DFMA CHALLENGES AND SUCCESS AT BELL HELICOPTER

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Abstract

In 2008, Bell Helicopter brought in the BDI Design for Manufacture and Assembly (DFMA) software tool to help provide cost visibility to our design engineers, beginning with a series of 3- day workshops at our two design centers in Fort Worth, Texas, and Mirabel, Quebec. While initial feedback from all attendees and their management was positive, there was reluctance to embrace the tool for use as a standard procedure. Reasons for this included software issues, such as the libraries not conforming to Bell operations and processes, as well as reluctance in committing additional time and budget for a new process. This paper discusses some of these challenges and successes achieved using DFMA.

Bell Helicopter

An industry leader with unmatched name recognition, Bell was the first to obtain certification for a commercial helicopter. Over its rich history, Bell has delivered more than 35,000 aircraft to our customers around the world.

With forward thinking in advanced concepts, Bell Helicopter invented tiltrotor aircraft. These unique aircraft lift like a helicopter, then fly like an airplane with twice the speed, three times the payload, and five times the range of traditional helicopters. Aerospace and aircraft will never be the same.

Headquartered in Fort Worth, Texas, Bell Helicopter has additional plants in Amarillo, Texas and Mirabel, Canada. We maintain key logistics supply and service centers in Europe, Canada, and Singapore, as well as in the United States. As the world's premier provider of vertical lift aircraft, Bell Helicopter continues to provide every customer with products, service, and support second to none.

Introduction

Design for manufacture and assembly is hardly a new concept. In fact, the basic principles of DFMA like reducing part count and fasteners are, in the words of a former Bell Helicopter CEO "nothing new, just common sense." Bell's newest aircraft, the 429, is a quantum leap forward in the use of design for manufacture and assembly principles compared with our previous aircraft. This was done through the use of Design for Six Sigma tools such as lean design.

Fig. 1. One Piece Side Body

Some of the notable design features employing these principles include a one-piece sidebody and a two-piece tailboom. The one-piece composite sidebody (Fig. 1) covers each side of the aircraft, and encompasses the openings for all of the doors. Previous generation aircraft have literally thousands of sheet metal panels, stiffeners, and fasteners, which make up the outer surface of the airframe.

The two-piece tailboom is a monocoque design, which does not require a longeron (longitudinal stringers), and replaces traditional aluminum designs consisting of multiple longerons, skins, frames and fasteners.

The 429 uses a metallic backbone/skeleton to carry the primary loads of the aircraft. The skeleton is clad with lightweight modular composite cowlings, panels, and other structures. This design approach produced a 20% overall weight reduction and a 40% shorter cycle time than our previous generation helicopter.

However, many of our cost reduction efforts still focus only on part cost. There was little visibility of assembly cost in the design world at Bell Helicopter. After some time benchmarking the DFMA type tools available, Bell felt the BDI platform showed the most potential for helping us take a deeper dive into our assembly costs.

Bringing DFMA Onboard

Beginning in 2008, Bell conducted five separate 3-day DFMA workshops over the course of three months (four in Fort Worth, one in Mirabel) in order to evaluate the potential of the software. Each workshop was made up of cross functional groups including design, manufacturing, procurement, and cost analysis. Combined results for all of the assemblies studied during the workshops showed impressive potential (Table 1).

Table 1. Summary of Workshop Results.

Assemblies Studied	Avg. Part Count Reduction	Avg. Assembly Time Reduction	Avg. Cost Improvement
29	49%	53%	31%

Despite all the positive feedback from the workshops, the negatives had to be addressed first. The two primary roadblocks identified during the workshops were

- Operation libraries lacking Bell standard times.
- Time and budget for a new process.

A third negative impression was that these "classroom" exercises couldn't be real savings because they did not go through a complete weight and stress analysis during the workshop.

Operations Library

Library updates seemed straight forward—gather the data and populate the software. However, two challenges arose with this effort. First, many of our subassemblies, and the related assembly processes, have been outsourced over the years to allow Bell to focus on our core manufacturing technologies. One example of this is basic sheet metal assembly. Once this process was outsourced, our Industrial Engineering (IE) department no longer maintained or tracked standards for those operations.

The second challenge had to do with how we tracked assembly operation times. The DFMA libraries allowed for capturing each simple operation step, but on the shop floor, we didn't worry about the small individual steps. The assembly times were often rolled up to the top assembly level instead of being tracked for each detail operation. This required help from the IE department to provide data that was useful for adding to the DFMA library.

Once the standard times were obtained, we loaded the DFMA libraries and created custom operations for Bell processes. This was the result of feedback from our designers, who wanted the software to be more intuitive for them to use. By calling out a Bell Process Specification (BPS), all the associated operations would be captured. This minimized the risk of omitting operation times and allowed the designers to pre-populate a DFMA analysis prior to getting together with the entire team. One example shown below (Fig. 2) is for adhesive bonding. If BPS 4403 is to be used, the DFMA library operation captures the required steps including area, surface preparation, adhesive type, and cure process.

New Process Acceptance, Step I

The new process roadblock was cleared in two ways. First, the obvious value of DFMA principles (separate from the software tool) led to incorporating them into our New Product and Service Introduction (NP&SI) process. See Fig. 3. NP&SI is a gated process developed and formalized by our Six Sigma group, which provides clear steps to our design development process. The primary benefit is to keep our customer's need aligned with the business case throughout the process.

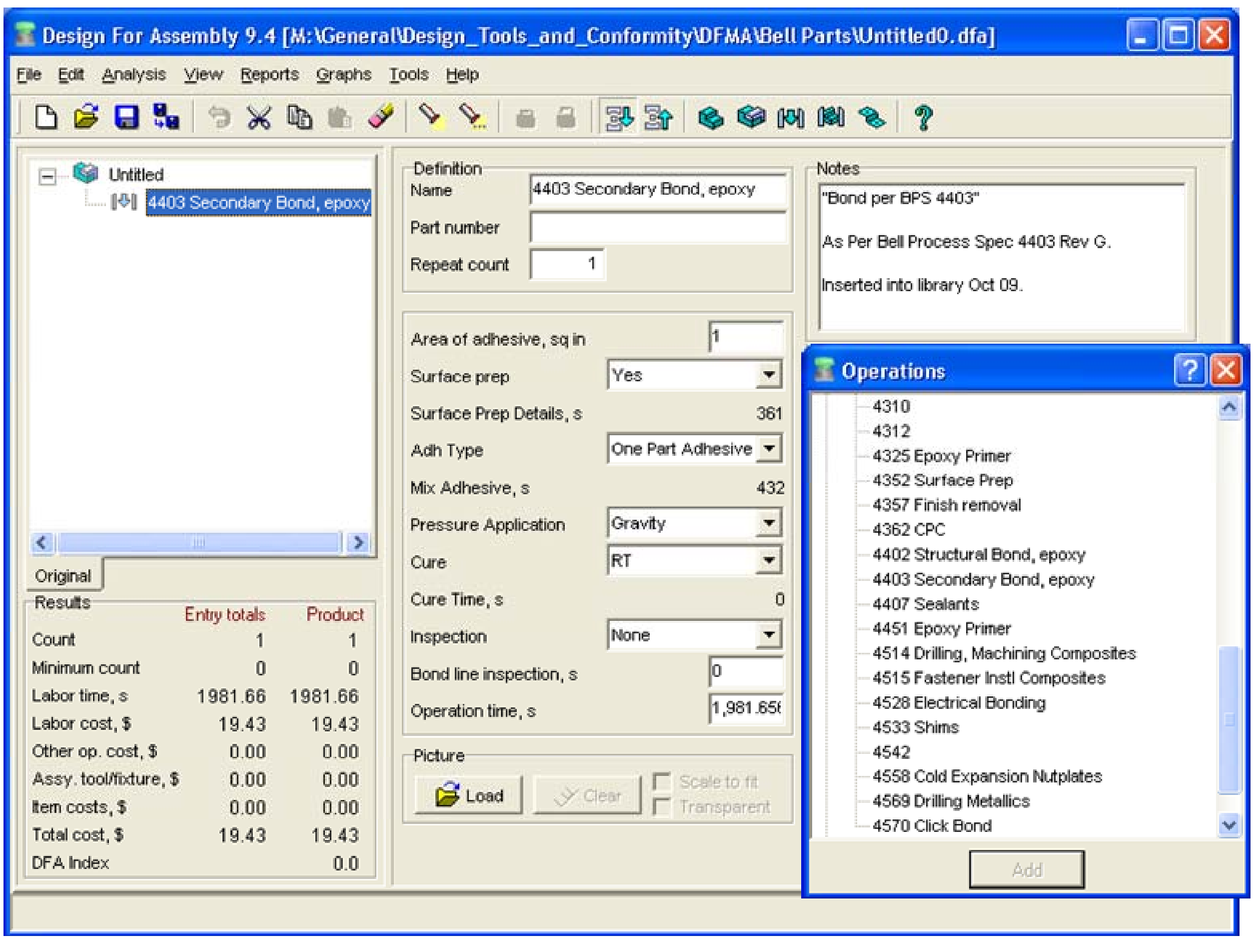

Fig. 2. Custom DFMA Operations Library
(Cost values shown are a generic example and do not represent any actual Bell part.)

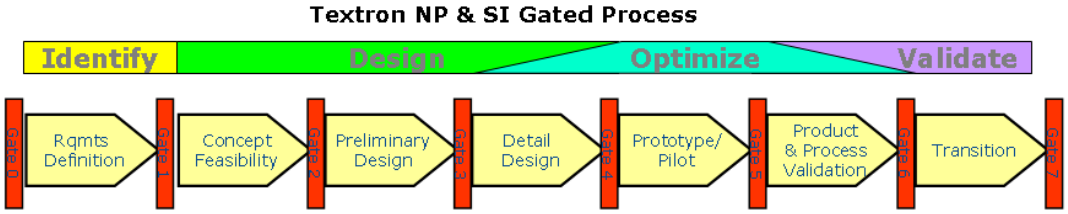

Fig. 3. NP&SI Process.

The NP&SI process requires all defined elements to be addressed at each gate review. The specific elements for each step are spelled out in the supporting documentation. Design for manufacture and assembly assessments are required within Concept Feasibility, Pre-Design, and Detail Design. This ensures that the principles are applied early in the design phase before it is too late to incorporate a meaningful change.

In the Concept phase, the design is still at a high level so there is no practical use for DFMA software at this point. However, by requiring a DFMA assessment based on the defined principles, we make sure the team is driving toward the best approach. At this phase, we are primarily looking at only DFA issues.

At the start of Preliminary Design, there are still no detail parts defined, so the DFMA software application is still limited. There are some early trade studies taking place and this is where the software begins to make an impact. Again, since no detail part configurations exist, the primary focus is still DFA. By the end of this phase, the DFMA assessment requires that a candidate assembly list be formalized, which will require analysis with the DFMA software during the Detail Design phase.

The Detail Design phase is where the actual assemblies and details are defined. This is where full application of the DFMA tool can take place. However, by enforcing the application of the DFMA principles in the two earlier phases, we anticipate only minor changes to the preliminary design at this point.

New Process Acceptance, Step II

The second way we achieved acceptance was by approval to use DFMA on a new development project just starting. This provided an ideal environment to implement the tool, since the most impact can be made on a "clean sheet" design. We planned to use this pilot opportunity to also track the cost and time required to use DFMA early in the design phase. This effort kicked off well, and many of the people assigned to the project had attended one of the original DFMA workshops. We also provided DFMA principles training for other team members to get everyone calibrated.

Challenges to Overcome

DFMA implementation at Bell, like any new process, has also faced a few challenges. The first came in the form of competing priorities. Bell is embarking on an aggressive Business Systems Modernization initiative, which is our top priority right now.

The second major challenge to affect the implementation was the fate of our DFMA pilot project. While management had enthusiastically accepted DFMA to be utilized on one of our new development projects, the project itself was cancelled before detail design work began.

Pockets of Success

Despite the setbacks, DFMA is still finding areas to help our designers be successful. The most widespread success has come not from utilization of the software tool, but by education and application of the DFMA principles learned during our initial 3-day workshops, and subsequent Bell-led training sessions. While these principles seem like “nothing new, just common sense,” when combined with a real Bell example part analyzed with the DFMA software tool, the real impact of DFMA is better appreciated. In every design review involving people who have received DFMA training, part count reduction, fastener minimization, and ease of assembly are always at the top of the discussion. We have even seen this behavior become contagious, as fellow team members pick up on the principles of DFMA.

Case Study No. 1

One example of mixed success is a small assembly analyzed during one of our initial DFMA workshops. This is the sheet metal electrical box in the nose of our new 429 helicopter. This assembly consists of a few sheet metal parts riveted together to form the box. See Fig. 4. Baseline analysis using the DFMA software matched the actual cost Bell was paying to procure this assembly. Two potential redesigns were evaluated, which showed promise for substantial part count and cost reduction, as seen in Table 2.

Table 2. Electrical Box DFMA Savings.

	Baseline	Redesign #1	Redesign #2
Design Change		Integrated attach angles	Single piece folded (origami)
Detail parts	4	2	1
Rivets	40	24	8
Assembly Time (minutes)	51	32	6
Total Cost (baseline =100%)	100%	66%	28%

This example provides a clear and simple example of how DFMA can affect our designs. One area of design resistance often comes from combining small simple parts into fewer but more complex parts. The fear is that the complex parts will drive the cost up and mitigate any assembly cost savings. The DFMA tool provides an easy way to quickly assess this on the fly. In the case above, the four initial sheet metal parts are relatively cheap and simple. Redesign No.1 incorporated the two attach angles into the cover.

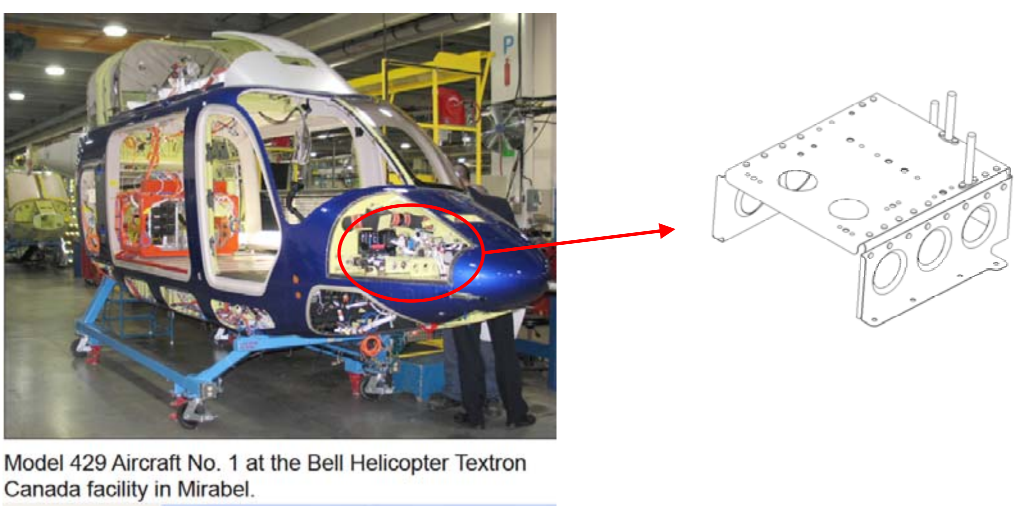

Fig. 4. 429 Electrical Box.

While the cost of the cover did increase from a $30 part to a $40 part with the addition of two bends, the new design eliminated the two $20 angles, for an overall drop in total part cost, before even considering labor savings.

Unfortunately, this example also shows one of the constraints we deal with at Bell. The actual cost savings, while large in percentage savings, was small in dollar savings (<$300). The cost of changing an assembly on an existing aircraft involves many layers of documents beyond the blue print (next higher assembly print, maintenance documents, etc.). Thus, the savings seen on this assembly do not meet the threshold required to implement. However, this also points out the value of using DFMA from the start so we don't end up with "simple" designs such as this.

Case Study No. 2

Another example, which shows more promise than the first example, involves the 429 cabin floor assembly (Fig. 5). The safety features of the 429 include energy-attenuating seats. As such, the floor must be structurally sufficient to support the design loads during a hard landing or crash. The floor assembly consists of structural beams to support the loads, floor panels, and seat tracks to secure the seat. One of the design challenges, which adds assembly difficulty, is the location of fuel cells (gas tanks) beneath the floor. This is a typical location for many helicopters, but requires any fasteners in the floor to be sealed after installation to prevent fuel vapors from entering the cabin.

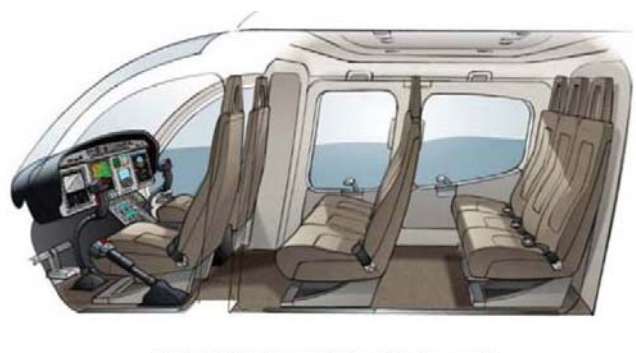

Fig. 5. Current 429 Cabin Floor Layout.

A proposed design concept improves the way seats and floor panels are installed, which eliminates many of the sealed fasteners responsible for significant assembly time. The challenge we had was to accurately quantify the potential labor savings associated with the proposed design. Bell's labor tracking system captures assembly times for the main structure, but does not capture each small detailed step. The DFMA software allowed us to quantify the assembly time savings for each operation and identify the labor savings potential. See Table 3.

Table 3. Floor Assembly Savings

	Qty
Part count reduction	8
Fastener count reduction	1000+
Assembly Time Savings	46 hours

A time study conducted to confirm these results was within 2% of the DFMA estimate.

The primary area of improvement came from the elimination of multiple rows of nut plates used for installation. Each nut plate required three holes to be drilled, and two rivets to secure the nut plate to the structure. Each rivet used also had to be sealed with adhesive due to its location above the fuel cells.

First Pass Yield

DFMA is also finding value in our efforts to improve first pass yields for new designs. Although quality and yield are not direct measures of the software tool, the principles of part count and fastener reduction have a direct impact on first pass yield. This can be seen in Table 4, illustrating defects per million opportunity (DPMO) for a given sigma level of a process.

Table 4. First Pass Yield Prediction.

	Sigma Level Impact on First Pass Yield					
# of Parts/Steps in Assembly (Defect Opportunities)	±1σ	±2σ	±3σ	±4σ	±5σ	±6σ
1	31.00%	69.20%	93.32%	99.38%	99.98%	99.9997%
2	9.61%	47.89%	87.09%	98.76%	99.95%	99.999%
4	0.92%	22.93%	75.84%	97.54%	99.91%	99.999%
8	---	5.26%	57.52%	95.14%	99.82%	99.997%
15	---	0.40%	35.45%	91.08%	99.66%	99.99%
25	---	0.01%	17.76%	85.58%	99.43%	99.99%
35	---	---	8.89%	80.41%	99.20%	99.99%
50	---	---	3.15%	73.24%	98.86%	99.98%
70	---	---	0.79%	64.66%	98.40%	99.98%
100	---	---	0.10%	53.64%	97.73%	99.97%
150	---	---	---	39.28%	96.61%	99.95%
200	---	---	---	28.77%	95.50%	99.93%
250	---	---	---	21.07%	94.41%	99.92%
300	---	---	---	15.43%	93.33%	99.90%

Using a 4-sigma process, shown in Fig. 6 as an example, the effect of reducing part count and operations can be clearly seen. If each step in the process has a 4-sigma quality level (99.38% success rate), then an assembly requiring 150 operations would have a first pass yield of only 40%. If the design is improved by reducing part count, fasteners, and other operations, the quality level will improve as well. If the assembly is redesigned to require only 70 operations, the first pass yield will improve to 65% in addition to the part cost and labor savings.

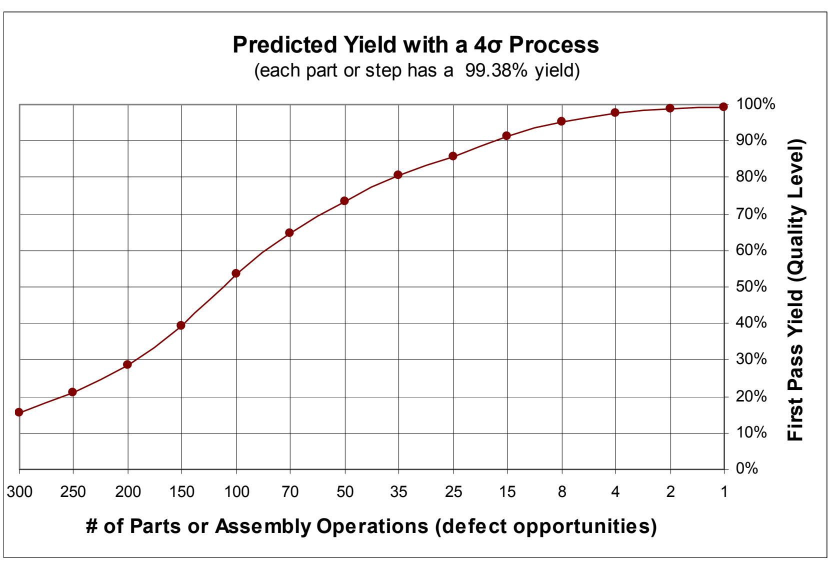

Fig. 6. First Pass Yield Curve.

Conclusion

Despite the limited application of the DFMA software tool at Bell, it has provided many benefits. The primary benefit has been through educating our design teams with DFMA principles, which are applied early in the concept phase of a new design. While these principles are "nothing new, just common sense" in many ways, the DFMA tool allows these principles to be quantified so the actual impact in dollars is clearly seen. Redesign of small assemblies already in production will likely not meet the cost savings threshold required to be implemented. Therefore, we will look to apply the DFMA tool on more substantial redesign projects as they arise in addition to the next new development program.

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