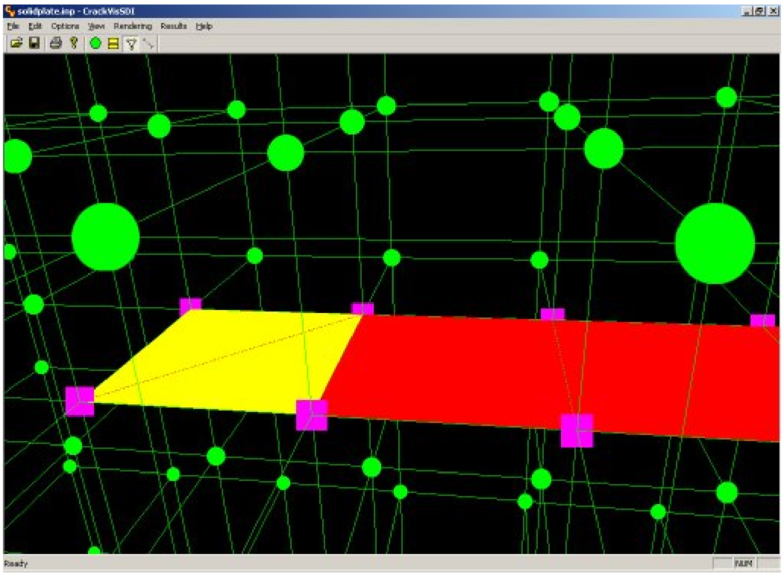

Figure 6. Insertion of an user-defined crack (red and yellow color) at node level

3.4 The ABAQUS remote module

CrackView can also connect to a remote server (challenge.cemr.wvu.edu) running ABAQUS and return the results to the user, thus allowing users to work on meshes and submit jobs without having ABAQUS running locally. For instance, this would be the case if one is at UFRN University in Brazil and needs to process a crack evaluation using some powerful computers at WVU in USA.

In order to accomplish this task CrackView provides a function that will take the name of an input file, the internet address of a computer running the AbaqusServer program, the port the server is running on and the name of the output file to be generated. The application then sets up a connection to the server and sends the input file to the server. After the server is finished running the job, the function receives the output file from the server and stores it. A message is then displayed to confirm if the job was completed successfully.

3.5 The virtual module

Having in mind that the visualization of microscopic cracks is the core of this project, this module aims to provide tools facilities to reload post-processor results output files (i.e. after FEM calculations) and manage the displaying of different parts of a cracked solid model at different scales.

The VRML output file produced by this module is responsible for allowing the visualization of cracks in a VRML-based CAVE-like 3 walled immersive projection system.

Therefore, this module is normally used for demonstration of application to a specific model of an airplane with a cracked wing.. It must be highlighted here that even electronic microscopes have limitation on their magnification power. On the contrary, virtual reality technique applied to this kind problem has its advantages because it can easily deal with any size scale ranging from galaxy to atomic spaces.

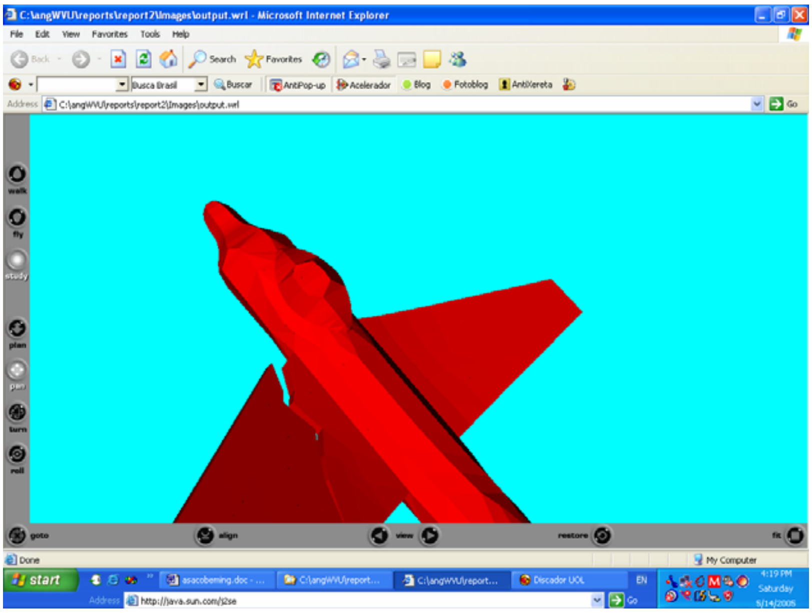

Figure 7. Virtual model of a cracked wing displayed in VRML

4. Conclusions

The following conclusions can be drawn from this work:

- A hybrid CAD, CAE and Virtual interface was successfully developed and tested for helping on the FEA evaluation and visualization of regular and microscopic cracks in airplane wings.
- The results obtained from a particular inspection using NDT mechanisms (i.e. ECT and ultrasonic) can be further explored to produce 3D visualization via CAD and Virtual Reality tools.
- Microscopic cracks can be magnified not only by ordinary scale or zooming facilities, but also through applied forces and proper boundary conditions simulated in CAE environment. CrackView has accomplished this task with the help of ABAQUS and ALGOR softwares.
- The task of converting electronic data obtained from NDT inspections to a geometric solid modeling representation is extremely complex. This subject needs further attention from researches in this field.

5. Acknowledgements

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6. References

Bucci, R.J. and Warren, C.J and Starke, E.A, Jr., 2000, “The need of new materials in aging Aircraft Structures”, Journal of Aircraft, Vol 37, pp 122-129.

Geetha, R. K., 2004, “Finite Element Modeling of Crack Detection in Aircraft Structures Using Electrical Current”, MSc thesis, College of Engineering and Mineral Resources at West Virginia University , Morgantown-WV, USA.

Van Scoy, Frances L.,et al., 2002, “A VRML Based Immersive Projection System”, Proceedings of Virtual Systems and Multimedia, South Korea.

Wenk, Samuel A. a Mc. Master, Robert C., 1987, “Choosing NDT: Applications, Costs and Benefits of Nondestructive Testing in Your Quality Assurance Program”, Paul Mc.Intire, Editor , ASNT , USA.

Wincheski, B. and Namkung, M., 1999, “Electromagnetic Detection of Fatigue Cracks under Protruding Head Ferromagnetic Fasteners”, Third Joint FAA/DoD/NASA Conference on Aging Aircraft, Albuquerque, New Mexico, USA

Xiong, Y. and Bedair, O.K., 1999, “Analytical and Finite Element Modeling of Riveted Lap Joints in Aircraft Structure”, AIAA Journal, Vol. 37, N^{o} 1, pp. 93-99.

7. Responsibility notice

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