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F-16 Wing Structure Lifecycle

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Abstract

The most widely used military aircraft in existence today, the Lockheed Martin F-16 Falcon, has provided a standard baseline for small fighter jet lifecycle structural integrity studies. Due to the high stress environment of combat flight, the lifecycle analysis of the F-16 provides key insight into design considerations for future aircraft. The United States Air Force is already using the analysis done on the F-16 Falcon on newer fighter aircraft such as the Lockheed Martin F-22 and F-35 to carry over the lessons learned from this very successful programme. In this analysis, real-life data collected from twenty years of the Air Force's Aircraft Structural Integrity Program (ASIP) is reviewed to highlight the most important advances in the structure of the F-16. In order to focus on the most stressed part of the aircraft, the analysis is only done on the wings. First, the F-16 crack database (CIRE) is reviewed to find the most common locations on the wing where cracking occurs. Next, certain exceptional cases are considered in order to understand unusual behavior. Then, the most detrimental cracks are analyzed to discuss potential risks if minimal repairs are done. After this, the design repairs for permanently reversing and preventing future cracks are reviewed to show effectiveness. Finally, predictions are made on the lifecycle and future areas of structural concern for the F-16 wing.

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Keywords: Structural Analysis, fracture, crack propagation, lifecycle, fatigue

1. Introduction

A common story about the F-16 Falcon fighter jet is the first flight on 20 January, 1974. The test pilot experienced some difficulties with the roll control that caused the plane to respond too strongly. As a result, the plane rolled so much during take-off that the left horizontal stabilizer actually hit the runway.

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The pilot was able to recover control of the airplane and keep the program from possible failure and cancelation. In the long run, this proved to be quite a success story because there were over 4,500 F-16’s built and several production lines in the U.S., Turkey, Israel, Belgium, Korea and India which are manufacturing the fighter today.

Due to the long history of F-16’s and the completeness of their structural failure data over the years, it has become a standard baseline for small fighter jet lifecycle studies. An initial lifecycle of 4,000 hours was assigned to the F-16 based on its low margin of safety factors at key stress points in the wing. A routine maintenance schedule of 500 hours limits the potential of cracks to cause failure. However, due to increased demands and continual improvements to the structure, most F-16’s are still operating at 4,500 hours and are intended to last until 2050.

Since the number of flight hours has gone beyond original projections, the structural integrity has to be intensely monitored. The United States Air Force maintains their aging aircraft through the Aircraft Structural Integrity Program (ASIP). This office records their crack findings and other fractures in the CIRE database in order to address recurring areas of failure. Based on their research, they offer recommendations for repairs and provide valuable insight into the maintenance considerations of future fighter aircraft such as the F-22 and F-35.

The focus of this research was to catalog the key fracture areas on the most stressed part of the aircraft, the wing. All of the fractures occur in areas with very low margins of safety which signifies a high potential for failure of the wing. Thus, these areas require the most in-depth review for proper repair. However, to provide a proper repair, the three main areas of failure on the wing need to be analyzed for the causes of these cracks. The three key areas are the wing tip rib, the upper skin of the wing, and the #5 internal spar vent holes. The repairs for these areas are also reviewed to show their effectiveness. Using all of this data, it is possible to better predict the failure points of aging aircraft and design better structures to prevent these failures.

2. Problem Setup

2.1. Material Structure

The F-16 was designed without much use of titanium or other high strength, more expensive metals in order to reduce costs. Thus, most of the structure is aluminum alloy, either 2024 or 7475. Some other components are steel and even composite. From a maintenance perspective, the metallic structure is easier to service and repair. Usually, repairs do not require a complete replacement of parts but rather basic sheet metal work to increase the strength of the area around the cracks. Favorable results have been shown that these repairs extend the life of the aircraft but can easily cause fractures to appear in other areas.

The wing structure was designed to be mostly composed of spars with four main rib sections. The root rib has attachment points for all of the 10 internal spars and the trailing edge spar. The BL 71 rib section has individual ribs that connect between each individual spar and provide fuel ports for refueling and dumping. The BL 157 rib section only connects the number 9, 10 and trailing edge spars together and then has an extension out to the wing tip rib. Armaments are attached to the Falcon along the BL 71, BL 157 and wing tip ribs. All of this substructure is exposed to JP-8 jet fuel and is therefore anodized to prevent corrosion. Unfortunately, because of the air tight seal of the inner wing box structure, cracks in this area are extremely hard to find unless the wing skins are removed..

2.2. Stresses

The wings experience constantly shifting loads inherent with changing inner fuel levels and flight configurations. Thus, the stresses on the wings vary greatly during flight. Manufacturer Lockheed Martin generally uses an assumed mode of failure in its calculations of stresses to show margin of safety. For the wing, these margins of safety calculations are limited to only the areas where failure would occur first. The upper skin is assumed to be loaded in compression which mostly focuses on buckling or bolt shear failure. Meanwhile, the lower skin mostly undergoes tension forces which cause inter-fastener shear out and cracking. For the interior spars and ribs, shear flow is assumed to be the cause of failure along the C beam profiles. In general, all parts of the wing box have an area with a margin of safety within +0.01 of failure due to the complexity of the loading. The locations of fractures from the CIRE crack database concur with these areas of failure. Three key failure areas are examined: the wing tip rib, #5 spar vent holes and the wing upper skin.