Analysis and Design Optimization of Seat Rail Structures in Various Operating Conditions

Santhosh Sivan Kathiresan, Master's Degree Student
Raghu Echempati, Professor
Department of Mechanical Engineering
Kettering University
Flint, Michigan-48504
Student email: kath4635@kettering.edu
Professor email: rechempa@kettering.edu

Abstract

Automotive seating rail structures are one of the key components in the automotive industry because they carry the entire weight of passenger and they are the holding structure for the seating foams and other assembled important components such as side airbag and seatbelt systems. The entire seating is supported firmly and attached to the bottom bodywork of the vehicle through the linkage assembly called the seat rails. These seat rails are adjustable in their longitudinal motion which plays an important role in giving the passengers enough leg room to make them feel comfortable. Therefore, seat rails under the various operating conditions, should be able to withstand the complete weight of the human with the seating structures, other assembled parts into the seating, and functional requirements such as crash safety which are important to avoid or minimize injuries to the occupants. Keeping the above requirements in view, the goal of this paper is to perform studies on the seat rails under different operating conditions through a detailed investigation using SolidWorks simulation tool for structural and vibration (dynamic) analyses with durability and design optimization using different grades of steel, aluminum, and multi-materials. Based on these studies a newly designed seat rail structure to increase the fatigue life, decrease the damage percentage, and increase the resonant frequencies are proposed.

Introduction

Automotive seating structures, the key component in vehicle, has to be designed and developed very precisely considering all the external loads which are acting on it. The subassemblies which are in the seat have to be very strongly designed such that no failure occurs because of the repeated usage. Seat rail which is the most important part in holding the complete seat assembly to the vehicle base floor, have to be robust enough to carry the entire weight of the seat assembly and the passenger. The detailed analysis of the seating rail structures are carried out in this paper, and based on the results obtained, design optimization is performed to rectify the failing portion of the seat rail through the finite element analysis (FEA).

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Literature Review

Adient[1] the supplier of automotive seating, says that they are taking the multi-material approach in reducing the seat weight without compromising comfort of the passenger or the safety. Therefore, in this research work, multi-material behavior is studied under the stress, strain, and displacement simulation by considering steel for bottom seat rail and aluminum for bottom floor holder, top seat rail, and top seat holder, refer Figures 1a, 1b, and 2 to locate these parts in the seat. Jaranson et al[2] found that their concept design achieved the weight saving by 17% for the front seat structures using the multi-materials, therefore multi-material is taken into this research work to study it under the finite element analysis (FEA). Wainwright et al[3] has described the design process for the structural analysis, which is considered for this research work in the design and structural analysis stage. There are many other papers available in the literature, that are not cited in this paper.

Model Design

Design of the seat assembly is taken in this paper for the analysis purpose, from which only the seat rail assembly is taken into the consideration. Since, the real seat shown in Figure 1a is difficult to model in CAD, a similar seat frame geometry available in GrabCAD[4] shown in Figure 1b is adopted. For this research work, only the seating rail assembly is used from the GrabCAD[4] data by extracting it from the remaining parts of the seat as shown in Figure 2.

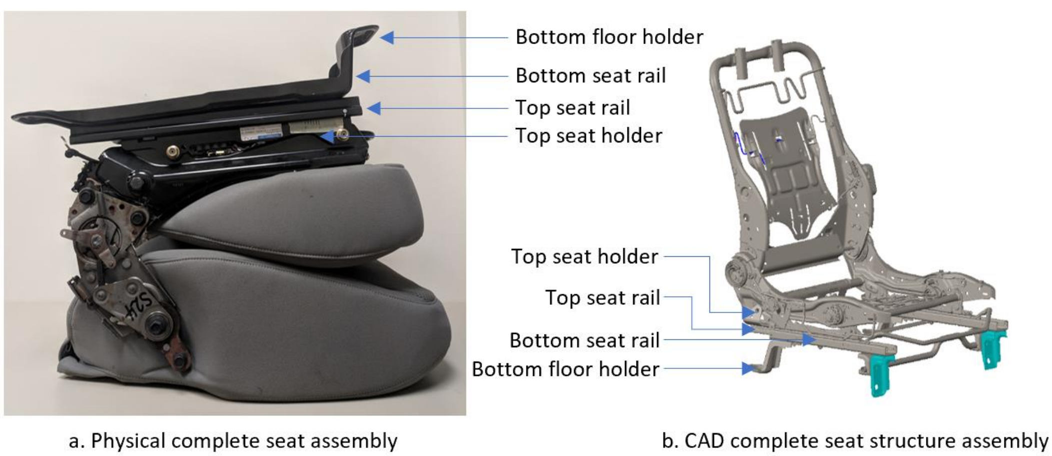

Figure 1. Complete physical/CAD seat labelled with seat rail assembly parts[4]

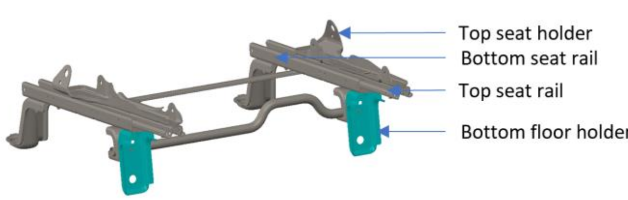

Figure 2. Extracted seat rail assembly from the complete seat assembly[4]

Operating Conditions

Simulation, is done with two operating cases, one with full seat in the full-back position, and other with the seat in the full-front position. Figures 3a and 3b show both the positioned seat rails, which are taken in to the study for simulation.

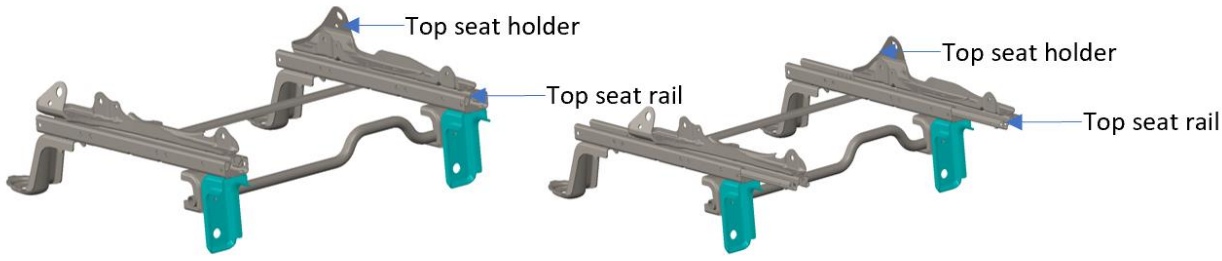

Figure 3. Top seat holder and rail in full-back/front position[4]

Materials Considered

Analysis is carried for the stress, displacement, strain, fatigue, and vibration with materials such as alloy steel (high-strength steel)[1], 6063 aluminum alloy[1], multi-materials[1] (alloy steel + 6063 aluminum alloy) is used. The material properties used in this analysis are tabulated in Tables 1 and 2.

Table 1 . Alloy Steel Properties[1]

Yield strength:	6.20422e+008 N/m^2
Tensile strength:	7.23826e+008 N/m^2
Elastic modulus:	2.1e+011 N/m^2
Poisson's ratio:	0.28
Mass density:	7700 kg/m^3
Shear modulus:	7.9e+010 N/m^2
Thermal expansion coefficient:	1.3e-005 /Kelvin

Table 2. 6063 Aluminum Alloy Properties[1]

Yield strength:	2.4e+008 N/m^2
Tensile strength:	2.55e+008 N/m^2
Elastic modulus:	6.9e+010 N/m^2
Poisson's ratio:	0.33
Mass density:	2700 kg/m^3
Shear modulus:	2.58e+010 N/m^2
Thermal expansion coefficient:	2.34e-005 /Kelvin

Boundary Conditions

Boundary conditions are defined by fixing the faces of the seat rail bottom mounting points to the vehicle floor body. The remaining sub assembly in the seat rail are carefully mated and defined with their contact sets of each sub assembly parts. Figures 4a and 4b show the fixed boundary conditions in the mounting points of the seating rail which are fixed to the vehicle floor body.

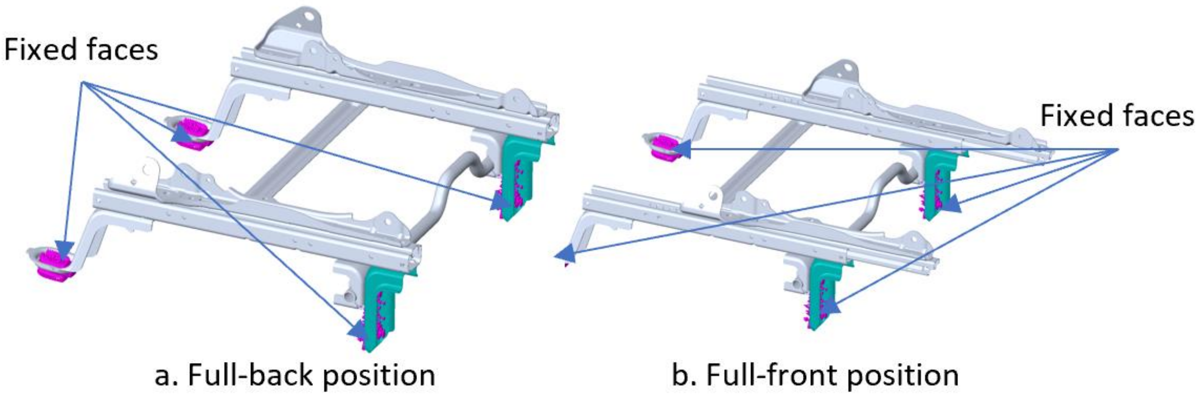

Figure 4. Fixed faces for full-back/front position[4]

External Loads

The weight of the full frame assembly above the seat rail is 10.88 kgs. (24 lbs.), and the passenger sitting on the seat is considered to have the weight of 100 kgs. (220.46 lbs.). Therefore in this analysis the total force on the top of the seat rail assembly acting through the seat mounting points is 110.88 kgs. (244.46 lbs.) which is equivalent to the force of 1088 N (with passenger). The loaded seat rail are shown in the Figures 5a and 5b.

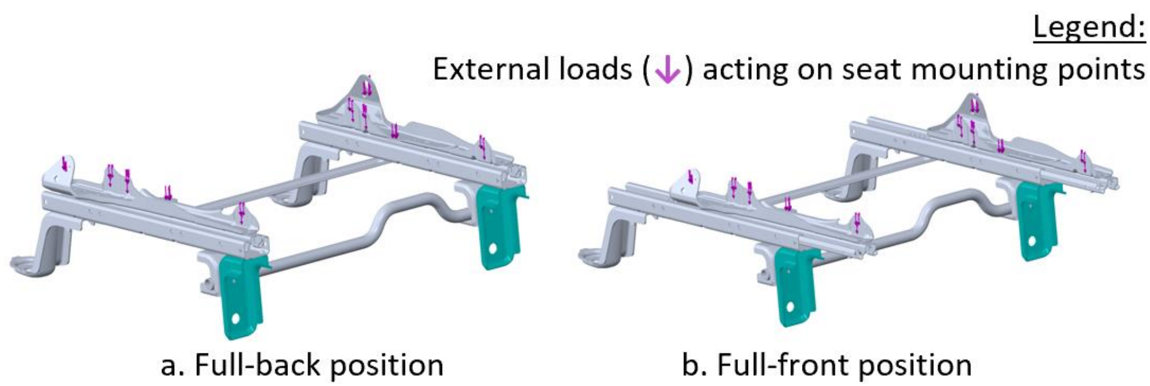

Figure 5. External loads for full-back/front position[4]

Mesh Model

The complete seat rail assembly is then meshed with the tetrahedral elements having the very high quality elements. The meshed results and information are tabulated in Tables 3 and 4 and also shown in Figures 6a, 6b, and 7.

Table 3. Mesh Information of Full-Back Position

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points	4 Points (Tetrahedral elements)
Maximum element size	21.1237 mm
Minimum element size	4.22474 mm
Mesh Quality	High
Total Nodes	306604
Total Elements	149953

Table 4. Mesh Information of Full-Front Position

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points	4 Points (Tetrahedral elements)
Maximum element size	21.1237 mm
Minimum element size	4.22474 mm
Total Nodes	306853
Total Elements	150038

a. Full-back position b. Full-front position

Figure 6. Meshed result of full-back/front position[4]

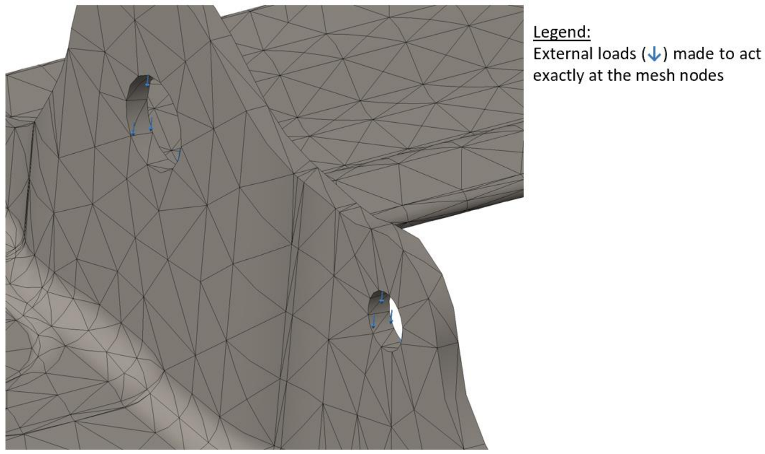

Figure 7. Meshed part showing loads acting on its nodes[4]

Solver Settings, Analysis, and Results

More accurate bonding option was selected in the SolidWorks solver settings option. The results for the seating rail assembly is simulated for 6 different cases, 3 for full-back position and 3 for full-front position. Each case is solved for stress, displacement, and strain using Alloy Steel, 6063 Aluminum Alloy, and Multi-Material (Steel+6063 Aluminum) as shown in Figures 8 to 13.

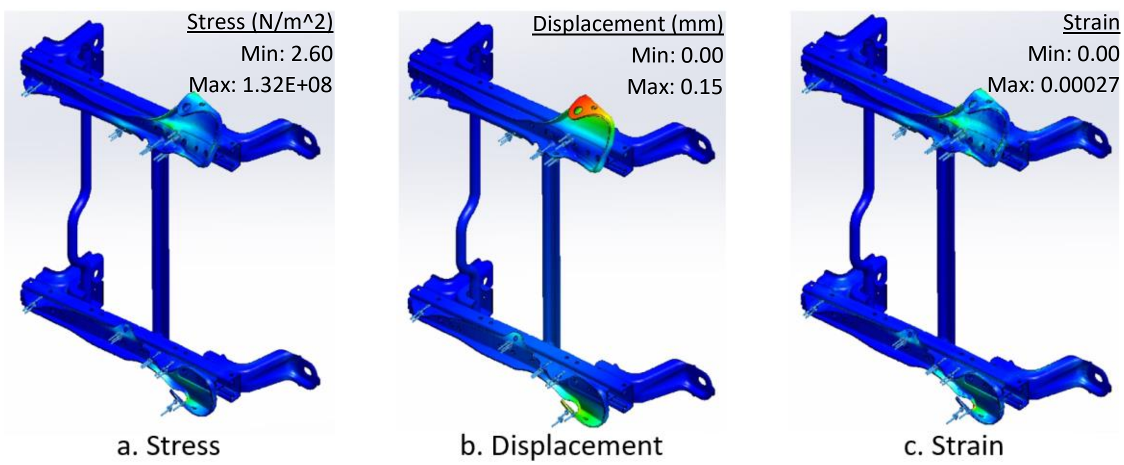

Figure 8. Full-back position: 1088 N of force in alloy steel[4]

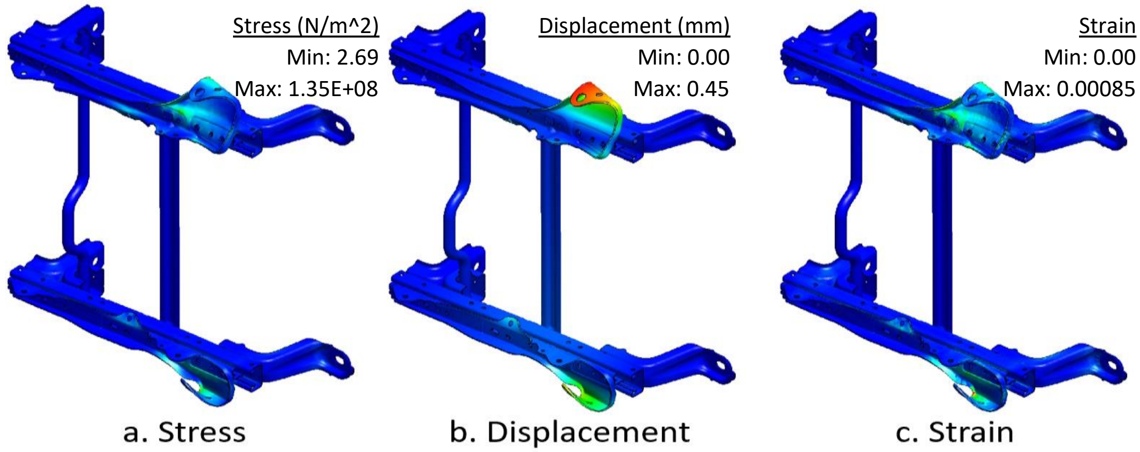

Figure 9. Full-back position: 1088 N of force in 6063 aluminum alloy[4]

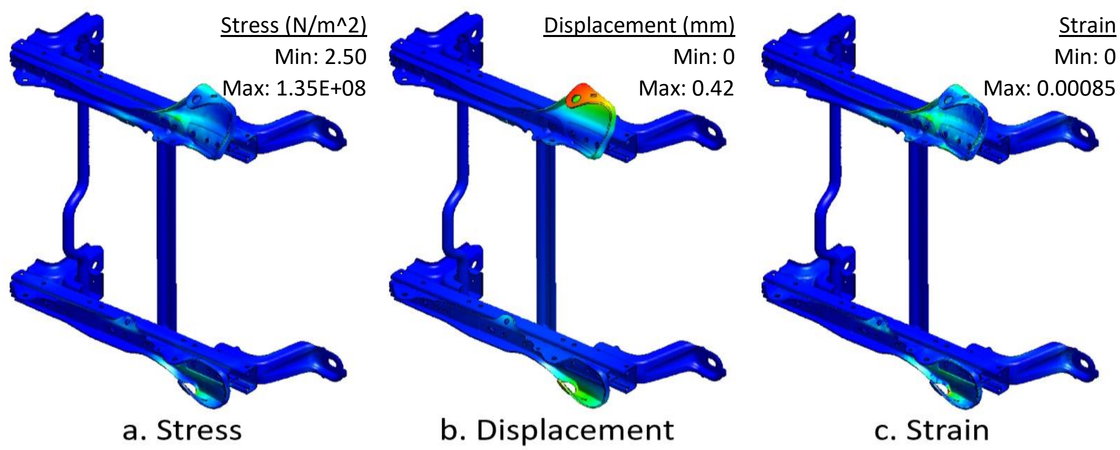

Figure 10. Full-back position: 1088 N of force in multi-material (alloy steel+6063 aluminum alloy)[4]

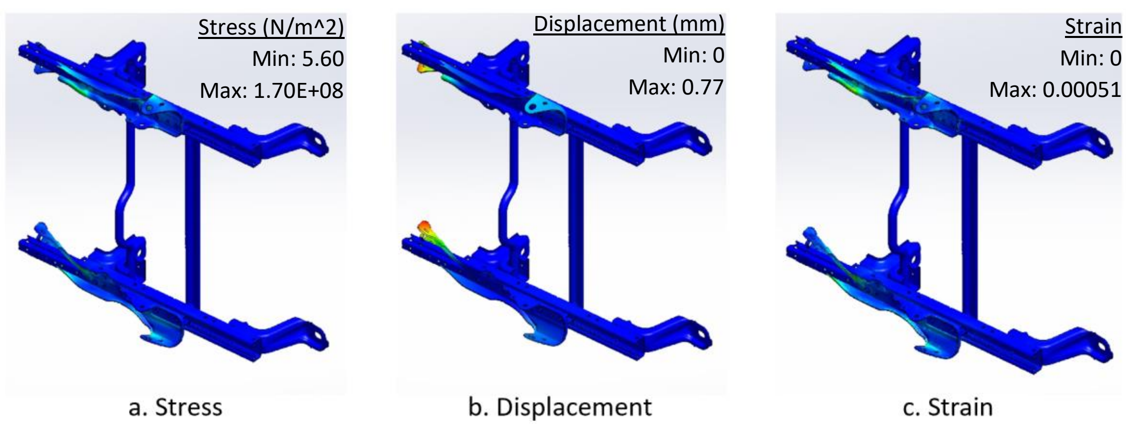

Figure 11. Full-front position: 1088 N of force in alloy steel[4]

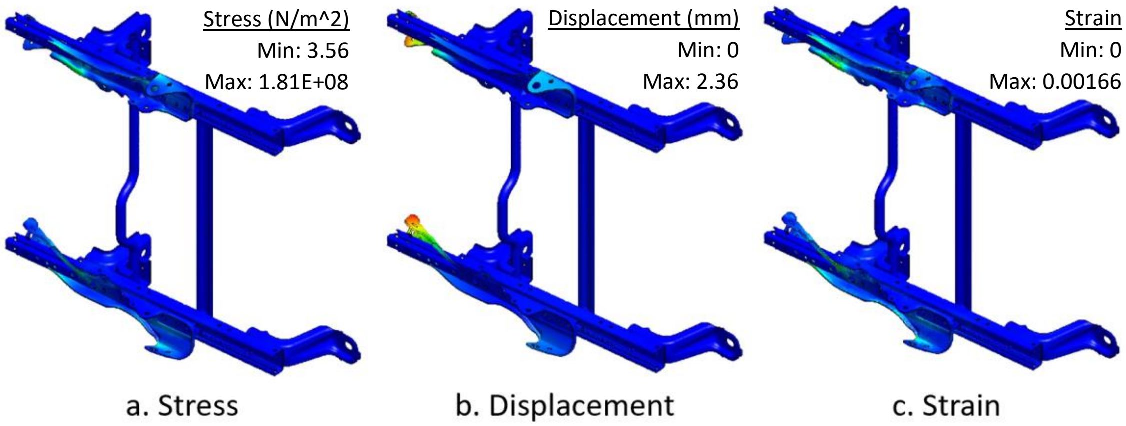

Figure 12. Full-front position: 1088 N of force in 6063 aluminum alloy [4]

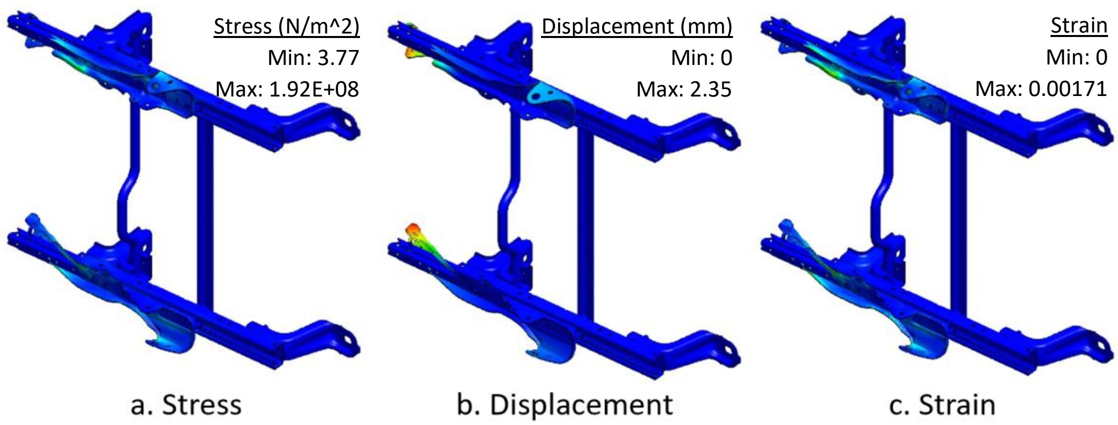

Figure 13. Full-front position: 1088 N of force in multi-material (alloy steel+6063 aluminum alloy)[4]

Table 5. Material with the corresponding Stress, Displacement, and Strain

Seat Position	**Static Load (N)**	**Case**	**Material**	**Stress (N/m^2)**		**Displacement (mm)**		**Strain**	
				Min	**Max**	**Min**	**Max**	**Min**	**Max**
Full Back	1088	1	Alloy Steel	2.60	1.32E+08	0	0.15	0	0.00027
		2	6063 Aluminum Alloy	2.69	1.35E+08	0	0.45	0	0.00085
		3	Multi-Material (Alloy Steel+6063 Aluminum Alloy)	2.50	1.35E+08	0	0.42	0	0.00085
Full Front		4	Alloy Steel	5.60	1.70E+08	0	0.77	0	0.00051
		5	6063 Aluminum Alloy	3.56	1.81E+08	0	2.36	0	0.00166
		6	Multi-Material (Alloy Steel+6063 Aluminum Alloy)	3.77	1.92E+08	0	2.35	0	0.00171

From the result summary of Figures 8 to 13 which are listed in the table 5, it is found that the worst situation scenario is for case-5, 6063 aluminum alloy material with the maximum displacement of 2.36 mm and stress of 181 MPa. The ultimate tensile strength of this 6063 aluminum alloy material is 255 MPa, and therefore the factor of safety is found to be 1.41 from (255 MPa divided by 181 MPa) under the load of 1088 N with the full front seat position.

Now, this case-5 is analyzed further for durability (fatigue) with the SolidWorks, the number of cycles are considered as 1000 which creates the repeated maximum stress of 181 MPa over the seat rail assembly. Therefore, the damage obtained for this durability is 32.06%, and the 2.36 mm displacement is found to occur at the cycle number of 3119. These are shown in Figures 14 to 16.

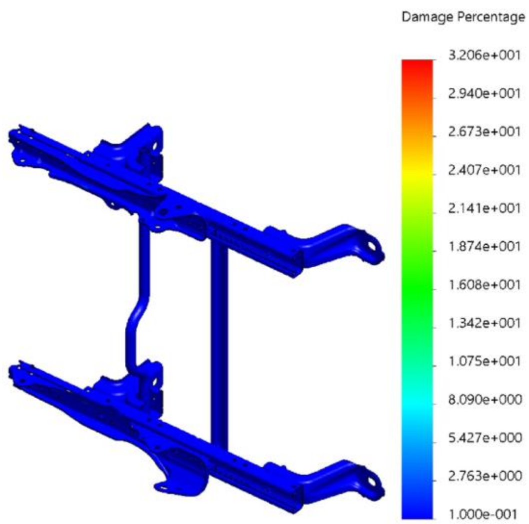

Figure 14. Damage percentage: 1088 N for full-front 6063 aluminum alloy[4]

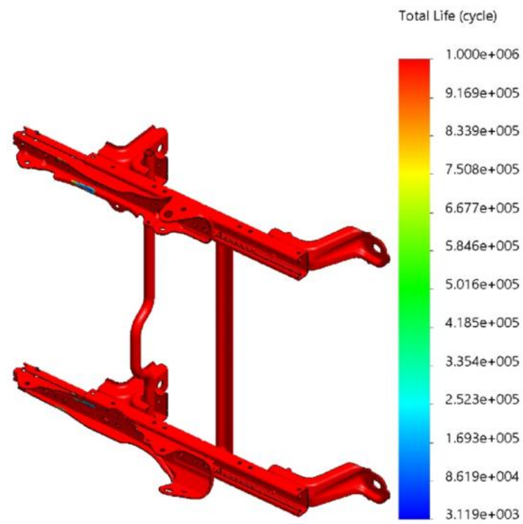

Figure 15. Total life (cycle): 1088 N for full-front 6063 aluminum alloy[4]

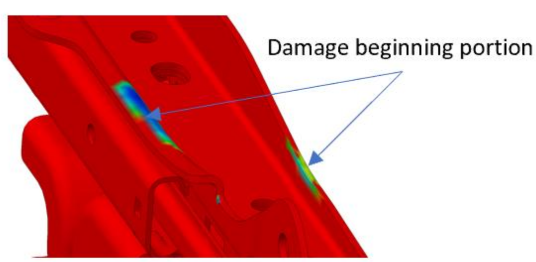

Figure 16. Cycle 3119: Damage Starts to Begin[4]

Having found the damage beginning region, vibration analysis is now performed on that particular top seat holder to calculate the resonant frequencies for 5 mode shapes. These 5 mode shapes resulted in the various bending and twisting profiles of the top seat holder structure as shown in the figures 17 to 21.

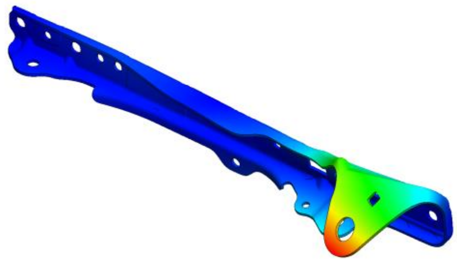

Figure 17. Mode 1: 465.16 Hz of Resonant Frequency

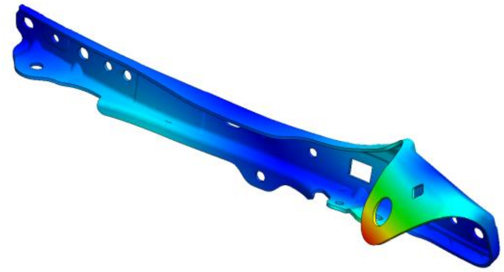

Figure 18. Mode 2: 843.43 Hz of Resonant Frequency

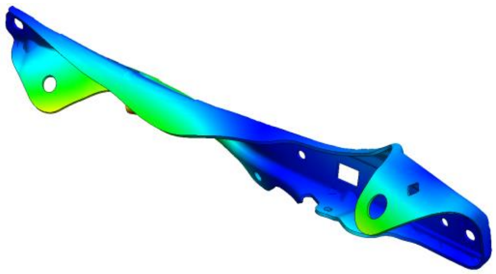

Figure 19. Mode 3: 884.07 Hz of Resonant Frequency

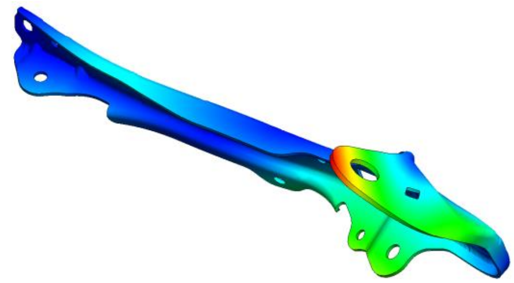

Figure 20. Mode 4: 1077.2 Hz of Resonant Frequency

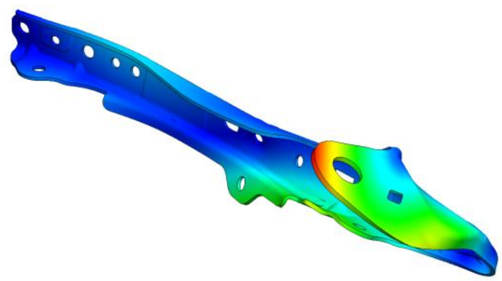

Figure 21. Mode 5: 1124 Hz of Resonant Frequency

Design Optimization

For the damage start portion found through the durability (fatigue) analysis, design optimization is now carried out. Through this optimization, the area is made robust at the damage start point, by joining an extra structure called 'seat structure tablet' to the top seat holder, as shown in Figures 22a, 22b, and 23.

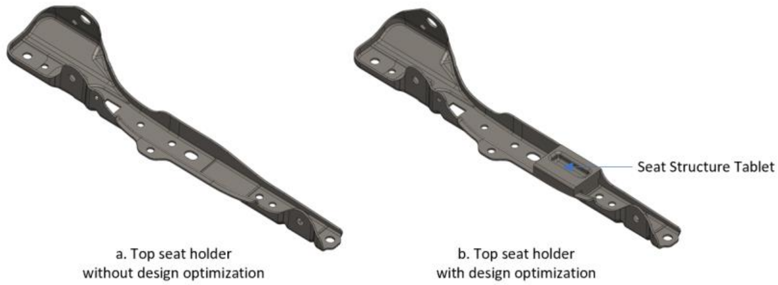

Figure 22. Newly designed-seat structure tablet on the top seat holder[4]

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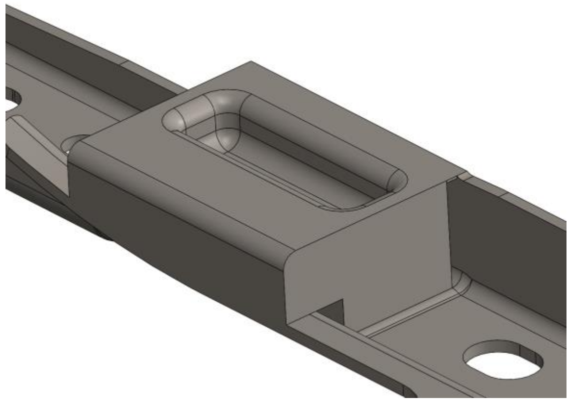

Figure 23. Zoomed view of seat-structure tablet[4]

Now this optimized design of seat rail assembly having the seat structure tablet is simulated again (Figure 24) for the case-6 with 6063 aluminum alloy material, here the maximum displacement is found to be 1.97 mm and stress is 168 MPa. The ultimate tensile strength of this 6063 aluminum alloy material is 255 MPa, and therefore the factor of safety is found to be 1.52 from (255 MPa/168 MPa) under the load of 1088 N with the full front seat position, which improved from 1.41 without the seat structure tablet.

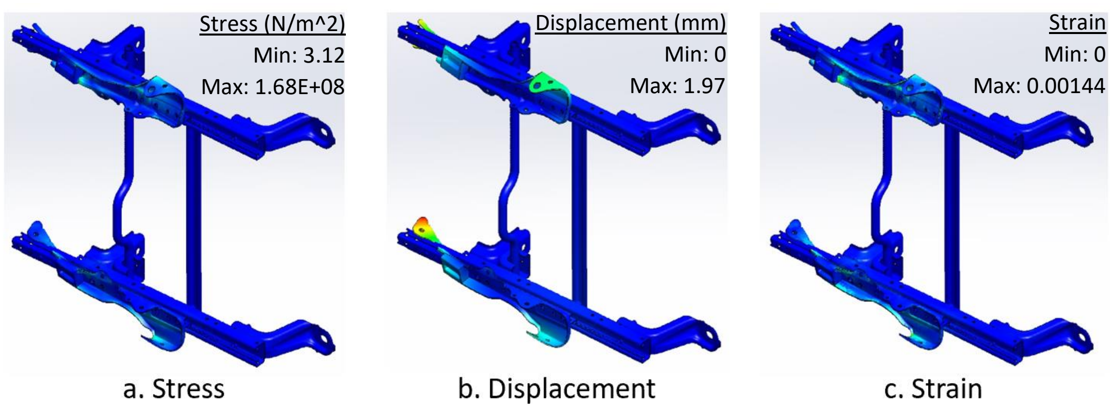

Figure 24. With design optimization for full-front position: 1088 N of force in 6063 aluminum alloy

The respective damage percentage is reduced from 32.06 (Figure 14) to 24.13 (Figure 25) and the life cycle of the seating rail got increased from 3119 cycles (Figure 15) to 4144 cycles (Figure 26). Also, with this new design, the damage beginning portion is reduced greatly as in the Figure 27 when compared with Figure 16.

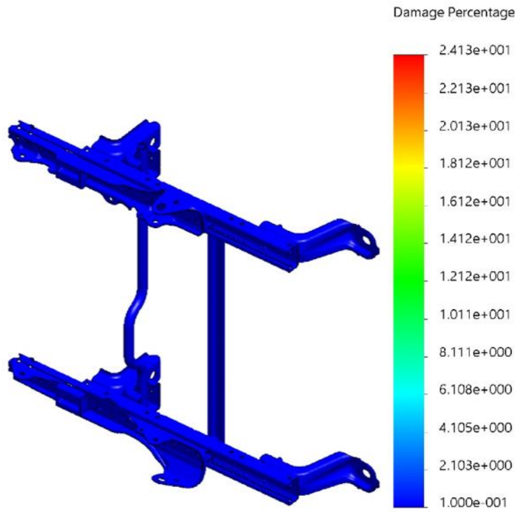

Figure 25. Damage percentage: 1088 N
for full-front aluminum 1060 alloy[4]

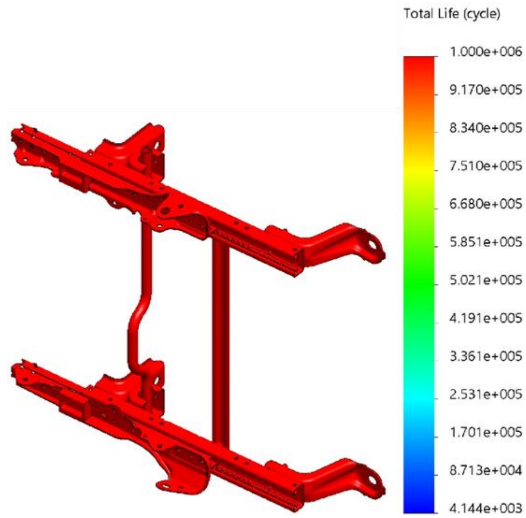

Figure 26. Total life (cycle): 1088 N
for full-front aluminum 1060 alloy[4]

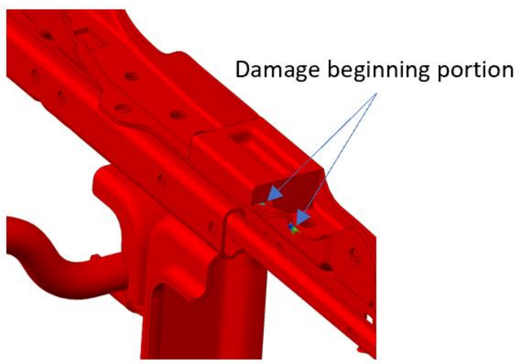

Figure 27. Cycle 4144: Damage Starts to Begin[4]

Now to confirm the working of seat structure tablet on the top seat holder, the vibration analysis is done for the optimized design of the top seat holder, figure 28 to 32, shows the improvement of resonant frequencies when compared with Figures 17 to 21, with the maximum increment of 94.27 Hz for the Mode 5. Thus confirming the improvement by the optimized design of the seat structure tablet on the top seat holder.

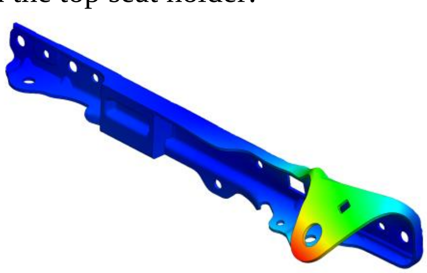

Figure 28. Mode 1: 470.99 Hz of Resonant Frequency

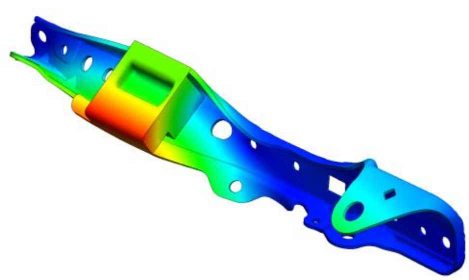

Figure 29. Mode 2: 890.03 Hz of Resonant Frequency

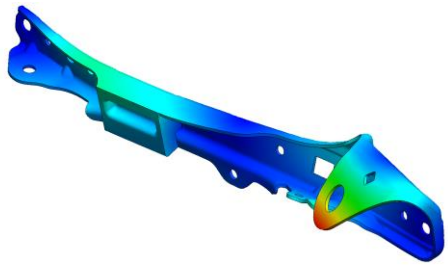

Figure 30. Mode 3: 902.89 Hz of Resonant Frequency

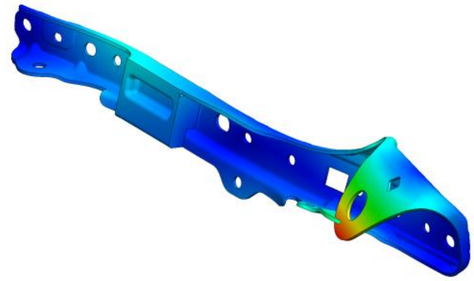

Figure 31. Mode 4: 1153.81 Hz of Resonant Frequency

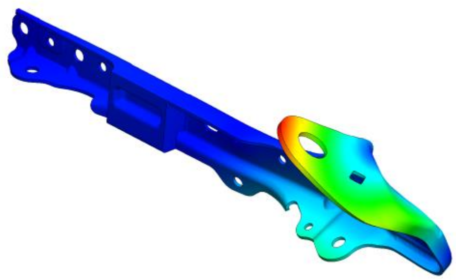

Figure 32. Mode 5: 1218.27 Hz of Resonant Frequency

Conclusion

In this paper the complete seat rail assembly is analyzed by performing design optimization and finite element analysis (FEA) for structural simulation and durability of an example automotive seat rail structures using multi-materials in SolidWorks. The result is that, the life cycle of the seating rail is made better by the new design, after joining the extra structure called 'seat structure tablet' to the top seat holder. This improved the life cycle from 3119 cycles to 4144 cycles, an increase of 32.86%. Also this reduces the damage from 32.06% to 24.13% along with the improvement of resonant frequency by 94.27 Hz, from 1124 Hz to 1218.27 Hz and factor of safety from 1.41 to 1.52.

Acknowledgment

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References

1. Lightweight solutions for seat structures: https://www.prnewswire.com/news-releases/adient-unveils-lightweight-solutions-for-seat-structures-300582496.html
2. Jaranson, J. and Ahmed, M., "MMLV: Lightweight Interior Systems Design," SAE Technical Paper 2015-01-1236, 2015. DOI: https://doi.org/10.4271/2015-01-1236

3. Wainwright, J., Verellen, L., and Glance, P., "Integrated Restraint Seat With Composite Frame," SAE Technical Paper 940218, 1994. DOI: https://doi.org/10.4271/940218
4. GrabCAD seating CAD data: https://grabcad.com/library/frame-of-car-seat-1
5. Yabe, K., Inagaki, T., and Kondo, T., "Adoption of Floating Seat in a Vehicle to Reduce Seat Vibration," SAE Technical Paper 2015-01-1122, 2015. DOI: https://doi.org/10.4271/2015-01-1122
6. Blaisdell, D., Levitt, A., and Varat, M., "Automotive Seat Design Concepts for Occupant Protection," SAE Technical Paper 930340, 1993. DOI: https://doi.org/10.4271/930340
7. Park, S., Subramaniyam, M., Kim, S., Kim, T. et al., "Enhancement of Automotive Seating Comfort using Double-Wall 3D Air Mat Cushion," SAE Technical Paper 2016-01-1430, 2016. DOI: https://doi.org/10.4271/2016-01-1430
8. Bronczyk, H., Kolich, M., and Cote, M., "Complete Seat Load Deflection Testing Methodologies," SAE Technical Paper 2017-01-1391, 2017, DOI: https://doi.org/10.4271/2017-01-1391
9. Katsuraki, M., Hanai, T., Takatsuji, K., Suwa, A. et al., "Development of the New Generation Ergonomic Seat Based on Occupant Posture Analysis," SAE Technical Paper 950140, 1995. DOI: https://doi.org/10.4271/950140