In Aviation Engineering, If You Don't Build It Right, You Need to Fix It Right

GLENN ARMELLINO MS, PE

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Experience and smart engineering will lead to the solution

As a structural engineer and subject matter expert, my clients look to me for a precise understanding and a comprehensive technical explanation of what went wrong in the case of an aviation disaster. It's important to accurately interpret the data and be able to explain the facts in a way that is relevant and makes sense to a judge or a jury. The aviation engineering field requires so much hands-on training and experience, and those who have this complete skill set are often difficult to find.

My 30+ years of experience in the aviation industry has taught me many things, and I've been lucky to have worked for some of the greatest aircraft manufacturing companies in the world. And while every position I've had has contributed to my skillset, the time I spent in the Stress Groups at Gulfstream Aerospace Corporation (GAC) in Savannah, GA was some of the best experience I've ever had, largely because of the company mindset.

The Gulfstream G650 business jet

When at Gulfstream, you either:

A. Get it right the first time, or
B. Fix it right if you don't

Our industry is complex, and mistakes are made. My first contract was with Systems Stress on the incredible G650 business jet. I arrived shortly after the official program launch, and it was my first 'drawingless' aircraft, and Gulfstreams first as well. The thought was that so-called 'model-based definition' using Catia v5 worked for Boeing on the 787 and should work for us, and it certainly did. Catia has endless capability, one of which is the ability to animate actuators functioning, linkages moving and control surfaces (in this example, main landing gear doors) opening and closing. But it is so 'beautiful' that it can give a false sense of security.

First flight of the G650 on November 25, 2009 resulted in a problem with its landing gear doors. This was by no means a life-threatening, in-flight aviation problem, but it was one that required serious attention, nonetheless. When the landing gear is retracted, two doors close and fit tightly to the underside of the fuselage, creating a smooth profile through the airstream. During takeoff and landing, the gear is extended and these doors are open, of course, and the aircraft must fly for a relatively short time in this 'aerodynamically undesirable' state, otherwise known as 'flying dirty'.

The certification of an aircraft involves an extensive FAA approved flight test plan which restricts altitude, speed, range etc. until a full Type Certificate is granted. One of these restrictions is to not retract the landing gear on the first flight for safety. The G650 landing gear doors didn't like this, and the test pilots reported a 'shuttering' sound forcing the aircraft to land prematurely during a highly publicized first flight.

This of course led to wild speculation and rumor, creating two areas of concern. One was the negative exposure, and the other was the engineering. Gulfstream handled the publicity so adeptly that the 'problem' was reduced to an 'incident' followed by an 'occurrence' leading to an 'anomaly' and ending with a distant memory. Now for the engineering. This was also so efficiently handled that the distant memory remains exactly that.

Getting real

How did Gulfstream do that? How did they minimize what could have been a PR nightmare and a potential delay in the certification process? The answer is by getting real. Unfortunately there are companies that have a culture of finger pointing and a philosophy of covering your ass that serious engineering problems are never truly solved, but instead are continually patched over. Not Gulfstream. Definitely not Gulfstream.

Two parallel efforts were immediately put in place, one that did involve retrofitting the one and only G650 main landing gear (MLG) door and fairing in existence, and the other that entailed a complete redesign for future aircraft. As far as I know, there have been no ongoing G650 MLG door and fairing problems to date. The point is that it was fixed right the first time, by getting real.

The Gulfstream G500 and G600

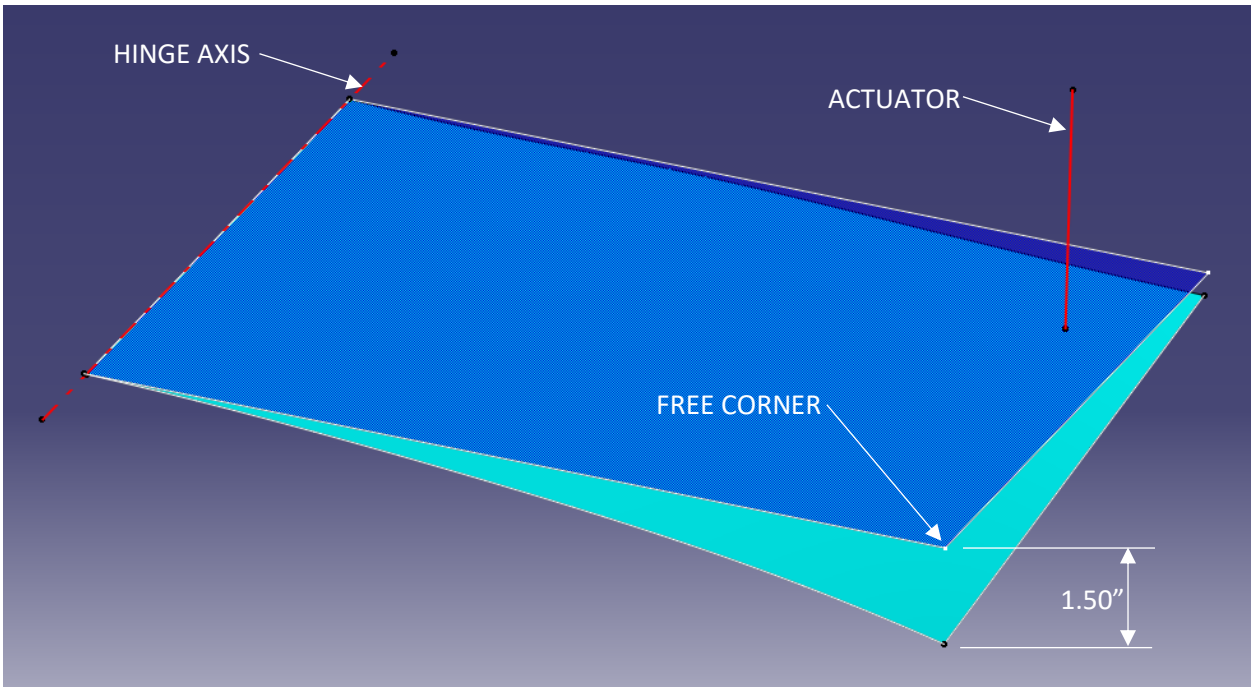
I returned to Gulfstream in March of 2011, again in the Systems Stress Group, on the then classified P42 program, which ultimately evolved into the G500 and G600 business jets. And even though my door and fairing experience was a bit limited, I was immediately tasked with analyzing the P42 main landing gear door and fairing.

The preliminary design I was presented with was similar to the G650, but anything reminiscent of the G650 first flight 'memories' could not be risked. I recall being somewhat surprised when granted a clean slate and allowed to experiment with virtually any design from the initially proposed G650-like composite co-cure to a G450-like sheet metal buildup.

The G650 doors experienced high buffeting when open, making stiffness-to-weight driven modal frequencies a design driver. Static and fatigue strength, parts count, system weight, reliability and maintainability and on it goes were all performance indicators, with cost being dead last on the list. Making it safe and getting it right the first time was the priority, and this task had some profile.

I was fortunate to work with and for some very skilled designers and managers, and after maybe three major design choices we agreed that a honeycomb co-cure was the way to go. The complexity of these doors is quite significant, including a contoured outer and inner skin, machined core, heavily loaded actuator link and hinge attachment points, and the tendency of the door to pull away from the fuselage at high speed when closed due to aerodynamic suction forces.

Now how do you prevent that problem? How do you make the door stiff enough to stay closed when it is closed without adding weight, altering natural frequencies and going right back to buffeting when it is open? The answer lies in a pre-warp analysis, consistent with the industry-advanced engineering that Gulfstream delivers.



What is a pre-warp design and analysis? My simple schematic shows the door hinged along one edge with an actuator linkage member in one corner of the door. There is a large recess in the door to accommodate the tire when the door is closed, and this leaves the corner opposite the actuator linkage to be relatively free, so the door is really constrained in only three out of the four corners. The entire door sees an aerodynamic suction at high speed, and the free corner could deflect a lot, perhaps 1.50 inches from the fuselage which is obviously unacceptable. Just making the door stiffer is not a realistic solution because the amount of weight that must be added presents a huge penalty, not only in gross aircraft weight but also its impact on natural frequencies of vibration. A pre-warp design is an innovative solution but can only be executed with some very advanced CAD/CAM/CAE software. Catia and Femap can handle this, provided the engineer knows what he’s doing.

So how does it work? A finite element model of the door is created in Femap, in the neutral position and the suction load is applied. The door deflects under load and the displacements are then inverted, meaning the 1.50 inch outward deflection of the free corner is multiplied by -1, creating a 1.50 inch inward deflection. All nodes in the finite element model representing the door are multiplied by -1, and the new shape is captured. This deflected door shape is then exported from Femap into Catia, and the door is resurfaced. The deflected door shape, or pre-warped shape is what is manufactured and installed on the aircraft. Now, under load the free corner will not deflect 1.50 inches away from the fuselage – it won’t deflect at all because the furthest it can go is back to the initial, neutral position. This design adds no weight at all, and often presents a weight savings and is absolutely elegant. But picture the complexity of this shape and the analysis, initially beautiful, free-formed surfaces conforming to the shape of the fuselage, then displaced and inverted. This can only be handled by expensive, sophisticated software and a very skilled engineer, and this is not an issue for Gulfstream.

A commitment to product and public safety

The takeaway here is that a well-managed engineering company like Gulfstream almost always gets it right the first time, and in the rare instance when they don't, they always fix it right the first time. This is more than just a company that strives for excellence, it's a foundational value that they instill in their employees and suppliers.

It's an ethos that can only be successful with a commitment to product and public safety, backed up with state-of-the-art aviation engineering executed in an atmosphere based on honesty and integrity. In an industry where lives are at risk, few companies have a greater obligation to people's well-being. But what's truly special is that companies who embrace these types of core values also impart them into their people for the rest of their lives.
I consider myself lucky enough to be one of them. Imagine what the world would look like if all companies adopted such a practice.

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Glenn Armellino MS, PE
President
Armellino Engineering, LLC
973-768-7490

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