The GE Aircraft Engine Bracket Challenge: An Experiment in Crowdsourcing for Mechanical Design Concepts

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Abstract

An emerging international engineering design trend has resulted from widespread use of social media: a large number of people are engaged in collaborative engineering design activities to build their design expertise through interaction with other designers, to compete for recognition or prizes, or simply for the enjoyment of doing so. The term “crowdsourcing” was introduced in 2005 and implies soliciting contributions from a large group of people, usually an online community, in order to get a broad perspective from various points of view. This community-generated creativity is contrary to conventional practice in most manufacturing companies, which prefer tight control of engineering designs and practices because they represent key intellectual property and know-how. Recognizing that crowdsourcing represents a potential resource, GE embarked on an experiment to see how a for-profit company might benefit from soliciting new design approaches from this non-traditional source. The design of a specific part, an aircraft engine bracket, was released to an online community of engineers with an invitation to submit improved designs in an open competition. Entrants were encouraged to consider additive manufacturing as the fabrication method. Hundreds of designers submitted concepts and some achieved 80% reduction in weight.

Introduction: Open Innovation

Open innovation is the formal practice of engaging the world to help drive innovation, add value, and solve problems creatively and rapidly. Examples of open innovation include innovation contests, crowd-sourced product development, and innovation networks.[i] Open innovation is contrary to conventional practice in most manufacturing companies, which prefer to control engineering designs and design practices because they represent key intellectual property and know-how. The term “crowdsourcing” was introduced in 2005 and implies soliciting contributions from a large group of people, usually the online community[ii], in order to get a broad perspective from various points of view.

Recognizing that crowdsourcing represents a potential resource that can benefit the company, GE embarked on an experiment to see how a for-profit company might engage the open community. Two design challenges were selected, one for GE Healthcare, and one for GE Aviation. The GE Healthcare focused on tungsten materials for CT detectors.[i] For the GE Aviation challenge, the topic of this paper, the choice was made to release the design of a rather simple though important part of the aircraft engine to the open community with the challenge to improve its design by reducing its weight. The part is an aircraft engine bracket, and its function is to support the weight of the cowling during engine service – it plays no active role during the operation of the engine. The part, shown in Figure 1, is made of titanium and weighs about 1.8 kg (4 lb.). It was recognized that the part could meet all functional requirements at a lower weight.

A cash prize was offered for the satisfactory design of the least weight. A manufacturing technique was not stipulated, though contestants were encouraged to take advantage of modern additive manufacturing methods if they desired. Everyone in the world was invited to compete, and almost 700 people chose to do so.

Figure 1. The original bracket design. This part was machined from titanium bar stock and weighed 4 lb.

The Value of Weight Removed from an Aircraft Engine

Weight minimization is often a key engineering design goal: an efficient design is usually a light design that is capable of handling whatever loads are applied without fracturing or permanently deforming under load. Weight is of importance in static applications, but grows in significance in dynamic or moving applications (such as automobiles) and becomes very significant with lifting applications (such as air travel and space flight).

A very large number (93,000) of commercial aircraft fly every day worldwide. Modern aircraft are, of course, heavy vehicles: the Boeing 737 weighs approximately 65 metric tons at takeoff. Recognizing that only passengers and cargo are revenue-generating, airlines are faced with the fact that transporting the airframe, fuel, and engines represents a necessary but unwanted cost of operation. With that in mind, an intriguing question: *How much fuel would be saved annually by reducing the weight of each worldwide aircraft by one pound?* We will answer the question from two perspectives, that of a businessman and that of a physicist.

The CEO's Answer

In 2012, a well-known airline flew 109,346,509 revenue passengers on a total of 1,361,558 trips at a cost of $6.12B in fuel[iii]. These values indicate an average fuel cost of $4500 per trip, or $56 per passenger. If we assume that the average passenger weighs 200-lb, including luggage, then the fuel cost is $0.28 per pound per trip. Thus, if one pound could be stripped from all of its aircraft, the airline would save just over $380,000 per year. Scaling this number to include all aircraft worldwide, the savings increases to more than $9.5M per year (> 3M gallons).

The Physicist's Answer

Let's assume an efficiency, $\eta = 20\%$, as given by the Brayton Cycle using a compression ratio of 30:1, and assumed losses due to friction, cabin services, cooling, electronics and controls, etc. The energy required to elevate a pound-mass to a height of 10-km (~35,000 ft) is then:

$$E = \frac{m\, g\, h}{\eta} = 222\ kJ$$

However, the weight of the aircraft and fuel must be included in the calculation along with the weight of the payload; perhaps two pounds must be added for each pound of payload, tripling this number. In addition, fuel cost for taxiing, idle, cruise, approach and landing has been ignored; based on a cursory review of the literature, we will assume that takeoff amounts to 10% of the total flight fuel usage. Further, assuming a jet fuel energy density of 34.7 MJ/L,[iv] and a cost of $0.8/L ($3.00/gal), the cost per pound is $0.15 per pound per trip. Scaling this number to include all airlines worldwide gives a total savings of over $5M per year (1.7M gallons).

The two answers are surprisingly close given the difference is problem solving method and assumptions. It is worth noting that, since most airframes require two, three, or four engines, the incentive for weight reduction in aircraft engines is proportionately higher. We conclude that the incentive for weight reduction in aircraft engines is enormously high.

The Contest

Recognizing that low weight is a key requirement, GE designers reviewed several parts and eventually selected the bracket of Figure 1. GE decided to engage *GrabCAD*[v], an established community of over 1M engineers to handle the interaction with the global community. The contest was announced in June 2013 and the following requirements were stipulated:

- Any CAD software could be used as long as a STEP or IGES file was submitted.
- The optimized geometry must fit within the original part envelope.
- The material was Ti-6Al-4V with an assumed yield strength of 131 ksi at the service temperature (75°F).
- Minimum material feature size (wall thickness): 0.050 in.
- Interface 1: 0.75 inch diameter pin. The pin was to be considered infinitely stiff for analysis purposes.
- Interfaces 2–5: 0.375-24 AS3239-26 machine bolt. Nut face 0.405 in. max ID and 0.558 in. min OD. The bolts were to be considered infinitely stiff.
- Loading conditions were stipulated as shown in Figure 2.
- The top ten designers would share $20,000 in prizes.

The contest generated a great deal of interest and contestants began to upload their entries almost immediately. Recognizing that this was not a typical open design contest where entries would be judged subjectively for their aesthetic appeal, contestants needed clarity on the objective factors of merit to be applied by the judges. Many questions and much online interaction resulted. The contest was closed on Nov. 2013 and almost 700 people had submitted designs. Judging commenced.

Judging

Judging proceeded in two phases. The first phase involved selecting the top ten designs with the highest likelihood of meeting the design requirements, and the second involved actually fabricating the top ten and applying the design loads on a test machine.

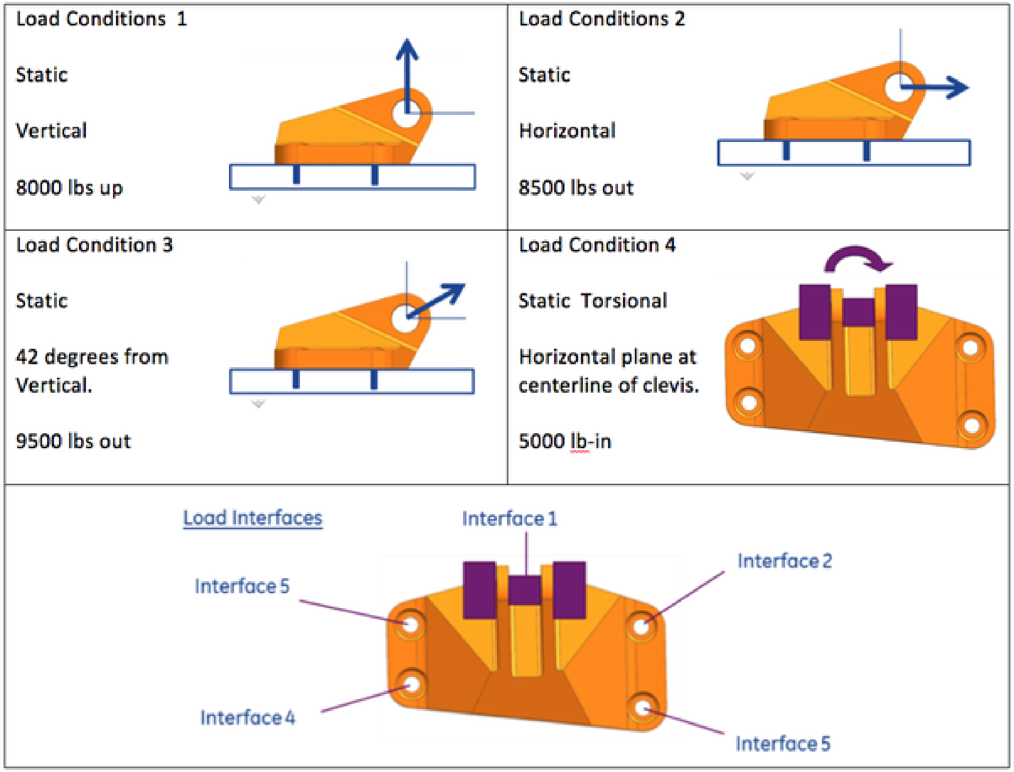

Figure 2 Load Conditions. Each bracket entry was required to pass finite element analyses to verify that the bracket would not plastically yield when loaded under the four specific loading conditions above.

Phase 1

The enclosed volume of all entries was calculated and the entries were ranked by volume from lowest to the highest. Starting with the lightest entry and proceeding until ten leading designs were identified, the following analyses were performed:

1. The volume of the entry was confirmed to be totally enclosed within the geometry of the original bracket. Unfortunately, several promising candidates failed this test. The judges acknowledge that some of these entries would likely fit within the constraints of the actual application, and therefore may have worked for the actual application, but were forced to apply the as-stated rules and disqualify these candidates.
2. Each entry was meshed with finite elements. Four finite element analyses were performed on each entry, one for each of the load cases. In these analyses, the bolts and mounting surfaces were treated as rigid bodies as described in the rules.
3. The maximum von Mises stress was computed within all finite elements. If this value exceeded the yield stress of the material (131 ksi) the entry was disqualified. If the maximum von Mises stress was within 5%, the results were carefully scrutinized to ensure that the finite element discretization did not over-predict these values. In some cases the geometry was

remeshed with a finer mesh for verification, but in none of these cases was the outcome reversed.

4. When the lightest ten entries that met the yield stress requirement were identified, analysis of further designs was stopped.

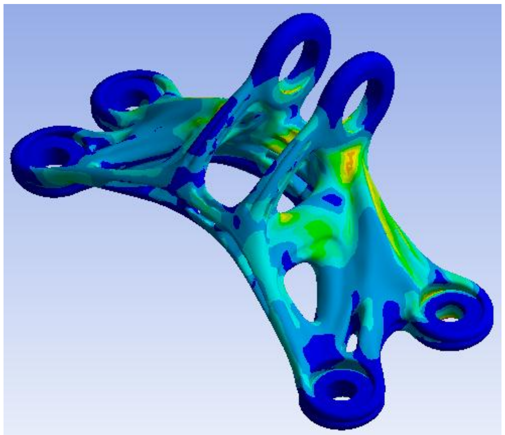 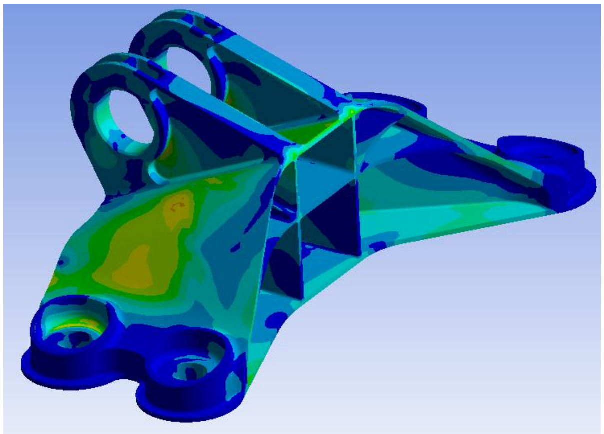

Figure 3 Typical FEA results from phase 1 of the judging. Von Mises stress is shown, where red indicates exceeding the yield stress.

Phase 2

The top ten entries were built from titanium powder in an ARCAM additive manufacturing system. The build direction was consistent for all entries, though it was recognized that some could be built more efficiently in other orientations – this was left for post-contest manufacturing optimization. Support structure was added as deemed necessary by the manufacturing engineer for successful construction; this support structure was removed immediately after the build using hand tools.

Several uniaxial tension specimens were built beside the test parts in the AM system to verify that the yield stress given in the rules was correct. A yield stress of 131 ksi was indeed measured using the 0.2% offset yield stress criterion.

A single load fixture, shown in Figure 4 on the left was built to test the brackets under Load Conditions 1, 2, and 3, and the fixture shown on the right hand side of Figure 4 was built to apply the pure torque loading of Load Condition 4. The loading fixtures were placed in a test frame with capability up to 20,000 lb. and each bracket was inserted with new screws to a specified torque. A load-displacement curve was generated and the judges carefully examined the curves to detect any departure from linearity that would indicate permanent deformation of the bracket resulting from plastic deformation. The top three winning entries showed no measurable plastic deformation, though some of the other entries did – these were ranked by a weighted value that included both weight and load at the onset of plastic deformation.

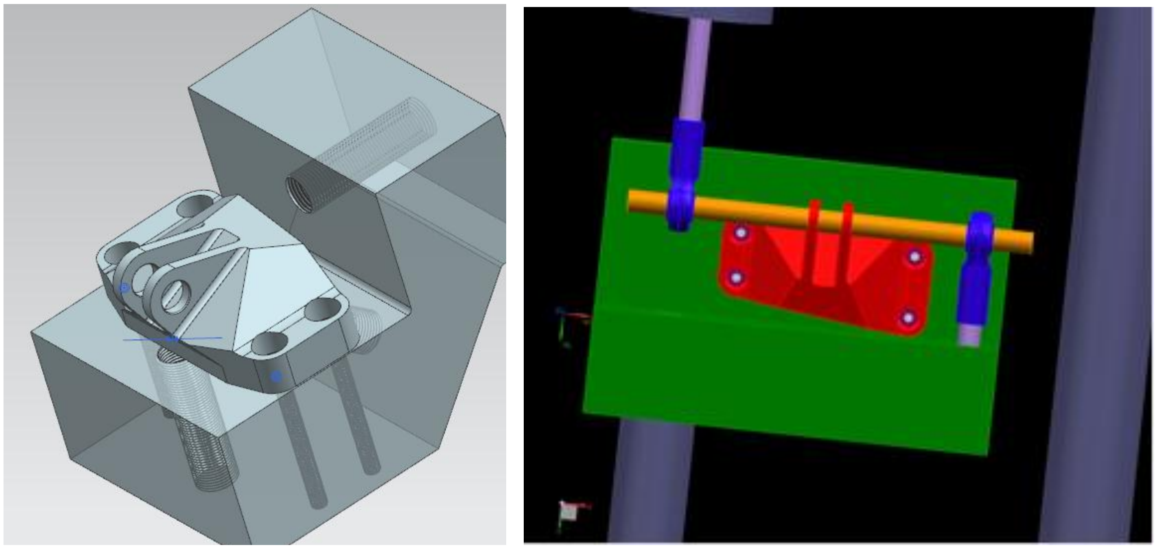

Figure 4. Text Fixtures. Test fixtures for Load Cases 1, 2 and 3 (left) and for Load Case 4 (right). The bracket was free to slide in slots on the plate for Load Case 4.

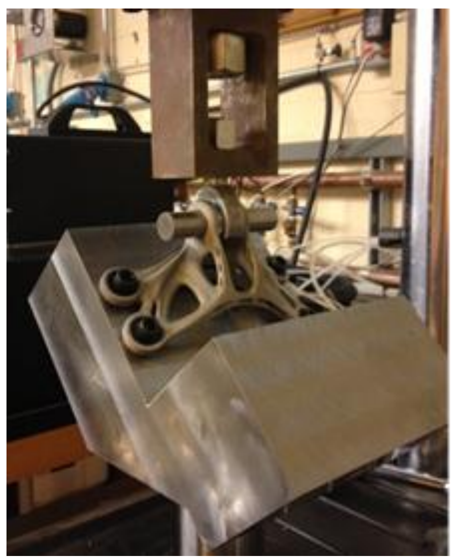

Figure 5 One of the finalists under test.

<u>The Winning Designs</u>

The top eight designs are shown in the figure below. The winning designer was able to remove 80% of the weight of the bracket without reducing its load-bearing capacity. Additive manufacturing is not a requirement for all the designs, though several showed features that would be expensive to include using conventional manufacturing methods.

First Place:
M.Arie Kurniawan
Indonesia

Second Place:
Thomas Johansson
Sweden

Third Place:
Sebastien Vavassori
United Kingdom

Fourth Place:
Nic Adams
Australia

Fifth Place:
Fidel Chirtes
Romania

Sixth Place:
Mandli Peter
Hungary.

Seventh Place:
Andreas Anedda
Italy

Eighth Place:
Piotr Mikulski
Poland

Figure 6. Winning bracket designs

Lessons Learned

As already mentioned, many promising entries failed to fit within the original design envelope, which was required by the rules. This check could have been automated with immediate feedback to the entrants so that design modifications could have been made before the close of the contest.

Both phases of judging were far more difficult than anticipated. Many of the light entries failed to meet the yield stress requirement, and it became clear that some of these entrants had not performed the analysis themselves. In the future, proof of a successful analysis should be a requirement for consideration.

File size became a concern. Though most entries were of reasonable size, some were in excess of 300 MB. Some of these large files were impossible to analyze in Phase I because they could not be meshed.

Communication between GE and the community was difficult and improvements will be implemented in future challenges. GE’s evaluation became an unexpected bottleneck as judges were simply overwhelmed. An interesting suggestion evolved: Can the evaluation itself be somehow crowd-sourced, thus eliminating the need for judging in Phase I?

Conclusions

The Challenge created a high level of interest throughout the community and large number of innovative design concepts were proposed and exchanged. This was educational for all those involved. A key question regarded the sustainability of such a crowd-sourced solution approach: Ten of the 700 entries in GE’s contest were awarded cash prizes, which left 690 entrants who were uncompensated for their efforts. Since many efforts were significant, would participation in similar future challenges result in similar worldwide interest? The answer is clearly “yes,” as interest in further contests is high.

Several specific benefits to the Company were identified:

- Before the contest was announced, GE internal designers used proprietary design optimization tools to predict the outcome of the contest. Opening up the contest to the entire world community allowed GE to benchmark its own capabilities against hundreds of other approaches.
- It was enlightening to see the vast number of design innovations that could be applied to this rather simple part. The GE team recognizes a considerable potential that may unlock creativity in more complex parts.
- One of the top ten contestants was hired as a GE employee under an internship program in Hungary, demonstrating to our Human Resources organizations that open innovation adds a valuable recruiting tool.

In terms of dollars and fuel savings, implementation of the winning bracket will reduce the weight of a GE LEAP aircraft engine by 1.7 kg (3.76 lbm). If similar weight reductions were to be applied to all flying aircraft worldwide, annual fuel savings from 12 to 22 million gallons of fuel (at a current value of \$37M - \$71M) could be realized.

As a result of the success of the experiment, GE announced in May 2104 the activation of its global co-creation community FirstBuild.com[vi] – an online community dedicated to conceiving, engineering and building the next generation of major appliances for use in the modern home. Engineers, designers, scientists and home enthusiasts will participate in the development of breakthrough major appliances and solve engineering challenges. Participants will identify market needs, directly participate in the product development and watch via social media as ideas speed from mind to market at the FirstBuild™ micro-factory[vii] in Louisville, KY. GE opened the community to the public on May 15 with two challenges already in place.

- Developing a micro-kitchen: FirstBuild is participating in the NYC Economic Development Council's annual "BigApps" challenge that started May 7. FirstBuild will engage existing online communities as well as the FirstBuild.com community to help solve a growing problem in many metropolitan areas across the globe: increasing urbanization and population growth, which are driving the size of homes down and mortgages up. The challenge is to solve the design and engineering hurdles in creating a micro-kitchen that will maintain the style and functionality, but in a significantly smaller footprint than traditional kitchens.
- Indoor grilling: Grilling is a major part of the American lifestyle. A 2013 study shows that 80 percent of U.S. households own a grill or smoker. Yet, grilling can be dependent on the weather. FirstBuild is asking the global community of makers, designers and aspiring chefs to take the weather out of the equation by designing and engineering the ultimate indoor grill.

In addition to these challenges, GE has more than 40 challenges under consideration for future engagement via crowdsourcing.

References

[i] Brian Yanoff, et.al., Open Innovation in Precision Additive Manufacturing with Refractory Metals, RAPID 2014 Conference and Exposition, Detroit, MI, June 9-12, 2014.
[ii] Wikipedia, the free encyclopedia.
[iii] Southwest Airlines Co., 2012 Annual Report to Shareholders, p.43.
[iv] http://en.wikipedia.org/wiki/Jet_fuel
[v] http://grabcad.com/
[vi] https://firstbuild.com/
[vii] Microfactory, Inc. is a wholly owned subsidiary of GE, and FirstBuild is a registered trademark of Microfactory, Inc.