

Root Cause Failure Analysis: Reducing Costs & Increasing Customer Satisfaction

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Root cause failure analysis is a technology for objectively identifying all potential failure causes, and then objectively and systematically identifying the likelihood of each potential cause. This article describes how root cause failure analysis identified and eliminated recurring Apache main rotor blade rejections.

During the Apache helicopter's first decade of production, the helicopter suffered main rotor blade disbands both during the manufacturing process and in service. Composite Structures Division in Monrovia, California (then an Alcoa subsidiary) manufactured the rotor blades, which they supplied to McDonnell Douglas Helicopter Company (the Apache manufacturer).

Rotor Blade Vulnerability and Survivability

The Vietnam War marked the U.S. Army's first wide-scale use of helicopters as a modern warfighting tool. The Army's iconic UH-1 Huey suffered from a serious weakness, though, and that was its vulnerability to small arms fire. The helicopter fuselage was fairly robust (it was not uncommon to see helicopters with multiple bullet holes still flying), but the Huey's rotor blades were extremely vulnerable. The Army learned the hard way that if a single rifle bullet struck a Huey rotor blade it would fail, resulting in loss of the helicopter and its crew.



The AH-64 Apache helicopter's main rotor blade hits from both small arms fire

Based on the above, the Apache requirements included greatly-improved main rotor

blade survivability. The Army wanted the Apache's blades to survive direct hits from small arms fire up to and including the Russian 23mm high explosive anti-aircraft projectile.

To meet this requirement, the Army and McDonnell Douglas designed the Apache rotor blade with redundant load paths. Each blade consisted of four stainless steel sheet metal spars. These spars were bonded together to form the blades' structure, with each running the entire length of the helicopter blade. If the blade were struck in any one of its four spars, the remaining spars would keep the blade together and the helicopter could return to base.

Manufacturing State-of-the-Art Combat Helicopter Components

Composite Structures Division manufactured the Apache main rotor blades using a typical composite layup and bonding process. The steps included:

1. Suppliers produced components required for the blade (including the stainless steel spars described above).
2. Composite Structures either source inspected or inspected parts in its Receiving Inspection area.
3. The parts went to stock.
4. Composite Structures issued parts kits including metal parts, tooling, and adhesives to a clean room layup area.
5. In the clean room layup area, Composite Structures technicians assembled the parts in special assembly tools. This operation consisted of applying adhesives to the surfaces to be bonded, assembling the parts and the adhesive, and then enclosing the parts in a foil bag.
6. The assembled blade and fixture entered an autoclave, which subjected the assembly to a vacuum and a specified temperature profile to cure the adhesive.
7. After the autoclave operation, technicians removed the blade from the fixture, stripped the bagging from the assembled rotor blade, and moved the rotor blade to the next assembly operation.

The Failures

The blade failures consisted of the glue joint that held the bonded spars together debonding. These failures always followed the autoclave curing operation (sometimes immediately after the autoclave operation, sometimes after the blade moved on to subsequent operations, and sometimes after the blades had been delivered to McDonnell Douglas). While still in the Composite Structures, approximately 50% of the rotor blades experienced the debonding failures. Amazingly, this had been steadily occurring during the blades' 10-year production history.

Unknown to Composite Structures, the Army also experienced similar debonding failures on blades in service. The Army had specified a 2000-hour blade life [1][1] requirement for its Apache main rotor blades, but on average, the blades were

lasting only 800 hours.

Both McDonnell Douglas and Composite Structures felt that the rotor blades were state-of-the-art, custom-engineered components, and a 50% yield was inherent to the process. Both companies appeared willing to live with the recurring failures.

After a management change at Composite Structures, the company's new management sought to improve profitability through many actions, including the elimination or reduction of recurring nonconformances. The 50% rotor blade rejection rate surfaced as the highest rework cost area in the company, and Composite Structures assigned a team to identify the causes of and eliminate these failures.

Much to Composite Structures' surprise, McDonnell Douglas seemed uninterested in correcting the problem. In fact, when Composite Structures showed McDonnell Douglas that blade disbonds were its most frequently occurring and highest cost nonconformance, McDonnell Douglas took the position that Composite Structures' quality had deteriorated.

The Failure Analysis

Undeterred by their customer's reaction, Composite Structures pressed ahead with their failure analysis efforts. As a first step, the company prepared a detailed fault tree analysis to identify all potential failure causes. The fault tree's hypothesized failure causes fell into the following categories:

- Inadequate bond strength induced by bonded surface contamination.
- Inadequate bond strength induced by adhesive anomalies.
- Inadequate bond strength induced by design shortfalls (i.e., the loads were greater than the adhesive's strength).
- Inadequate bond strength induced by component nonconformances.
- Inadequate bond strength induced by autoclave curing nonconformances
- Inadequate bond strength induced by expired adhesives. [2][2]

Composite Structures initially focused on contamination, as contamination is a common cause of disbonds. The company inspected its clean room assembly area for food, silicone-based spray lubricants, and other contaminants. Although they found and eliminated several potential contaminant sources, these actions had no effect on the blade failure rate. Overall, the company felt it had improved its contamination discipline, but the blade disbond failures continued.

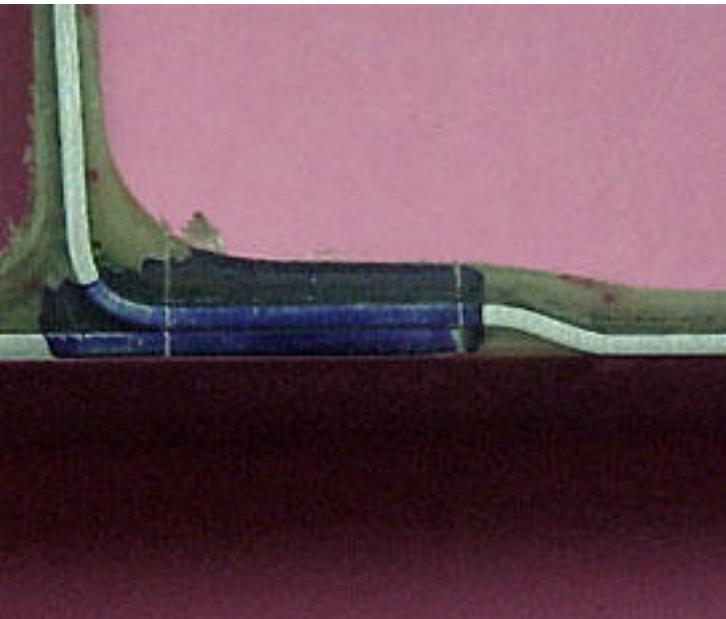
The failure analysis team next disassembled and inspected several failed blades. None of the disbonded blades' components exhibited any dimensional nonconformances.

The failure analysis team next monitored the production of 12 blades. The team observed no process departures. The 12 blades were built with conforming parts in accordance with all process requirements. Within 2 days of the autoclave operation,

however, 5 blades experienced spar disbonds.

At this point, the fault tree analysis had identified potential failure causes in several areas. After the above actions, however, the failure analysis team felt confident that the failures were not process, component conformance, or contamination driven.

The failure analysis team suspected a design problem. During a meeting with McDonnell Douglas, the failure analysis team explained to the McDonnell Douglas designers that the failures appeared within the adhesive, and not at the adhesive-spar interface. It appeared that the adhesive lacked the necessary structural strength. The McDonnell Douglas engineers stated that this would not occur if the bond joint width were wide enough. The failure analysis team members next asked McDonnell Douglas how wide the bond joint had to be to form a sound joint. McDonnell Douglas replied that the bonded areas had to be at least .440-inch wide or the bond could fail.



The AH-64 Apache main rotor blade bond joint. If the area marked by the scribe lines dropped below 0.440 inches, the blade was likely to debond.

Armed with this information, Composite Structures x-rayed the failed blades (the bond width was not visible in assembled blades, but it could be seen in an x-ray). To everyone's surprise, every failed adhesive bond had a bond joint less than 0.440-inch, and the team realized it had found its "smoking gun."

The failure analysis team next analyzed the main rotor blade drawing tolerances and another surprise emerged: The design allowed the bond widths as low as 0.330 inches.

Composite Structures met with McDonnell Douglas to present the results of its findings. McDonnell Douglas agreed that their drawings allowed the bond width to go below 0.440 inch, but it took the position that Composite Structures should have known this and controlled the bond width to tighter dimensions. McDonnell Douglas stated that it believed Composite Structures' quality had deteriorated in recent months, and that was why the bond widths were now below the .440-inch

dimension.

Composite Structures felt that McDonnell Douglas wanted to avoid responsibility for its deficient design, and was attempting to shift responsibility to Composite Structures with their claims of deteriorating quality. To address this concern, Composite Structures inspected blades produced earlier in the production program. Composite Structures was the Army's rotor blade depot repair facility, and it had older blades in-house for repair. Composite Structures quickly x-rayed the depot repair blades and found that they displayed the same bond width variability as the current production blades. Composite Structures shared this information with McDonnell Douglas.

Corrective Action

Composite Structures asked McDonnell Douglas to revise the engineering drawings to control the minimum bond width such that it would always be at least 0.440 inches. McDonnell Douglas advised Composite Structures to define and then control new tolerances to meet the minimum bond width dimensions, and not to violate existing drawings' dimensions (in other words, McDonnell Douglas did not change their engineering drawings; they dumped the problem on Composite Structures). Composite Structures did as McDonnell Douglas requested. The blade disbond rate dropped to zero (the failures were completely eliminated), and the blades delivered to the Army met their blade life specification requirement.

Lessons Learned

Several lessons emerged from this complex root cause failure analysis:

- Don't accept the argument that state-of-the-art products necessarily have low yields.
- When failures occur, assembly errors or nonconforming parts aren't always the root cause. The part may be completely conforming to its design, yet still fail.
- When the above situation exists, the design must be carefully scrutinized. If a failed item meets all drawing and process requirements, then the fault must lie with the product or process design.
- The very act of attempting to identify and rank order all recurring nonconformances brings more visibility. This increased visibility may be perceived as deterioration in quality. Organizations seeking to identify and eliminate recurring nonconformances need to educate all involved to prevent adverse perceptions.
- Don't accept complacency. Even if your customers accept poor quality, you don't have to.

Composite Structures Results

Composite Structures did an outstanding job in finding and eliminating the cause of the Apache main rotor blade disbonds. They fixed a problem that had been plaguing

their production efforts for 10 years, and they reduced cost, improved quality, and increased customer satisfaction as a result. The Army appreciated Composite Structures' efforts immediately, and McDonnell Douglas ultimately came to do the same.

In addition to finding and fixing the actual cause of the main rotor blade disbond failures, Composite Structures identified many other potential failure causes. A rigorous review of these potential failures resulted in the implementation of many other corrective actions that kept these from occurring, too.

Do you have recurring nonconformances in your organization? Are you hearing that such recurring failures are inherent to the process and there's nothing that can be done? Root Cause Failure Analysis (RCFA) may just be what's needed to eliminate these cost drivers and quality detractors. Eogogics offers a full suite of courses and workshops on [RCFA](#) [3] and [related topics](#) [4]. Root cause failure analysis is an important element of any quality improvement and cost reduction program. It worked for Composite Structures and it can work for you.

Joe Berk, Principal Eogogics Faculty, possesses 30+ years of experience in Root Cause Failure Analysis. He teaches several of the Eogogics [engineering](#) [4] courses including [Root Cause Failure Analysis \(RCFA\)](#) [5], Process FMEA, engineering statistics, design of experiments, statistical process control, quality management, cost reduction, engineering creativity, technical management/leadership, and technical communications. Before starting his training/consulting practice, he held senior management positions in engineering, quality assurance, and manufacturing. He's the author of ten books on engineering. He holds undergraduate and graduate degrees in mechanical engineering from Rutgers University and an MBA from Pepperdine University.

[6][1] Helicopter rotor blades do not have an infinite life. They have to be replaced periodically due to wear and other factors.

[7][2] The adhesive had a shelf life; if the shelf life had been exceeded, the adhesive strength could be degraded.

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[1] http://www.pddnet.com/blogs/2013/05/root-cause-failure-analysis-tool-reducing-costs-increasing-customer-satisfaction?et_cid=3256218&et_rid=280324681∓linkid=http%3a%2f%2fwww.pddnet.com%2fblogs%2f2013%2f05%2froot-cause-failure-analysis-tool-reducing-costs-increasing-customer-satisfaction#_ftn1

[2] http://www.pddnet.com/blogs/2013/05/root-cause-failure-analysis-tool-reducing-costs-increasing-customer-satisfaction?et_cid=3256218&et_rid=280324681∓linkid=http%3a%2f%2fwww.pddnet.com%2fblogs%2f2013%2f05%2froot-cause-failure-analysis-tool-reducing-costs-increasing-customer-satisfaction#_ftn1

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[3] <http://www.eogogics.com/engineering/rootcausefailureanalysis>

[4] <http://www.eogogics.com/engcurriculum>

[5] <http://www.eogogics.com/courses/RCFA3D>

[6] http://www.pddnet.com/blogs/2013/05/root-cause-failure-analysis-tool-reducing-costs-increasing-customer-satisfaction?et_cid=3256218&et_rid=280324681&linkid=http%3a%2f%2fwww.pddnet.com%2fblogs%2f2013%2f05%2froot-cause-failure-analysis-tool-reducing-costs-increasing-customer-satisfaction#_ftnref1

[7] http://www.pddnet.com/blogs/2013/05/root-cause-failure-analysis-tool-reducing-costs-increasing-customer-satisfaction?et_cid=3256218&et_rid=280324681&linkid=http%3a%2f%2fwww.pddnet.com%2fblogs%2f2013%2f05%2froot-cause-failure-analysis-tool-reducing-costs-increasing-customer-satisfaction#_ftnref2