ROI for FEA in Composite Aircraft Part Repair

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How much is it worth to introduce a new repair process that improves profitability while reducing risk?

Background

Aircraft on the ground are expensive. Debt service alone on a commercial airliner costs up $100k per day. Lost passenger revenue at $500/seat can cost as much as $500k per day. Lost freight revenue can exceed $250k per day. A single airplane in the hangar for a single day can cost almost $1 MM. Accelerating turnaround of maintenance, repair, and overhaul, returning airplanes to service faster, is a powerful means of improving profitability and relieving pressure on your bottom line.

That's not rocket science. But determining the best inventory of replacement parts for overhaul comes a lot closer to rocket science. New and replacement composite aircraft parts are expensive. A new radome can cost hundreds of thousands of dollars. Articulated aerodynamic control surfaces (slats, flaps, spoilers, ailerons, movable tail surfaces) are nearly as expensive. And other static parts that are frequently damaged (such as leading edges and access doors) can also set you back some. A single duck can ruin your whole day if it happens to try to fly through your radome. And let's not even talk about geese!

You could stock your MRO facility with all possible replacement parts for all your aircraft types, and make sure that you supplement your stock with sufficient lead time to support your MRO facility's scheduled and unscheduled service requirements. This is a wonderfully robust and fabulously expensive strategy. If there were no competitors, it might even be practical. But in a competitive environment the high cost of inventory militates the leanest possible spares strategy.

Another possible strategy is to repair the damaged composite aircraft parts whenever possible. This dramatically reduces the cost of inventory. But it puts return to service at risk, because any difficulties repairing the part(s) that delay flyout incur costs of about $1MM per day. Unfortunately, because of their very nature, difficulties abound in composite aircraft part repair that make costs hard to rationalize.

Composite repairs inevitably introduce distortions into the part that is being repaired. These distortions will impact their fit and performance. Doors might no longer fit. Ailerons might no longer align properly with their mounts. Flat panels might be unacceptably warped. Radomes will have different electromagnetic characteristics and may need recalibration. Workmanship issues exist in any repair, but these effects are not workmanship issues. They are intrinsic to the nature of the composite part and its repair characteristics. Consequently, even the best mechanics can't always be confident about the results of their composite aircraft part repair.

But, if you could do better, if you could remove the schedule risk, if you were assured of the time and expense to repair a composite aircraft part, you might be able to rationalize the best mix of new and repaired parts in your spares inventory. This can save impressive amounts of money by avoiding the cost of buying excess spares, and assuring that airplanes are returned to service as quickly as possible. But if you are less than confident about your ability to satisfactorily repair the parts, then you will be unable to develop a supportable mix of new and repaired aircraft parts that adequately supports your known and projected repair requirements.

The Role of Finite Element Analysis (FEA)

Predicting the deformations intrinsic to composite aircraft part repairs is a powerful application of finite element analysis. Patran and MSC Nastran provide a comprehensive set of tools for modeling and analyzing self-induced part distortions caused by composite aircraft repair processes. An example is shown below. This example is a representative wing leading edge, not a part from an actual airplane, but contains many features of such a part.

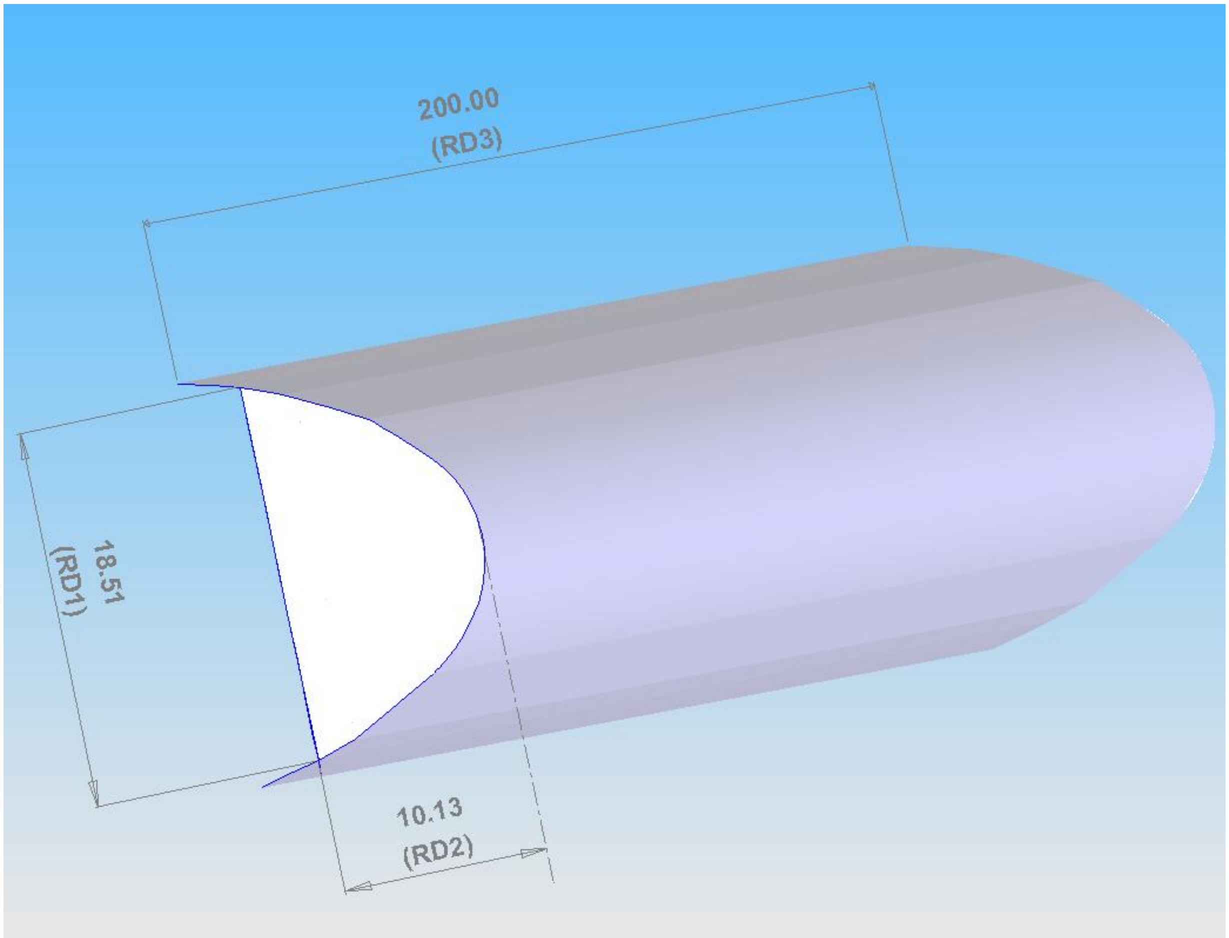

Figure 1 - Dimensions are inches. This example uses 7 plies of composite prepreg.

When an airplane lands after an unfortunate bird has had a disagreement about the right of way, the leading edge may well be damaged. If the damage is visible, it will be repaired right away. It may, and often does, happen that the damage is only detected when the aircraft undergoes scheduled maintenance. What is the role of finite element analysis in that situation?

First, finite element analysis usually has no role in composite aircraft part repair because it takes too long, and analyst access from the hangar floor is practically nonexistent. One of the unfortunate aspects of typical finite element analysis is that it often takes weeks or months to model a single part, collect needed engineering data, complete a satisfactory finite element analysis, and validate the analysis results. With a million dollars per day at risk, this is unacceptable. And because there are usually no routine communications between mechanics and finite element analysts, they don't even speak the same language.

Putting those issues aside for the moment, there are other impediments to use of finite element analysis in composite aircraft part repair. For example, analysis proving that damage has occurred has no value. You already know the part is damaged. More important, analysis can tell you how the composite part will deform when it is repaired. This is useful information. This result can help you determine if a repair is feasible, or if you need to purchase a replacement part. But knowledge of the composite part deformation alone is insufficient. It would be much better if the analysis showed what would be required to repair the part in such a way that unacceptable deformations were eliminated. With that information, the mechanics could project the time to make a repair and return the part to service on the same airplane, or repair the part and place it in inventory for the next airplane. Knowing the time it takes to repair a part that supplements the spare parts inventory allows management to determine the number of, and minimum lead time for supplemental spares, reducing the number of purchased parts while assuring sufficient stock to return airplanes to service as quickly as possible.

Let's look at what does work.

First, assume that the leading edge described above (Figure 1) was damaged, and the mechanic determines that a section of the leading edge skin about 6 in. x 6 in. in planform needs to be replaced. The replacement material will be the same composite prepreg, made in the same shape, and cured at the specified temperature and pressure. The part deformation will depend on the patch location. For this example, I've assumed that the patch covers an area symmetric about the leading edge located about a foot from one end of the part. The deformations are shown in the figure below: FEA can certainly predict the deformations induced by this composite aircraft repair. That works.

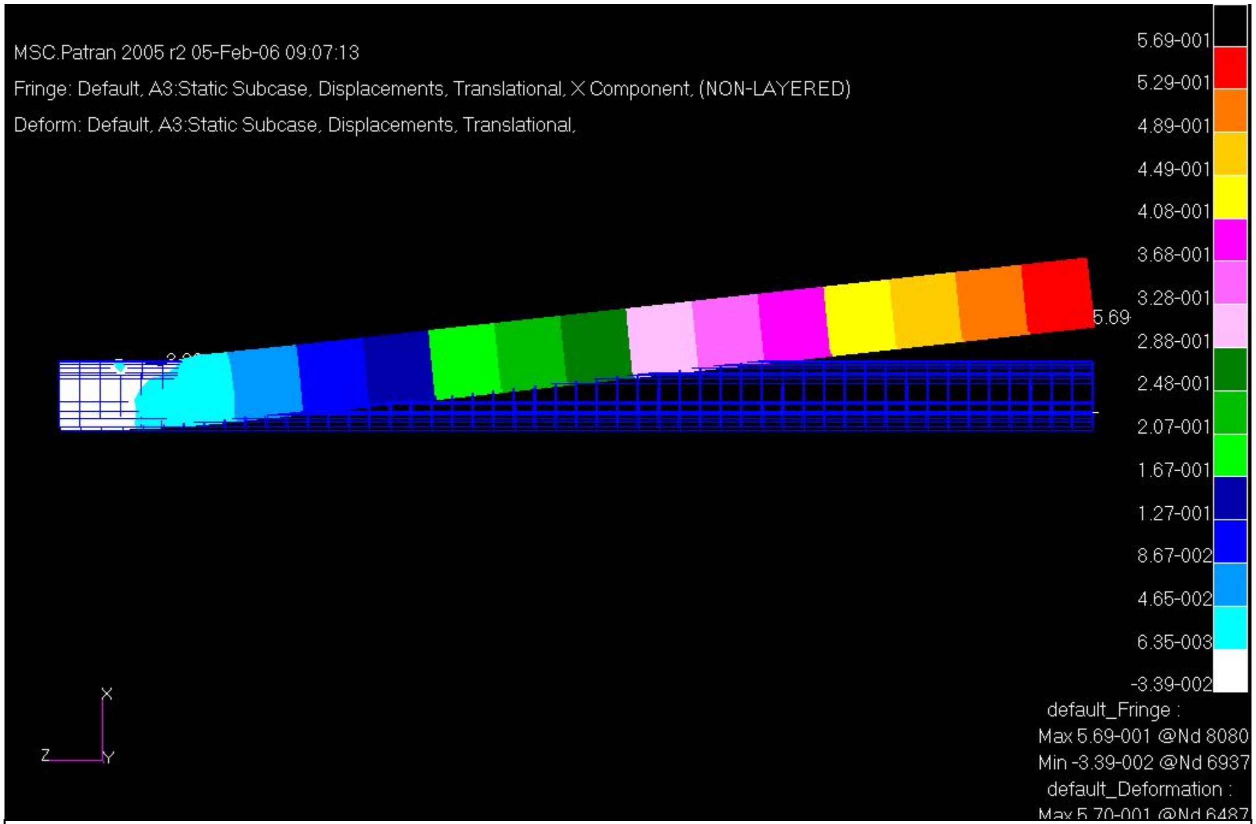

Figure 2 – Composite aircraft part repair induces > 0.5 inch warping over part length

Unfortunately, remating this repaired part to the wing from which it was removed will as a minimum require a significant amount of force, inducing residual stresses and chordwise bending in both leading edge and wing. (Rarely will you find an approved procedure for remounting aircraft parts that involves a come-along, but these are sometimes used as persuaders in real-world maintenance situations involving such repairs.)

A better approach is to use the intrinsic composite repair characteristics to your advantage, making the repaired part self-compensating and eliminating or minimizing residual deformations. Of course, you might say that's an obvious conclusion. In practice, it's not so obvious. The reason it's not obvious is that the repair location is apparent from the cracks and scattered feathers, but the best location of the compensating part modification requires sophisticated analysis. If finite element analysis is not (as is typical) a part of the repair process, then there is no means of determining where the compensating modifications need to be made. Given use of finite element analysis, the process is straightforward. Figure 3 shows both the initial repair and the structural modifications necessary to null the part's deformation along its entire length.

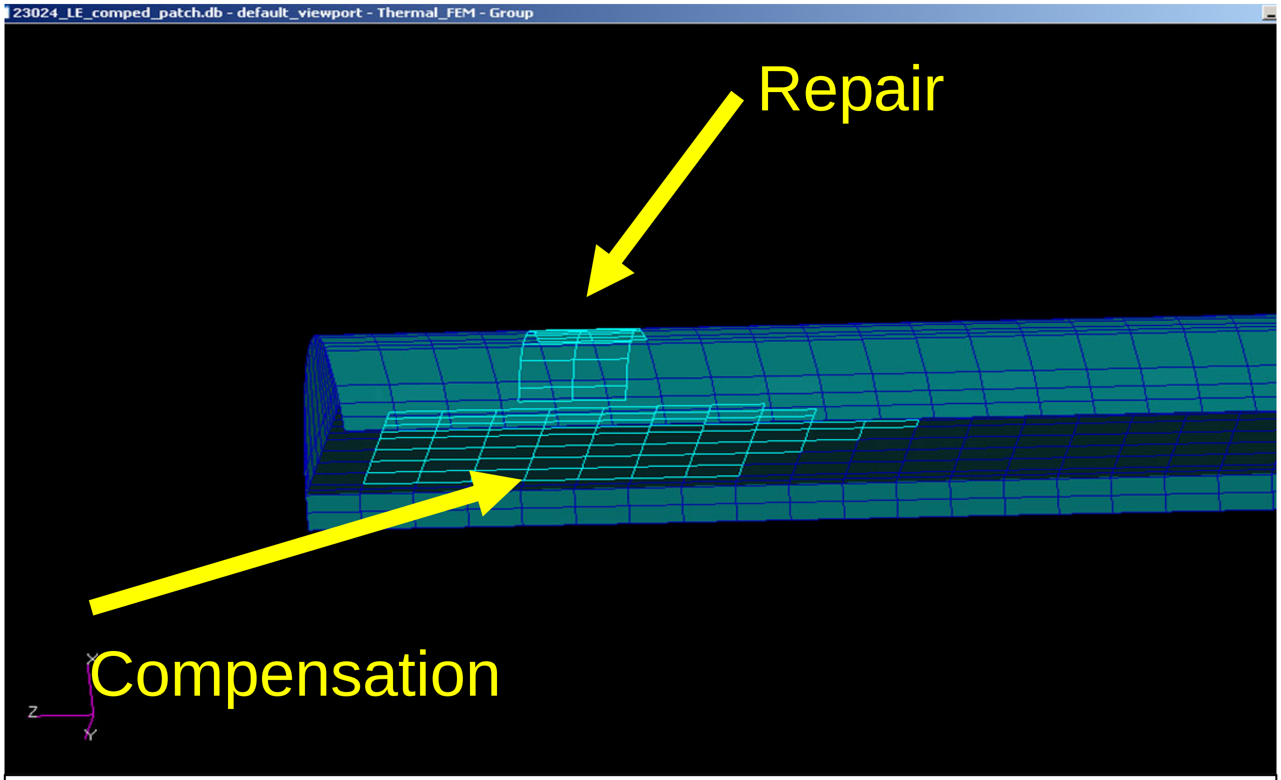

Figure 3 – Modifications to the part backplane eliminate repair-induced composite part warping

Like the leading edge repair, the compensation uses approved materials and processes, and provides strength equivalent to the new part. Fundamentally, it trades the typically minimal cost of a small amount of material and a minor addition to the labor to repair the part with the considerable cost of purchasing a replacement part. With typical parts running in the hundreds of thousands of dollars, and typical repairs running in the tens of thousands of dollars, it is an easy trade to make, if and only if it does not delay aircraft return to service.

With these modest changes to the repair process, the deformations at the mating flange are reduced to negligible amounts along the entire length of the part, as shown in Figure 4 below. That works even better.

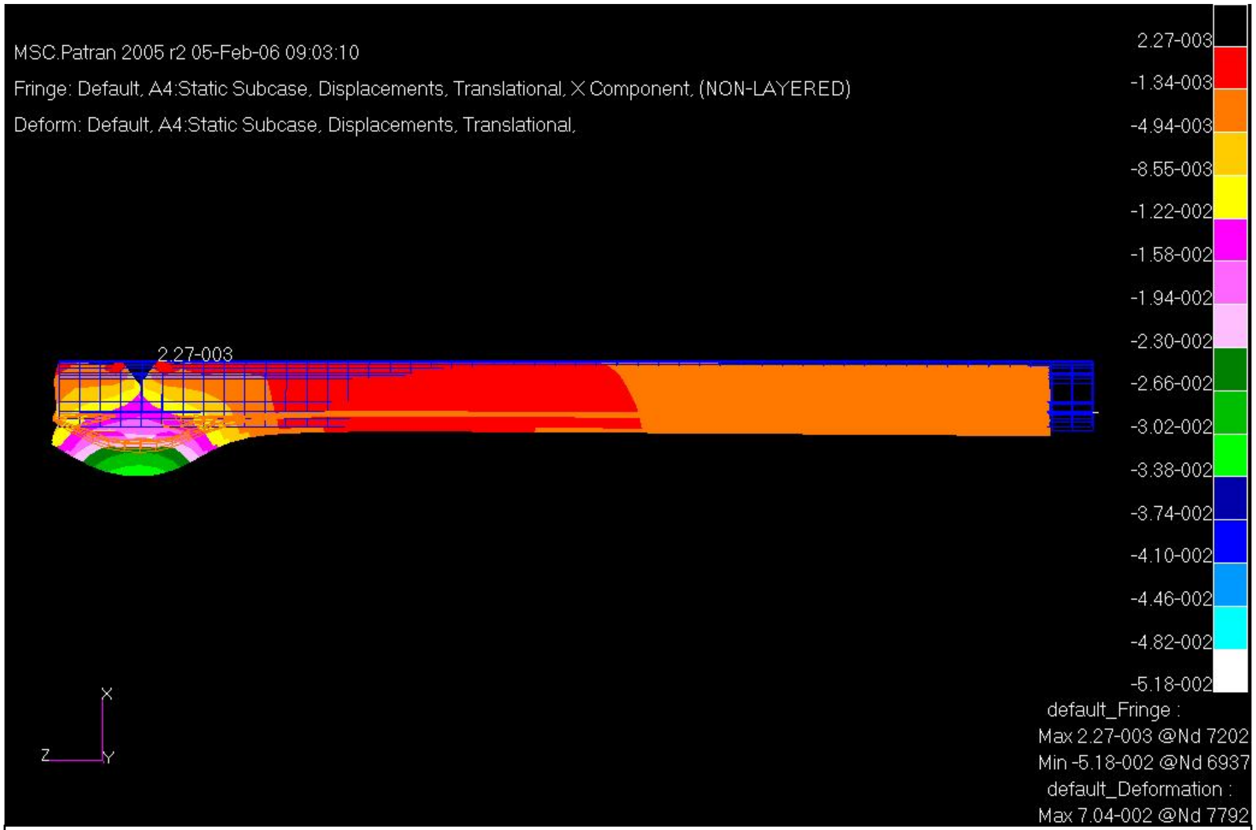

Figure 4 – Compensating modifications eliminate composite part warping

Repairs are typically much less expensive than new parts. It's good to know that the part can be repaired and returned to service, since reuse of the part will save money. Even more important than the extent of the compensating modifications is the knowledge of its extent. Armed with this information, the aircraft repair crew can make reliable estimates of the time to repair the part and return the aircraft to service, or estimate the time and resources required to return it to the spares inventory in anticipation of the next aircraft overhaul. In either case, the finite element analysis provides management the information needed to rationalize spares inventory management, assuring an adequate supply of needed parts from inventory at minimum cost.

A New Approach to Finite Element Analysis

Finite element analysis has obvious value for composite aircraft part repair, if it provides timely results, and if those results provide the data needed by repair crews and management to improve repair processes and spares inventory management. Traditional finite element analysis does not provide those essential capabilities. Federal Engineering Associates has developed a new approach that responds to the real-world needs of the aircraft repair community.

The new approach includes a finite element model of the part that can be readily modified to reflect the location of damage repair, and scripts that then calculate the part warping induced by the repair. As shown above, the software then automatically calculates the location and extent of the smallest compensating modifications that null the part warping given the limitations on where those compensating modifications are permissible. For a typical part, permissible areas are accessible and do not require any special treatment. A graphical user interface designed for use by mechanics is being developed. The whole system will be hosted on a server accessible to both analysts and mechanics, so the mechanics have the rapid response they need and the analysts can audit the analysis results, assuring safety and accuracy. This automated system provides a common language and format for communications between mechanics and analysts, tying these two important parts of the organization together for their mutual benefit.

Once an inventory of pre-defined models is developed, then the mechanics will be able to receive finite element analysis results in minutes that can guide their work, results that would previously have taken weeks or months and were, therefore, never sought or used. At that same time, it provides management and analyst insight into the MRO world that they have never before had, enabling improved control of spares inventory, work flow, quality and safety, all with quicker aircraft return to revenue generation.

That works best of all.

Return on Investment

If it works great, how much does it cost, and what is it worth?

This advanced finite element analysis system has not yet been deployed, so all of the costs presented below are notional. Nevertheless, it is clear that the potential of this system to improve aircraft operation profitability is easily justifiable.

Assumptions underlying the analysis are:

Item	**Required Investment**
Software and training	$250,000
Cost per model development	$25-50,000
Models per airplane	6-10
Total investment	$500,000 - $1,000,000

Since the upper limit on required investment is about $1MM, and knowing that such programs often expand, we will assume required investment of $2MM in the following ROI calculations.

Lets further assume:

- 12 airplanes per year overhauled
- 1 day per airplane overhaul reduction attributable to the FEA
- 30 critical spare parts per airplane kept in inventory with an average cost of $100,000 each, with a turnover of one complete set per year
- 25% reduction in spares inventory due to improved use of advanced FEA
- Revenue recovered = $750,000 per airplane-day
- Contribution margin[1] = 20%

Given these assumptions, the 5 year return on investment is:

ROI = 5 * (recovered revenue * contribution margin + annual inventory savings) / investment
= 5*($1,800,000 +$750,000) / $2,000,000 = 638%

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[1] It isn't entirely clear that contribution margin is the most proper parameter. It is clear that credit for all of the revenue is not correct, and equally clear that profit is not correct either, particularly in an airline that is currently losing money. In any case, it should be clear how this parameter is applied and the reader can substitute any other parameter that makes more sense to them. Contribution margin works for me.

Annualized ROI = 145%

Remembering that generous assumptions were made about the required investment, and rather stingy assumptions were made about the return to service acceleration, the suggested approach to introducing advanced finite element analysis into composite aircraft repair processes seems to be easily justified, even without taking credit for the enhanced quality, reduced liability, and more efficient MRO operation that it brings at no additional cost.