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The detection, inspection, and failure analysis of a composite wing skin defect on a tactical aircraft

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ABSTRACT

A routine ultrasonic inspection of a lower wing skin revealed a defect between the titanium alloy stepped-lap joint and composite surface. Since the wing skin passed high-tension loads through to the fuselage, the possible presence of such a defect had the potential to compromise other aircraft with the same construction. Naval Air Station (NAS) Jacksonville personnel took the lead in coordinating the approach to identify, diagnose, and manage the defect by synchronizing efforts between non-destructive testing, metallurgy, and composites experts. The defect was identified as a disbond between the splice plate and bond primer that led to a delamination fatigue crack between composite plies. From these results, staff implemented a novel inspection program to search for similar defects in the fleet.

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1. Introduction

The use of composite materials in lieu of traditional metal alloys has expanded greatly due to the needs of high-performance aircraft structures, particularly military aircraft [1,2]. However, the use of composite materials presents challenges in the production and maintenance of aircraft components, and the investigation of these components when they fail.

Failure analysis of fiber-reinforced composites has been investigated extensively on lab-based specimens to determine fracture features in a variety of conditions [3,4]. However, the determination of the root cause in a failure analysis has been found to be dependent on the effects of the layup pattern [5,6], loading conditions [7,8], and environmental conditions [9,10]. Furthermore, internal defects may not be readily observed externally and require specialized detection techniques with experienced trained operators [11–13].

Such was the case when a defect was located in a composite-to-titanium bonded joint on a tactical aircraft wing during a routine ultrasonic inspection of the wing skins (location shown Fig. 1). This joint was comprised of woven carbon-fiber reinforced-epoxy composite bonded to a titanium-alloy stepped-lap joint, which conferred high mechanical properties with low life-cycle costs [14]. The titanium splice plate was coated with an epoxy bond primer, and was bonded to the composite with an epoxy film adhesive. This layup was designed to impart high toughness, shear strength, and stiffness [15]. There was no apparent damage to exterior surface of skin.

2. Methods and materials

Non-destructive testing (NDT) of the lower and upper wing skins was performed by use of an ultrasonic C-scan Mobile Automated Ultrasonic Scanner (MAUS) with a 5 MHz transducer. Additional ultrasound inspection and extensive mapping of the defect were performed using A-scan using a Krautkramer USN 52 using a variety of transducers. The thin composite steps near the titanium root were inspected with a 10 MHz delay line broadband transducer, while the thicker steps and the bulk composite areas were inspected with a 5 MHz broadband transducer without delay line.

The lower wing skin was prepared for examination by sectioning the area surrounding the defect. The major sectioning was performed using a pulse water jet cutter. Finer sectioning of plugs and other areas were performed using a variety of instruments from handheld drills and accessories to tabletop cutoff wheels.

Analysis of the wing skin components was performed by using a CamScan MaXim scanning electron microscope (SEM) with Oxford INCA energy dispersive X-ray spectroscopy (EDS) and wavelength dispersive X-ray spectroscopy (WDS) attachments. A variable-pressure Tescan Vega SEM was also used to perform low-vacuum analysis on non-conductive materials—this microscope was also complimented with an Oxford INCA EDS and WDS.

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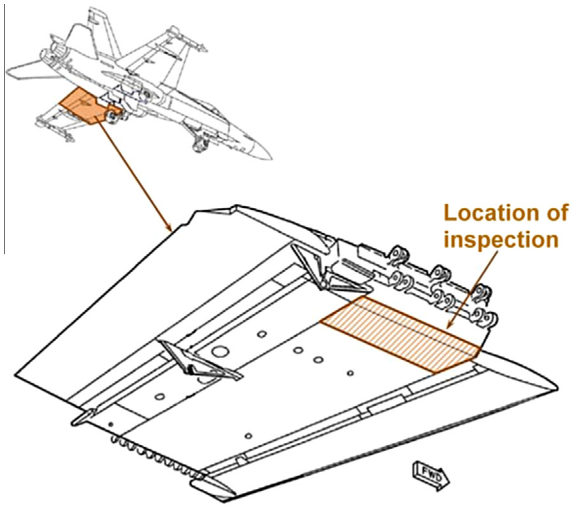

Fig. 1. The location of defect found on the lower wing-root stepped-lap joint.

Chemical analysis of the organic compounds was provided using a Bio-Rad Excalibur FTS-3000 Fourier transform infrared spectrometer (FTIR) and an EDAX Eagle III micro X-ray florescence (XRF) spectrometer. Additional analysis was obtained using Millbrook secondary ion mass spectroscopy (SIMS) provided by the Fleet Readiness Center Southwest (FRCSW) at North Island, CA.

3. Results

3.1. Non-destructive testing

The initial NDT (ultrasonic resonance and pulse-echo C-scan) images are illustrated in Fig. 2. This inspection used a resonance C-scan at relatively low frequency and a pulse-echo C-scan at higher frequencies. These scanning modes yielded information regarding the condition of composites and the integrity of the composite-to-titanium bonded joint. On this particular aircraft, operators found a large defect indication with two lobes. These lobes were largest between wing spars and smallest along the sections fastened to the spars.

Meticulous A-scan ultrasonic inspections were used to outline the boundary, as well as the likely location of the defect through the thickness of the lower wing skin from the outer mold line (OML), as shown in Fig. 3. Fig. 4 illustrates the nature of the location of the defect in cross-section, which was found to be a joint disbond with subsequent delamination and wraparound disbonding. The defect had propagated outboard from the inboard stepped-lap joint. However, there was a discernible elevation of the composite over the defect at the inboard joint seam. In additional, there was evidence of fuel leakage from one of the fastener holes near the kick rib (illustrated in Fig. 5).

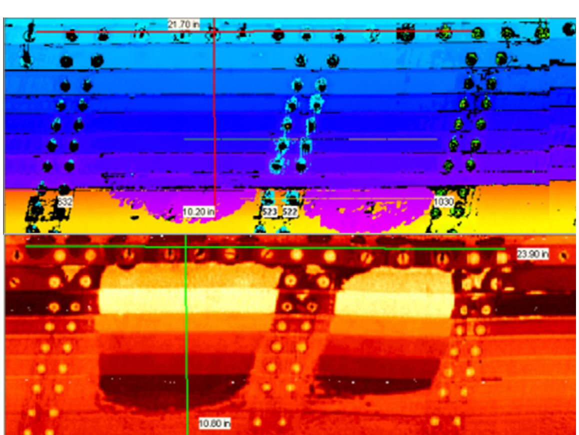

Fig. 2. Resonance C-scan (left side) and pulse-echo depth and amplitude C-scans (right) of the lower wing skin defect.

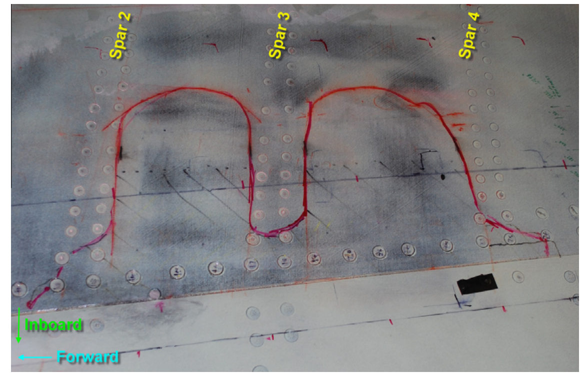

Fig. 3. Outline of the detected defect (red line) found by ultrasonic scanning on the lower wing skin. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

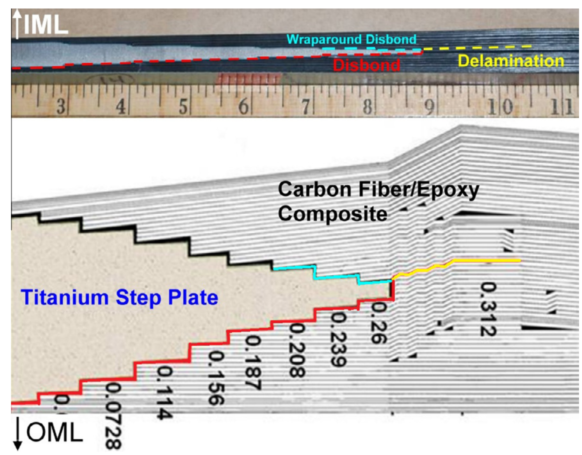

Fig. 4. Image (above) and schematic (below) of a cross-section of the lower wing skin, illustrating the location of the disbond (red) and subsequent delamination (yellow) and wraparound disbond (blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

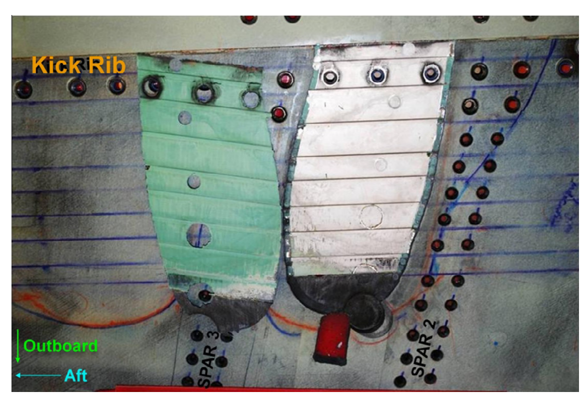

Fig. 5. The large section of composite side of the defect after excising between two spars.