2019 USACM Thematic Conference Topology Optimization Roundtable

Challenge Problem

Formula 1 is looking to select an engineering firm with expertise in design for additive manufacturing to help them with future projects. They have designed a contest to help them select a firm.

Your challenge is to design a suspension upright that meets a number of design requirements and performance metrics. This is your opportunity to convince Formula 1 that your engineering firm is the best choice.

Figure 1: Formula 1 race car (https://3c1703fe8d.site.internapcdn.net/newman/gfx/news/ hires/2018/formula1.jpg).

Problem Description

Design domain:

A suspension upright attaches the wheel, brake rotor, hub, brake caliper, and steering arm to the vehicle (https://www.buildyourownracecar.com/race-car-suspension-basics-and-design/2/). A schematic of the components interfacing with the suspension upright is provided in Fig. 2. An image of the design domain is provided in Fig. 3. In Fig. 3(a), components that do not participate in the optimization are highlighted in gold. In Fig. 3(b), the region subjected to Dirichlet boundary conditions (i.e., displacements in x, y, and z equal to zero) are highlighted in gold. All boundary conditions and loads should be applied using MPCs.

Note that the design envelope is fixed, and thus, your design cannot extend outside of the design envelope.

A STEP file is provided that contains all geometry-related information for the design domain (units are inches).

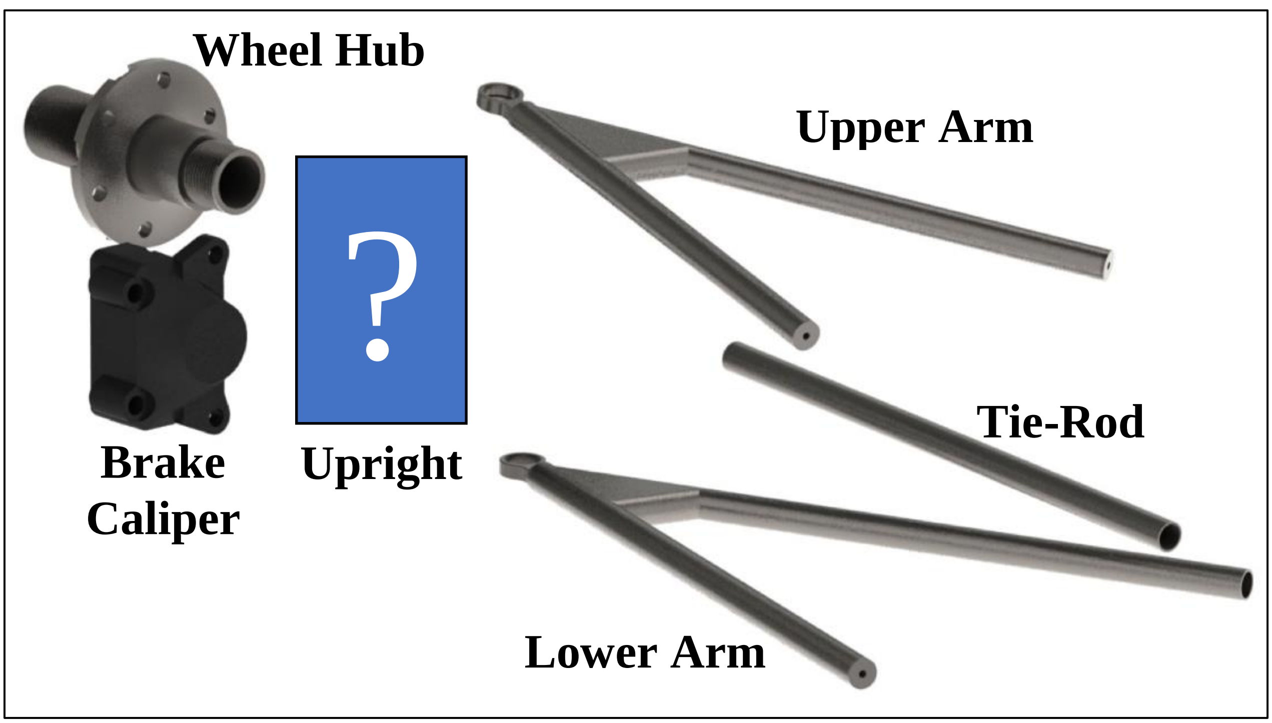
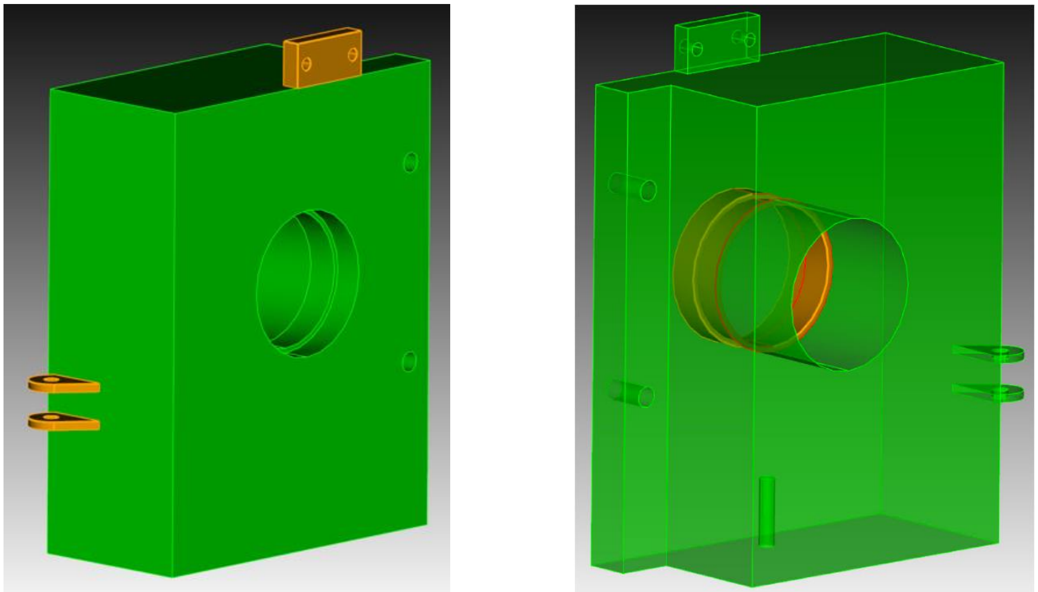


Figure 2: Suspension upright location and surrounding mechanical parts.



Front View
(a)

Rear View
(b)

Figure 3: Problem domain: (a) Front view with fixed regions, i.e., regions that do not participate in the optimization, highlighted in gold; (b) Rear view with dirichlet boundary conditions, i.e., regions with x, y, and z displacements set to zero, highlighted in gold.

<u>Materials:</u>

The suspension upright must be made from Aluminum (AL-6061-T6), Titanium (TI 6AL-4V), Stainless Steel (SST 304), or a combination. Material properties are provided in Table 1.

Table 1: Material properties

Property	**Al 6061-T6**	**Ti 6Al-4V**	**SST 304**
Density (g/cc)	2.7	4.43	8.0
Yield (MPa)	276	880	215
Tensile (MPa)	310	950	505
Elongation at break (%)	12	14	70
Young's Modulus (GPa)	68.9	113.8	200
Fatigue (MPa)	96.5	240	-
Strength/Weight[1] kNm/kg	102.2	198.65	26.88

[1] Yield to Density Ratio

Load cases:

A suspension upright is subjected to large forces due to cornering and breaking. Thus, your design must accommodate all, or a subset, of the load cases provided Tables 1 and 2, where all loads are magnitudes of the normal force vectors. Additional information related to the load cases is provided in Figs. 4-6. **If a subset of the load cases is used, please report which loads were considered and why.**

Table 1: Cornering load cases

Case	Inside Cornering	Outside Cornering
C1	-50 N	140 N
C2	-150 N	645 N
C3	380 N	1920 N
C4	45 N	-1750 N
C5	175 N	-3975 N
C6	-85 N	405 N

Table 2: Braking load cases

Case	Forward Braking	Rearward Braking
B1	-2500 N	390 N
B2	1700 N	-340 N
B3	2160 N	360 N
B4	4500 N	-1100 N
B5	-6500 N	800 N
B6	2170 N	-425 N
B7	20200 N-mm	-4200 N-mm

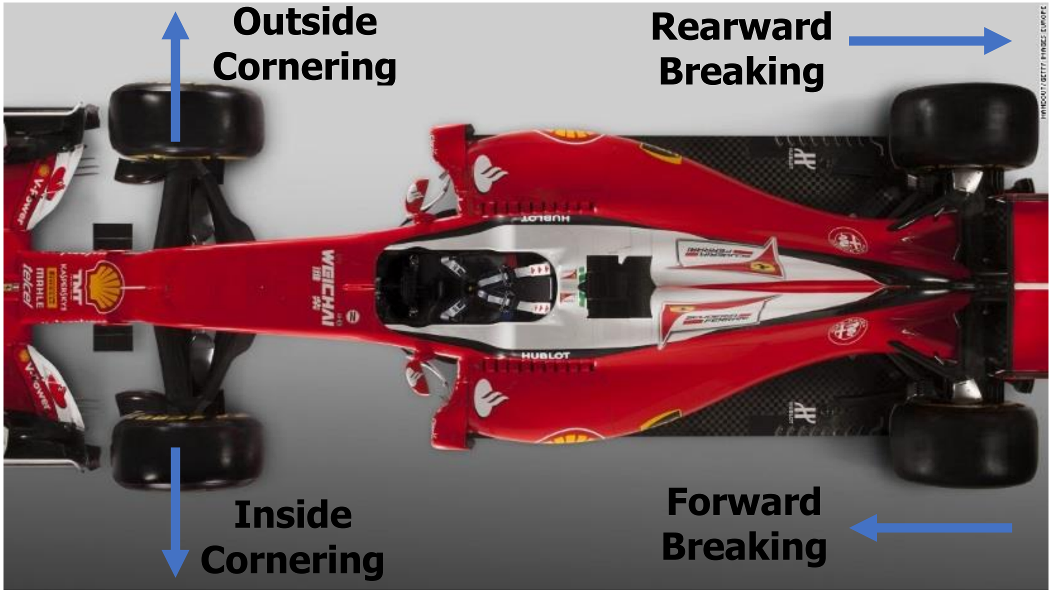


Figure 4: Top view of Formula 1 car with load cases shown.
(https://www.jamesallenonf1.com/decom_160219175406-ferrari-f1-car-aerial-view-super-169_59c43c98853f4-jpg/)

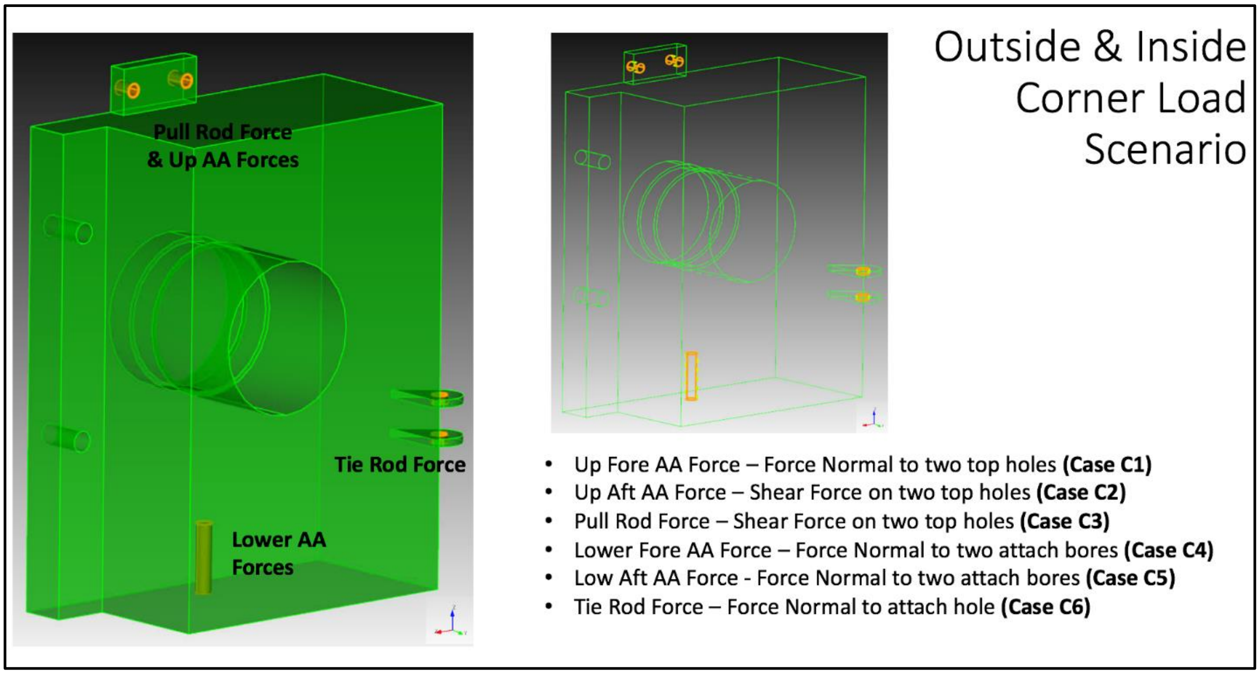


Figure 5: Inside and outside tight corner scenarios. Load magnitudes are provided in Table 1.

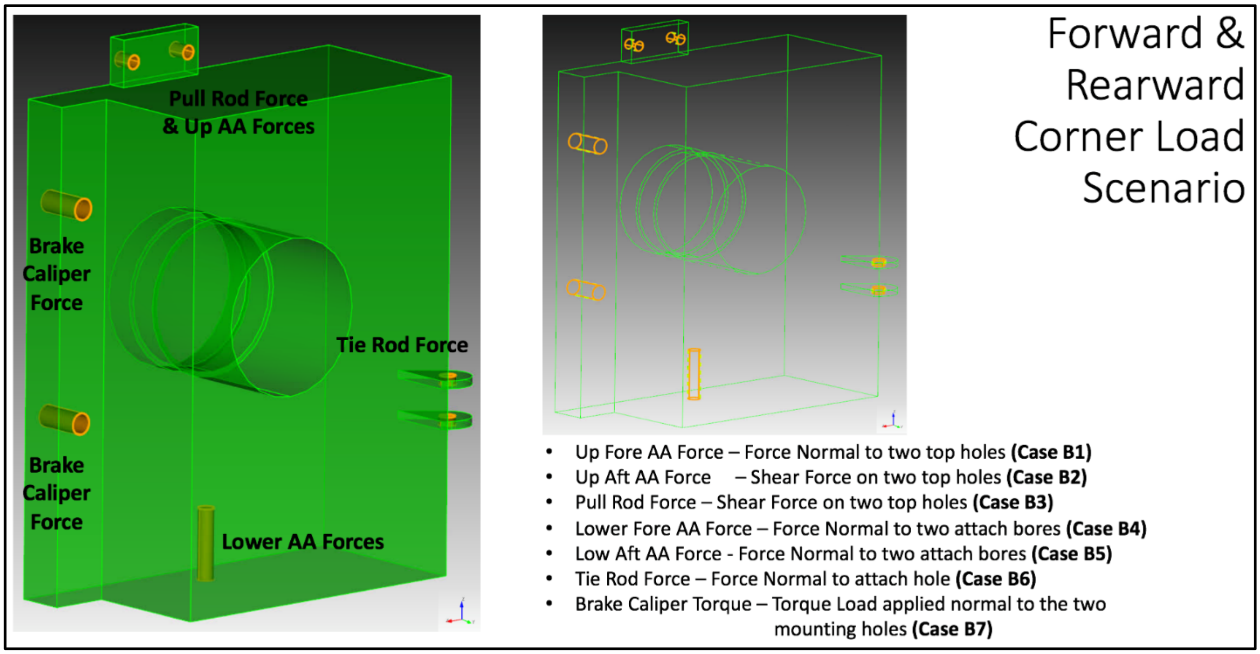


Figure 6: Forward and rearward breaking scenarios. Load magnitudes are provided in Table 2.

<u>Additional Design Requirements</u>

In addition to the requirements stated above, Formula 1 has listed some additional design requirements below. Formula 1 does not expect you to satisfy all of these design requirements, but the more design requirements that are satisfied in your final design, the more favorably Formula 1 will consider your firm as the winner.

1. **Weight requirement:**
    - Total weight should shall be minimized
    - Clearly indicate the weight of your final design
2. **Stress requirement:**
    - Maximum von Mises stress shall be less than **<u>250 MPa</u>**
    - Minimize residual stresses induced by the AM process (include residual stress information in the design optimization iterations)
3. **Deflection requirement:**
    - Maximum deflection at all points shall be less than **<u>0.12 mm</u>**
4. **Dynamics:**
    - Resonant frequency shall be above **<u>75 Hz</u>**
5. **Thermal:**
    - Maximize heat conduction
6. **Manufacturability:**
    - Minimum member diameter shall be determined based on manufacturing capabilities
    - Optimize the build orientation
    - Bracket shall be manufactured using Additive Manufacturing (e.g., Electron-Beam (EBM), Laser Engineered Net Shaping (LENS)).
7. **Design turnaround:**
    - The Formula 1 team desires fast design turnaround. Hence, the desired design tools shall allow multiple design iterations in a small timeframe.
    - Report the computational cost, i.e., how much time it takes to solve one optimization problem with all the load cases.
    - Report the problem size, i.e., the number of design and state variables.
    - Report the hardware used to solve the problem.

Deliverables

Please submit the following at the 2019 USACM Thematic Conference - Topology Optimization Roundtable:

1. Images or physical model of final design
2. Formulation used to solve the optimization problem
3. Design metrics – please report how well your design meets each of the design requirements, including those that are not met.

Extra Credit

Consider aleatoric uncertainty in the orientation of load case B4 (see Table 2 and Figure 6). The uncertainty is defined as a beta random variable with distribution, beta(2.1667,4.3333) on the interval [-20° 45°]. Use the maximum von mises stress as the quantity of interest.

Please report the following:

1. Formulation used to solve the optimization problem.
2. Approach/method used to quantify and propagate the uncertainty.
3. Computational cost – how much time it took to solve the optimization problem and what hardware was used.