INVESTIGATION AND REMEDIATION OF A COMPLEX FAILURE OF A HIGH STRENGTH STEEL FAN MIDSHAFT FROM A GENX ENGINE

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Abstract
On July 28, 2012, a Boeing 787-8 airplane experienced a loss of thrust in the right GEnx turbofan engine during a pre-flight, low speed taxi test at Charleston International Airport in Charleston, South Carolina. Inspection of the engine revealed the forward end of the fan midshaft had separated, causing the low-pressure turbine rotor to shift aft, damaging that section of the engine. A detailed investigation performed by the NTSB and General Electric found the fan midshaft on the GEnx engine had separated from an environmentally assisted cracking mechanism under static load. Cracking was predicated by an intricate and previously undetected reaction between the fan midshaft ultra-high strength steel, the dry film lubricant, and the assembly aid. This investigation explored multiple and fundamental aspects of the fan midshaft, including manufacturing, assembly, design, and loading. From the investigation, a non-destructive inspection was developed and employed throughout the fleet with multiple changes to the assembly of the GEnx engine to prevent future reoccurrences.

1. Introduction

The National Transportation Safety Board (NTSB) is an independent agency of the government of the United States of America, charged with investigating all aircraft accidents, along with significant accidents involving rail, marine, highway, pipeline, and hazardous materials transportation. This authority to investigate includes aviation incidents, such as aircraft that are not in revenue service or events at airports on the ground. One such incident occurred in 2012 when a Boeing 787-8 was performing a low-speed engine test while taxiing on a runway, during which the engine failed. The engine was the GE Aviation GEnx-1B engine, a novel design based on the GE90 high bypass turbofan engine. The primary component that fractured was the fan midshaft, which connected the low-pressure compressor to the low-pressure turbine sections of the engine. The fracture of the fan midshaft caused the LPT section to move aft, destroying those sections of the engine. The investigation was performed primarily at the GE Aviation facilities in Evandale, OH, with the NTSB and personnel from parties to the investigation present.

2. Results

The parties to the investigation performed an extensive fractographic inspection of the fractured fan midshaft as well as a multitude of metallurgical and fundamental scientific tests. The fracture surface exhibited primarily transgranular cleavage features, with some intergranular facets, as typified in Figure 1. These features were consistent with environmentally assisted cracking of the fan midshaft material, an ultra-high strength steel. These fracture features were compared with stress corrosion bending specimens, which exhibited comparable features once fractured. These features were also consistent with those in hydrogen-charged tensile specimen fracture surfaces and were inconsistent with those of developmental fatigue specimens. The remainder of the fracture features were dimpled rupture, consistent with the final overstress fracture of the shaft.

Testing and review of the design and assembly of the construction were performed to ascertain the source of the corroding species. In the configuration of the fan midshaft as assembled, the threads had been coated with a dry-film lubricant, and a graphite-based grease had been used to aid assembly of the fan midshaft with the forward fan via a coupling nut. The dry-film lubricant was found to absorb ambient moisture, and the graphite in the grease developed a galvanic couple with the shaft material. Finite element analysis of the assembled configuration found the highest stress concentrations at the aftmost thread root, which coincided with the location of the initiation of the cracking.

With these results, an inspection protocol was developed for the fan midshafts in the fleet of deployed engines. An ultrasonic inspection kit was commissioned to search for similar cracking in the fan midshafts, finding one other in service with crack indications. Intentional opening of the indications confirmed environmentally assisted cracking, with comparable features. The entire fleet of engines were repeatedly inspected to ensure continued airworthiness, with no further incidents occurring. In addition, the configuration of the fan midshaft assembly was improved, with the graphite grease being replaced as an assembly aid, and a new, less-susceptible dry-film lubricant being developed and implemented.

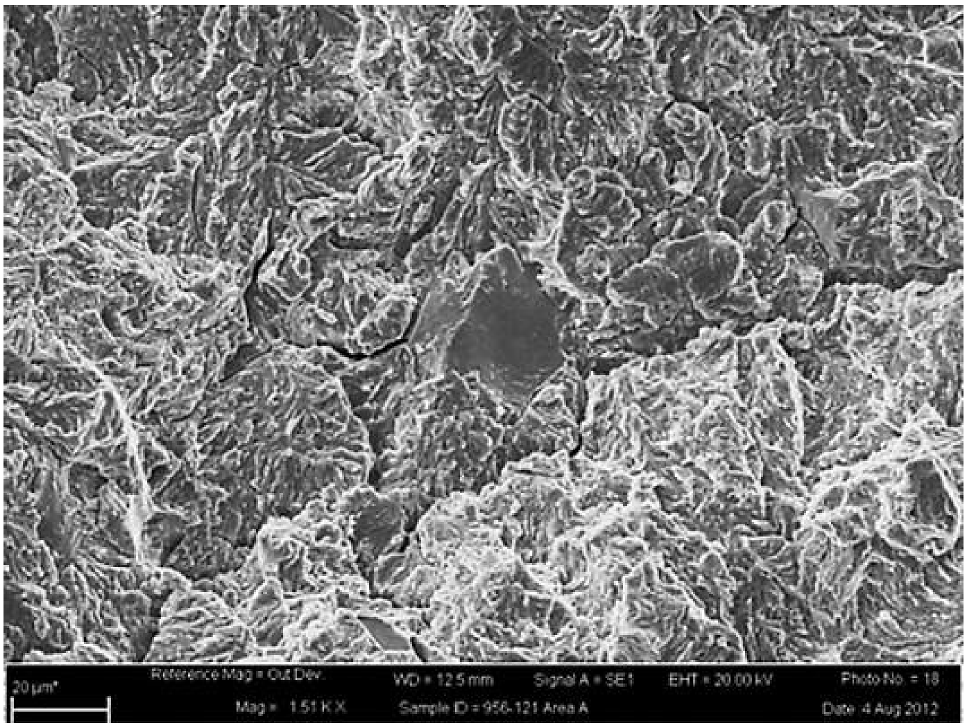

Fig.1 – Secondary electron micrograph of a typical area of the fracture surface features in areas consistent with environmentally assisted crack propagation.

3. Conclusions

The National Transportation Safety Board determined the probable cause of this incident was a separation of the fan midshaft that arose from environmentally assisted cracking under static load. Contributing to the incident was the combination of dry film lubricant applied to the fan mid-shaft and graphite grease used during assembly which made the fan mid-shaft susceptible to corrosion from trapped moisture. As a result of this investigation, continued inspection routines of the engine were developed that prevented a recurrence of the incident.

Acknowledgements

The investigation could not have concluded successfully without the direction of the investigator in charge, Dave Helson, and Jim Hookey (now retired) as the commercial engine expert for the NTSB. Joe Epperson, FASM, was instrumental in initial examination of the engine, and Mike Budinski, provided expertise to guide the fundamental testing. The investigation also was helped immeasurable by GE Aviation experts Mike Weimar and Walt Buttrill, and most especially W. Doug Pridemore, whose cooperation and assistance led to recommendations to prevent further incidents.