Thermal Wave Imaging for Detection and Quantification of Corrosion and Disbonds in Aging Aircraft

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ABSTRACT

The application of pulse-echo thermal wave imaging to nondestructive evaluation (NDE) of aging aircraft is described. This technique uses high-power photographic flash lamps as a heat source and an infrared (IR) video camera as a detector. The imaging system is hand-held and separated from the control system by a 50-ft cable, making it highly portable. This separation of the control computer from the imaging head also makes it suitable for potential robotic applications. The flash lamps launch thermal wave pulses into the skin of the aircraft and the IR camera images the returning thermal wave echoes produced by subsurface defects. The system includes hardware and software for time-gated imaging and real-time analysis of the images. It has the ability to image large areas (up to several square feet) in short times (a few seconds), and to make quantitative measurements of corrosion thinning with a sensitivity of better than 1% material loss. These measurements are in good agreement with profilometer and ultrasonic estimates. Applications to the imaging of disbonds doublers and tear straps are described, along with applications to the quantitative imaging of corrosion in skins and lapslices. The applications include the imaging of the entire belly skin of a DC-9, the detection and imaging of intergranular corrosion around wingfasteners in both military and commercial aircraft, and the detection of disbonded doublers in 747 aircraft.

INTRODUCTION

We have used a thermal wave imaging system, consisting of a flashlamp heat source, an infrared video camera, and a laptop computer, to nondestructively image subsurface defects and internal structure in aircraft. The imager is hand-held, and is readily moved around the aircraft. Figure 1 shows a photograph of the pulse-echo thermal wave imaging system in operation for the measurement of rear-surface corrosion in the belly skin of a DC-9 aircraft on an airfield. The operator is shown underneath the aircraft, using the hand-held imager, which contains the infrared video camera, flashlamp heat source, and a shroud which is used to direct the energy from the flashlamps onto the surface of the aircraft. The imaging head is connected to the computer controller and power supplies for the flashlamps through an umbilical cable which is 50 ft in length. During this operation, the entire belly skin of the aircraft was inspected, without moving the control cart and computer. This same system has been used in a variety of other hangar and airfield environments, including airline maintenance facilities, for imaging the integrity of bonded doublers and the measurement of corrosion thinning.
Fig. 1 Photograph of the pulse-echo thermal wave imaging system in operation for NDE of a belly skin section of a DC-9 aircraft, on an airfield. In this operation, the belly of the plane is less than one meter above the airfield, but this causes no difficulties for the measurements.

RESULTS

Figure 2 shows an example image of the aircraft shown in Fig. 1, taken with the thermal wave imaging apparatus, and Fig. 3 shows the corresponding corrosion analysis window. The corrosion analysis program uses nearby uncorroded skin as a reference, thus giving a relative percentage thinning without having prior knowledge of the skin thickness. The two small squares on the image in Fig. 2 indicate the reference and target areas. The lower square is located on an area of severe corrosion and the resulting percentage of material loss is shown in the upper right corner of Fig. 3. If absolute thickness measurements are required, a sample of aluminum of known thickness is placed in the field of view of the camera and used as a calibration reference, instead of the uncorroded skin of the aircraft itself. The program operates in real time and sliding the target square around on the image causes the percentage loss number to scroll through the corresponding measured values. The entire process of imaging and analysis takes less than three seconds. Laboratory tests have shown that skin thinning less than 1% can be accurately measured by this method.

Figures 4 and 5 show the applicability of the method for detection of intergranular corrosion in the vicinity of wing fasteners in B737 and C/KC-135 aircraft. The intergranular corrosion shows up as irregular light patches extending out from the images of the fasteners.

Figure 6 shows the application of the system to the imaging of bonded internal doubler structures. In this case, all of the doublers are well-bonded and show as darker areas in the images. The gaps between the horizontal and vertical doublers are intentional parts of the design, and do not represent disbonds. Figure 7 shows a doubler within which there are irregular regions of disbonding. The fasteners in Fig. 6 are aluminum and show as darker circles in the image, whereas the fasteners in Fig. 7 are made from steel, and show as lighter features in the image.
Fig. 2. Image of a region of the DC-9 belly skin which shows corrosion (lighter regions) on the rear surface of the skin.

Fig. 3 Corrosion evaluation software window, showing the percentage material loss (76.4%) in the small square centered in the brightest region of Fig. 2. The second small square is a reference region.

Fig. 4. Image of a region of the 737 wing skin which shows intergranular corrosion around the three circled fasteners.

Fig. 5 Images of an uncorroded (top left) and three corroded wing fastener regions, taken from an ARINC test of corroded C/KC-135 wing skins. The intergranular corrosion shows up as an irregular boundary around the image of the fastener.
Fig. 6  Thermal wave images of well-bonded doublers in Section 41 of a 747 aircraft.

Fig. 7  Thermal wave image of a partially disbonded doubler in Section 41 of a 747 aircraft.

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