COULD NASCAR HAVE GONE FASTER?

A FINITE ELEMENT ANALYSIS ON A WHEEL FLANGE

Daniel Tohti (dt3zjy)
08 May 2024
MAE 6710: Finite Element Analysis

EXECUTIVE SUMMARY

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2. Initial Design
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Background & Motivation

MAJOR NASCAR RULE CHANGE

Background & Motivation

- In 2020, NASCAR announced two big changes regarding car wheels used in races [2]
  - Increased tire sizes from 15″ to a production-standard 18″
  - **Five-lug tire design to a single lug nut** for increased durability on the bigger wheel
- While wheels with a single lug nut have many advantages, what if NASCAR had never changed their rules?
- **I will be exploring the design and optimization of a wheel flange from an old NASCAR wheel**

Fig. 1: NASCAR's old wheel (left) compared to the new design (right)

SELECTED WHEEL FLANGE

Background & Motivation

- Brad Keselowski is a renowned NASCAR racer with 3 championships, 13 top fives, and 19 top tens in 2019 [3]
- Raced for Team Penske and drove the **Ford Mustang Dark Horse** [4]
- The most recent Ford Mustang Dark Horse recently released with a relatively simple yet sophisticated wheel flange design
- Wheel flange design was modified to comply with given FEA project constraints

Fig. 2: Image of a 2024 Ford Mustang Dark Horse's wheel [1]

Initial Design

CAD MOCKUP

Initial Design

- CAD model followed given physical constraints and reflected main features of the Dark Horse wheel
  - **Wheel Diameter**: 450 mm
  - **Wheel Thickness**: 75 mm (<100 mm)
  - **Axle Pad Diameter**: 125 mm
  - **Bolt Circle Diameter**: 100 mm
  - **Center Bore Diameter**: 75 mm
  - **Wheel Flange Boundary Thickness**: 15 mm
  - **Bolt Diameter**: 15 mm
  - **Number of Bolts**: 5
  - **Material**: 6061 Aluminum
    - Very common material for wheel flanges
  - **Mass**: 4.004 kg

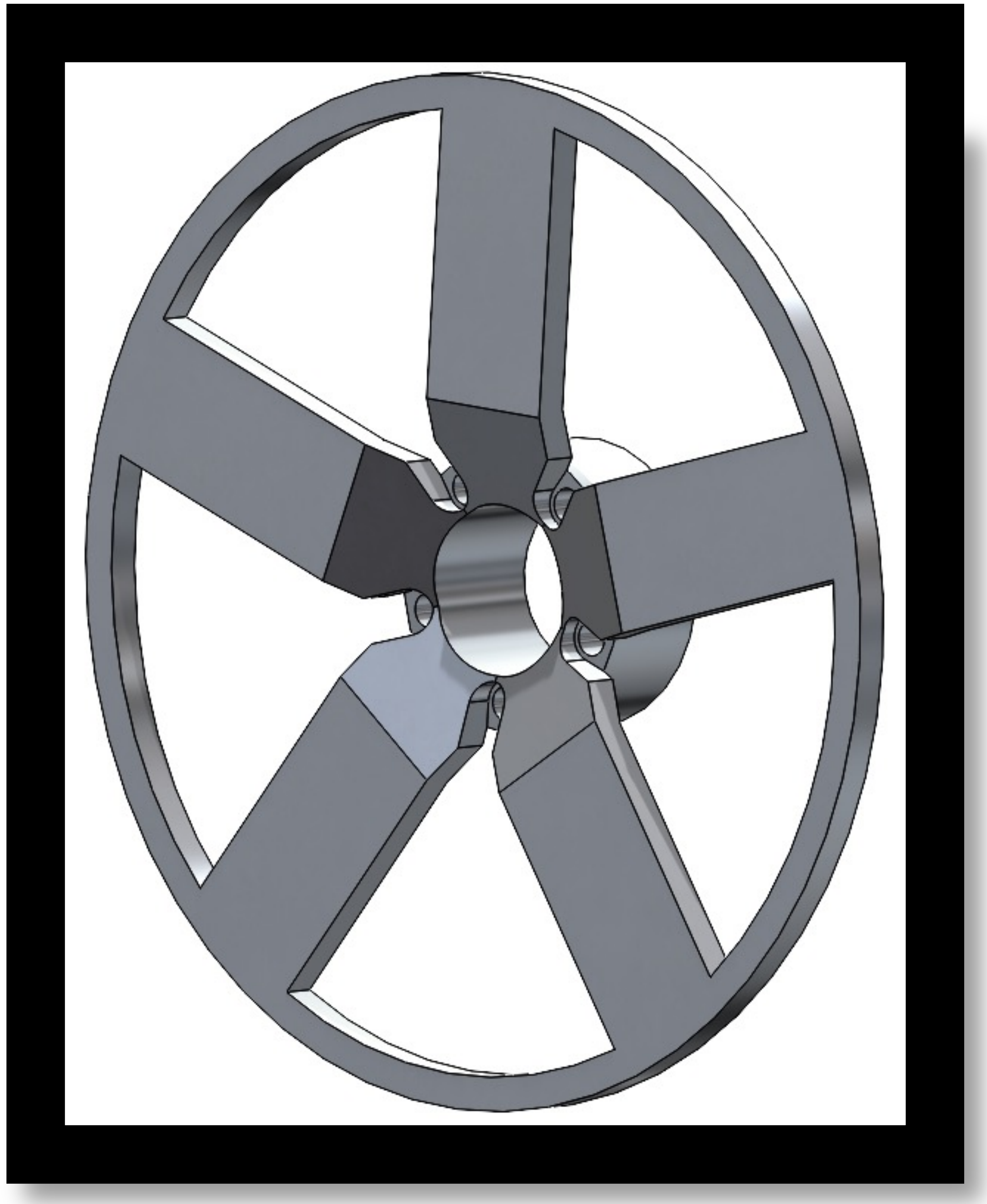


Fig. 3: Isometric view of CAD model. The five “bars” resemble the basic geometry of the Dark Horse wheel

MORE PICTURES
Initial Design

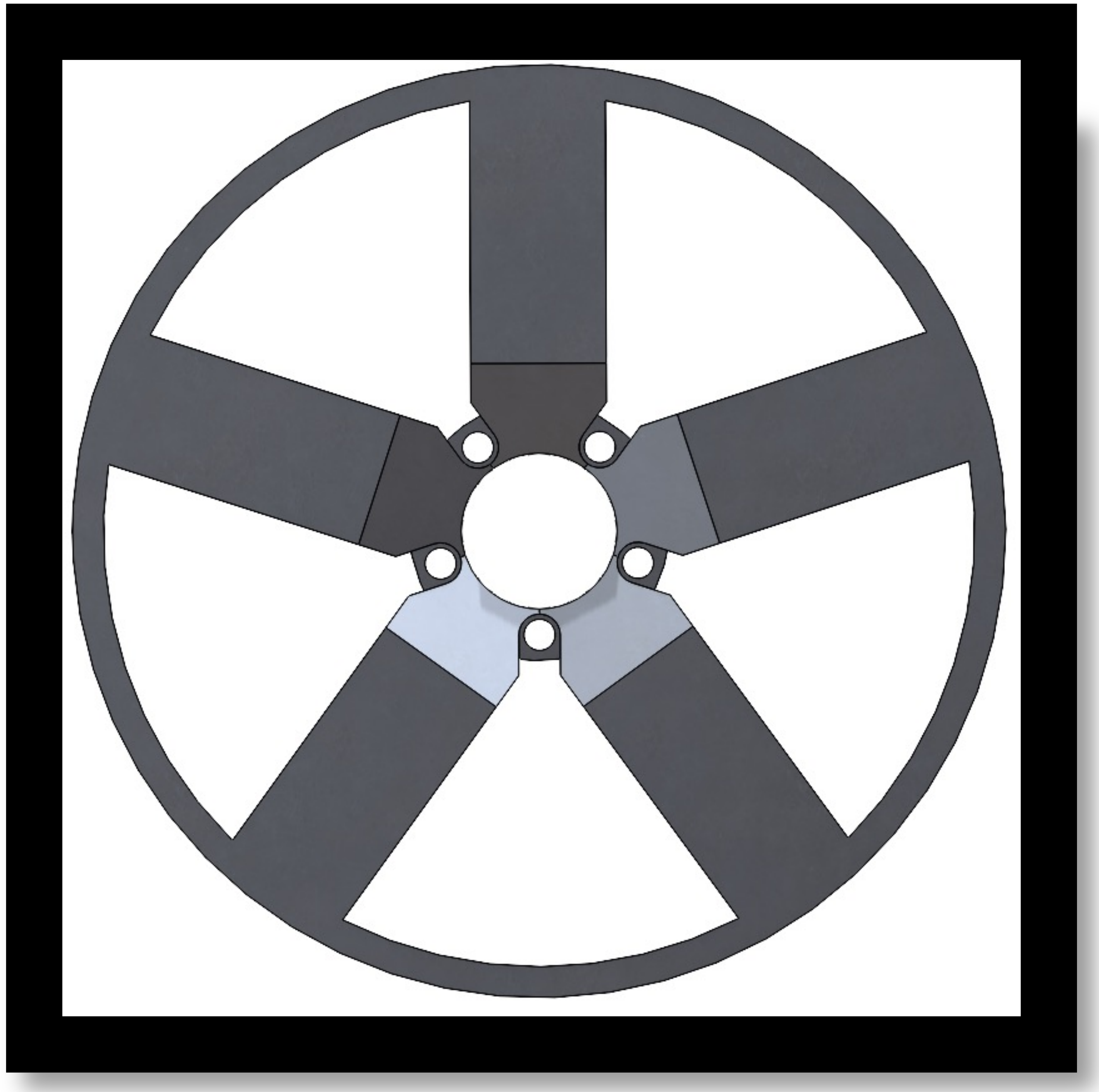


Fig. 4: Comparison of the front view of the CAD model (left) and the Ford Mustang Dark Horse wheel (right)

MORE PICTURES

Initial Design

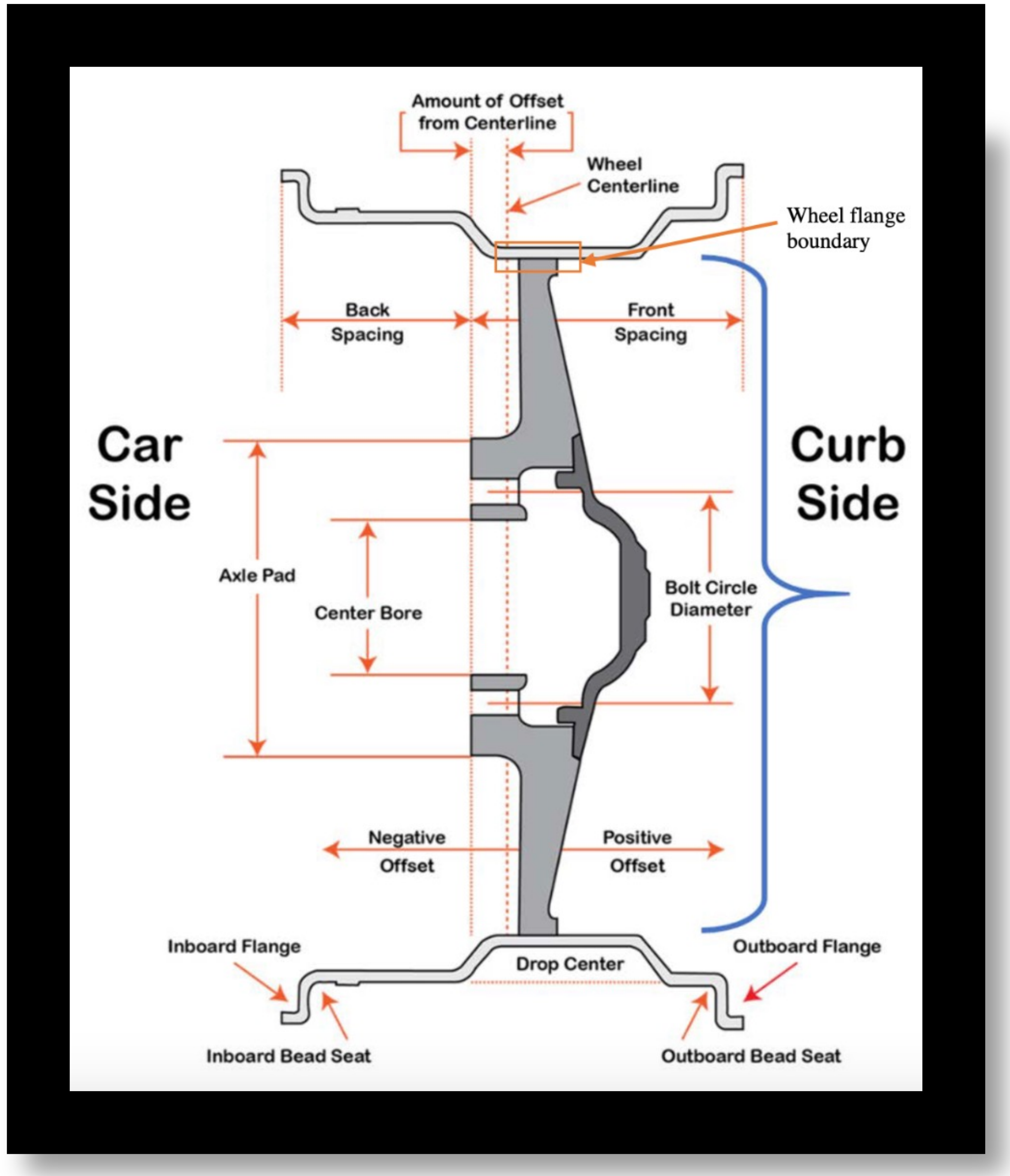


Fig. 5: Comparison of the side view of the CAD model (left) and the given image for the project (right

Simulation

STRUCTURAL SETUP
Simulation

- **Goals**:
  - Element sizing small enough to enable solution convergence
  - Element sizing big enough to save on computational resources (time & energy)
  - Proper reflection of given boundary, load, and other physical conditions
- **Mesh**:
  - Element size of 10 mm applied to the important parts of the wheel (see next slide), while non-critical areas were meshed with the default sizing at a resolution of 5
- **Loads & Boundaries**:
  - Inside face of every bolt hole was fixed
  - Counter-clockwise torque of 6000 Nm applied to outside face of wheel flange boundary
  - Constant normal pressure of 150 kPa applied to outside face of wheel flange boundary
- **Material**: Acquired from ANSYS database. Yield strength of **259 MPa**

SETUP IMAGES

Simulation

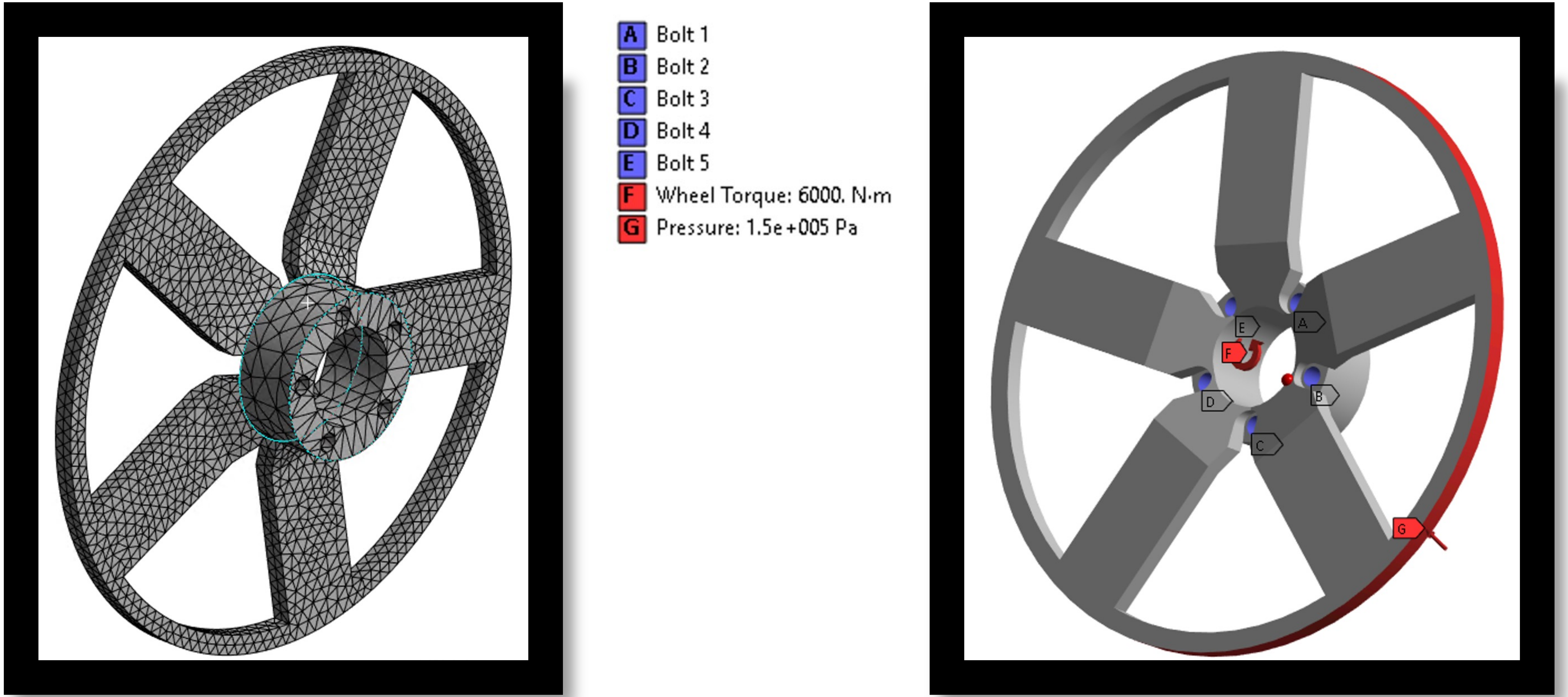


Fig. 6: Model meshing (left) and boundary/load conditions (right) with their values (middle) in ANSYS. Light blue outline in the left image shows the area where the default meshing sizes were used.

SETUP RESULTS

Simulation

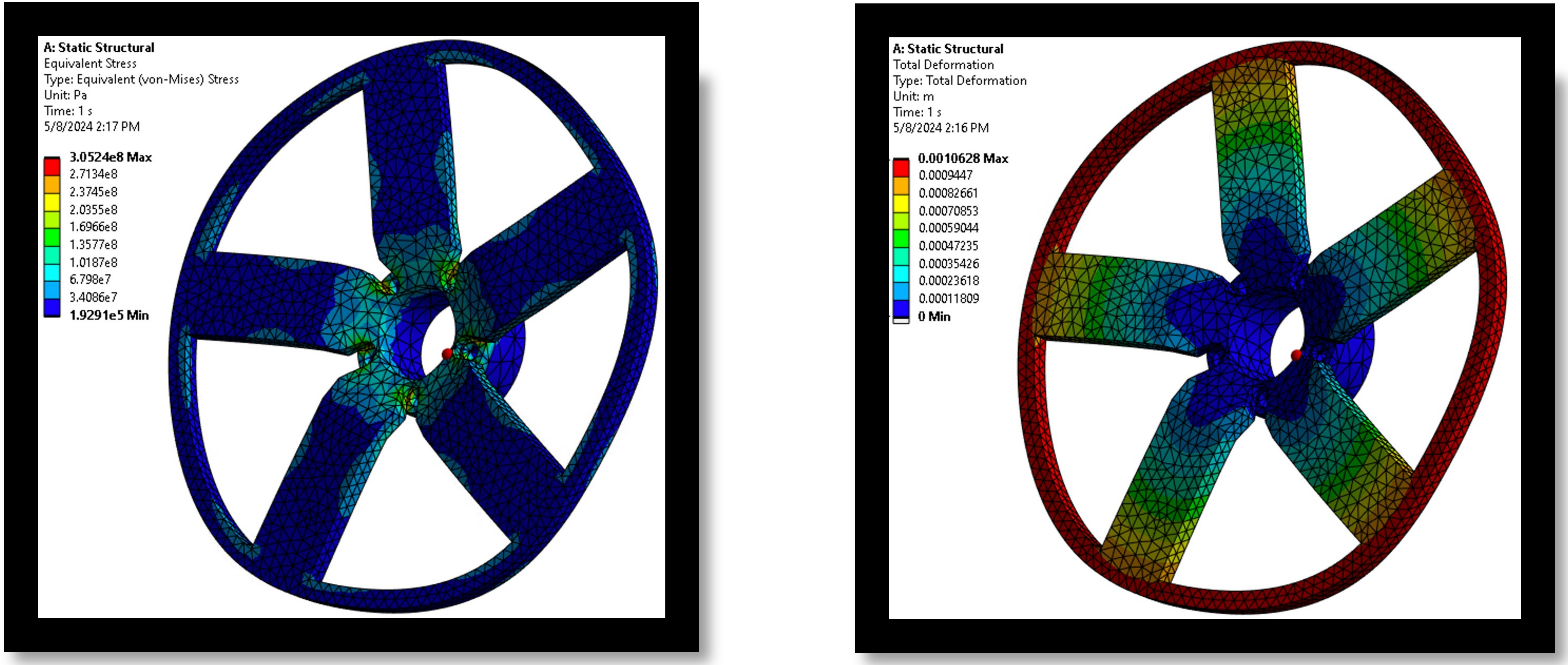


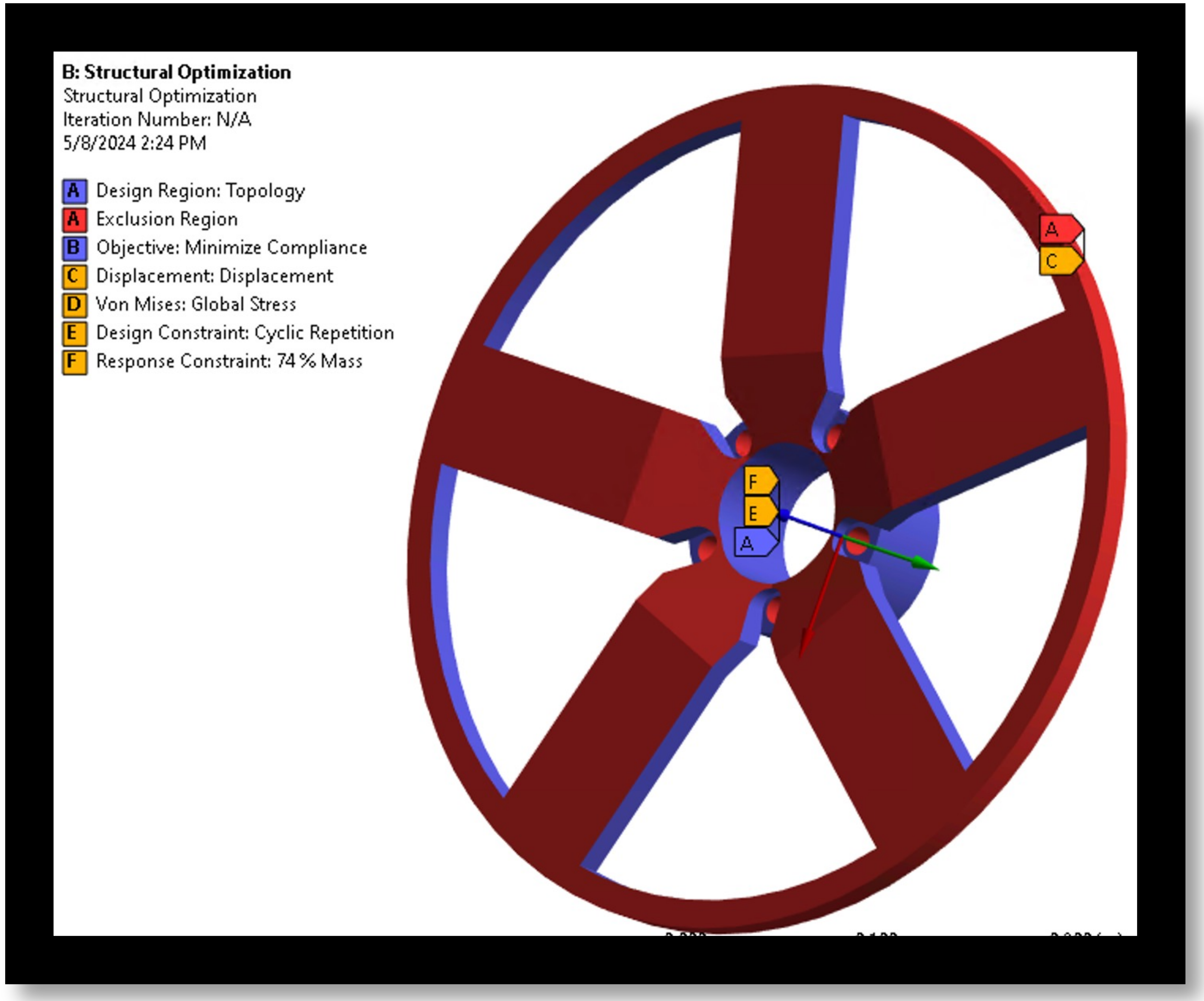
Fig. 6: Simulation von Mises stress (left) and total deformation (right) results. Maximum stress exceeds yield strength of 6061 aluminum, while total deformation is within the performance constraint of <4 mm.

Optimization

SETUP
Optimization

- **Goals**:
  - Reduce as much mass as possible while retaining critical features
  - Meet performance constraints for total deformation (<4 mm) and von Mises stress (< yield)
- **Analysis Settings**: Set for earlier convergence to save computational resources
  - Maximum of 50 iterations and convergence accuracy of 0.5%
- **Exclusion Areas**: Set to retain critical features. Wanted to keep the iconic 5 bar design of the Dark Horse wheel
  - Inside face of bolt holes, outside face of wheel flange boundary, and front face of the wheel
- **Optimization Constraints**: Minimize mass, maximize allowable stress & deformation
  - **Max Displacement**: $\frac{4}{\sqrt{3}}$ mm for each direction. Normalized from 4 mm
  - **Max con Mises Stress**: 259 MPa
  - **Cyclic Repetition**: Set to five to reflect wheel geometry for efficient fabrication
  - **Minimize Mass**: 74% retained mass was smallest number that led to convergence

SETUP IMAGES
Optimization



Definition	
Maximum Number Of Iterations	50.
Minimum Normalized Density	1.e-003
Convergence Accuracy	0.5 %
Initial Volume Fraction	Program Controlled
Penalty Factor (Stiffness)	3.
Region of Manufacturing Constraint	Include Exclusions
Region of Min Member Size	Exclude Exclusions
Region of AM Overhang Constraint	Exclude Exclusions
Filter	Program Controlled

Fig. 7: Visual of the optimization setup (left) with all constraints listed and color-coded. Analysis settings is on the right

OPTIMIZATION RESULTS

Optimization

- **Key Features**:
  - Much of the middle structure was shaved off, except near the bolt holes
  - The thickness of the bars were shaved down to almost half of its original thickness
  - The wheel flange outer circle developed a fillet or chamfer *except* for the part to the left of each bar
    - Material to the left of the bar was likely kept to combat the counter-clockwise torque

Fig. 8: Back view of the optimized wheel

Final Results

MODEL & DETAILED COMPARISON

Final Results

- **Final Design Details**:
  - **Mass**: 3.179 kg
  - **Maximum von Mises**: 234 MPa
  - **Maximum Deformation**: 1.695 mm
- **Initial Design Details**:
  - **Mass**: 4.004 kg
  - **Maximum von Mises**: 305 MPa
  - **Maximum Deformation**: 1.063 mm

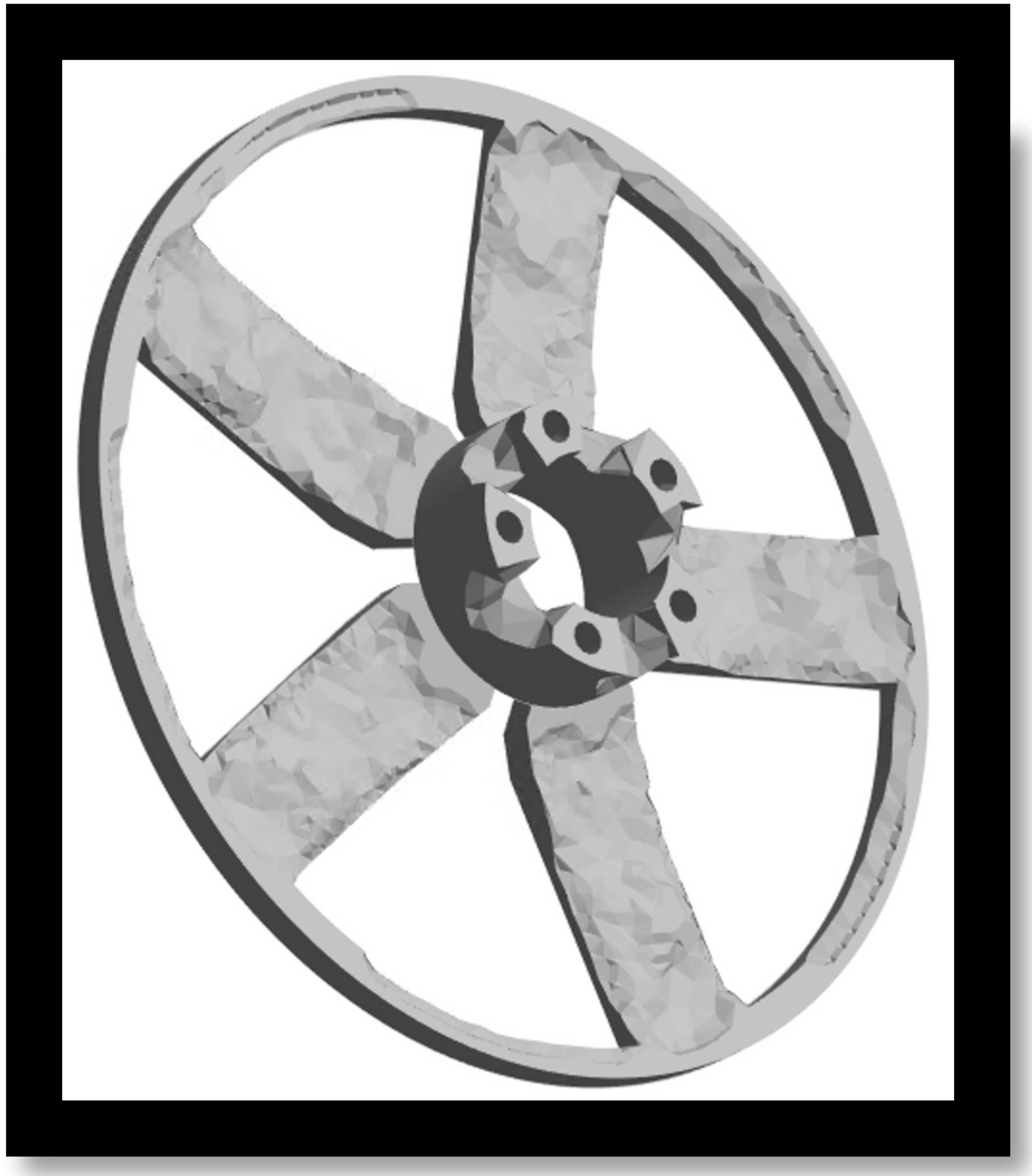
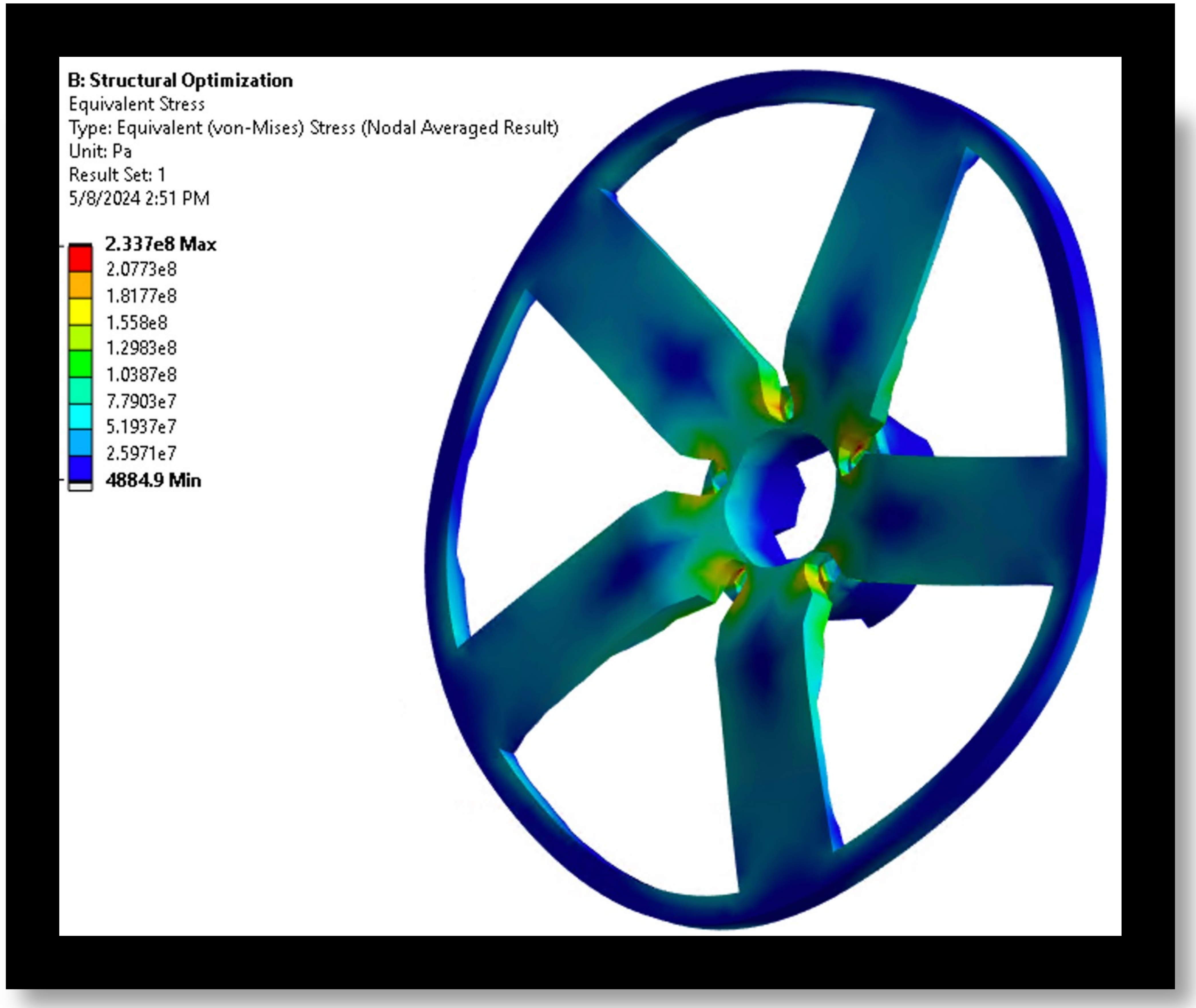


Fig. 9: Back view of imported final design geometry

STRESS & DEFORMATION
Final Results



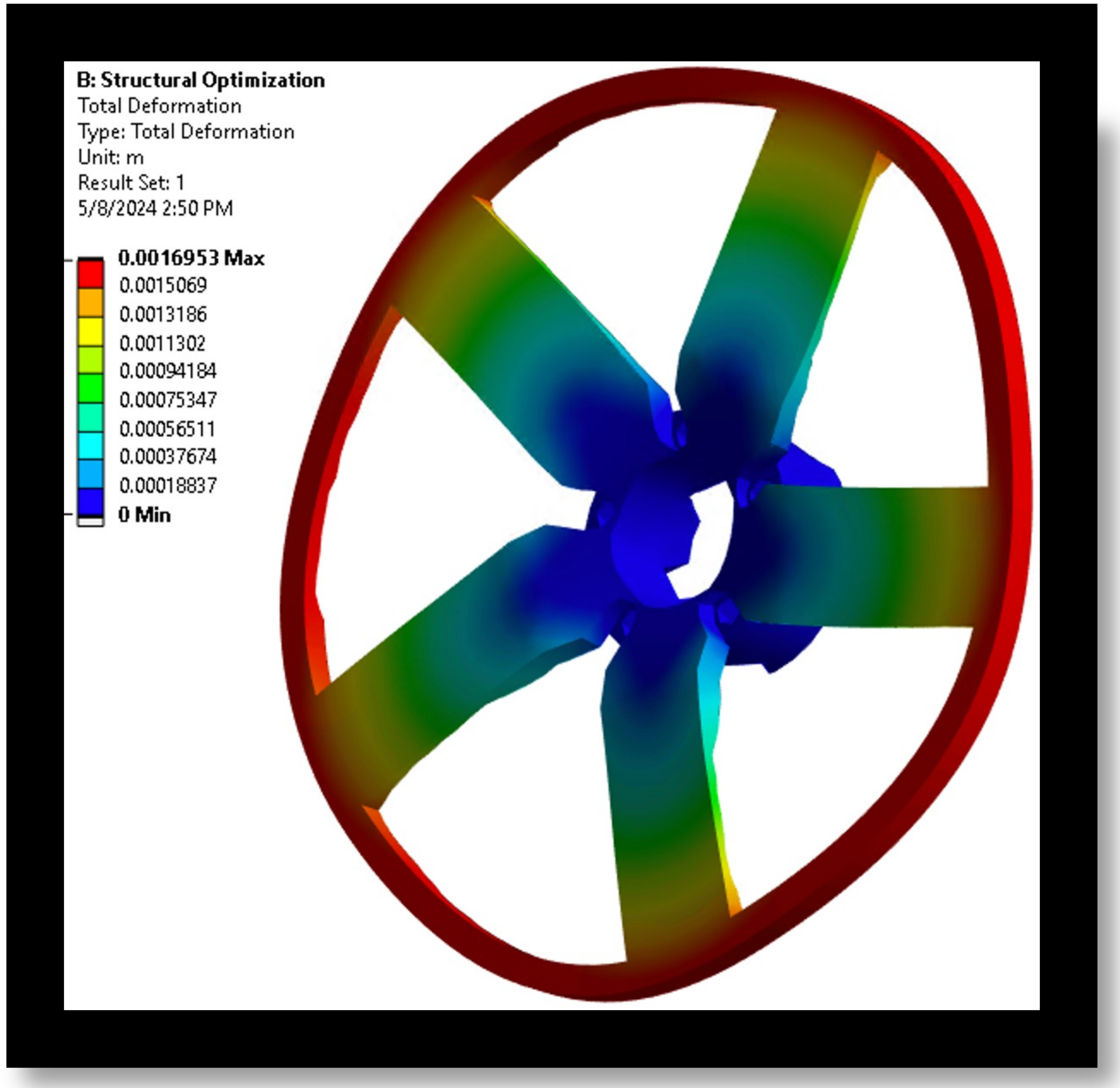


Fig. 10: Simulation von Mises stress (left) and total deformation (right) results

Conclusions

IMPROVEMENTS & RECOMMENDATIONS

Conclusions

University of Virginia

- **Summarized Improvements**:
  - **Mass**: Final design had a 21% decrease in mass from the original
  - **Stress**: Final design had a maximum von Mises significantly lower than 6061 aluminum yield strength
  - **Deformation**: Final design had a slight increase in deformation, likely to prioritize shaving away mass
- **Recommendations**: Exactly replicated the final geometry in Figure 9 would not be feasible with common manufacturing practices, so the following design changes are proposed
  - Take away material near bolt circles with an extruded cut between the holes
  - Fillet or chamfer the inside, back edge of the outer circle *except* for the area near the left of the bar
  - Shave off 33% of the thickness of each of the 5 bars
- **Conclusions**: If NASCAR continued along the five-lug wheel path, there would likely have continued to be innovative solutions to make the slightest improvements to maximize athlete potential in races

References

REFERENCES

[1] Alaniz, A. (n.d.). 2024 Ford Mustang Dark Horse Reveals Lightweight Carbon-Fiber Wheels. Motor1.Com. Retrieved May 8, 2024, from https://www.motor1.com/news/651790/mustang-dark-horse-carbon-fiber-wheels/

[2] Albert, Z. (2020, March 2). NASCAR moving to single lug-nut design for Next Gen car. Official Site Of NASCAR. https://www.nascar.com/news-media/2020/03/02/nascar-single-lug-nut-design-wheel-next-gen-car/

[3] Montgomery. (n.d.). Brad Keselowski 2019 season in review. Official Site Of NASCAR. Retrieved May 8, 2024, from https://www.nascar.com/gallery/brad-keselowski-2019-season-in-review/

[4] Staff, B. com. (2019, November 18). 2019 Season Comes to an End—The Official Site of Brad Keselowski. NASCAR Champion. http://www.bradracing.com/2019/11/18/bk-battles-to-a-3rd-place-finish-in-las-vegas-2-2-2-3-2-2-2-2/, http://www.bradracing.com/2019/11/18/bk-battles-to-a-3rd-place-finish-in-las-vegas-2-2-2-3-2-2-2-2/