UD FSAE Front Impact Analysis

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1 Introduction

We look to preform an analysis on the front aerodynamic devices and the front impact attenuator to ensure that it passes all rules needed for competition. Our team uses the standard impact attenuator that was bought from "BSCI Energy Impact Systems." In years past we have not done a aerodynamics package and thus have not needed to worry about having additional non-crushable objects in the front of the impact attenuator. Thus for this year, as per Rule T3.21.6, we need to preform an analysis on either the mounting or the bolts. We look to preform an analysis to find the force experience by the designed mounting bolt locations and then select the bolt that would ensure that the peak load is not reached in a frontal impact.

2 Standard Impact Attenuator

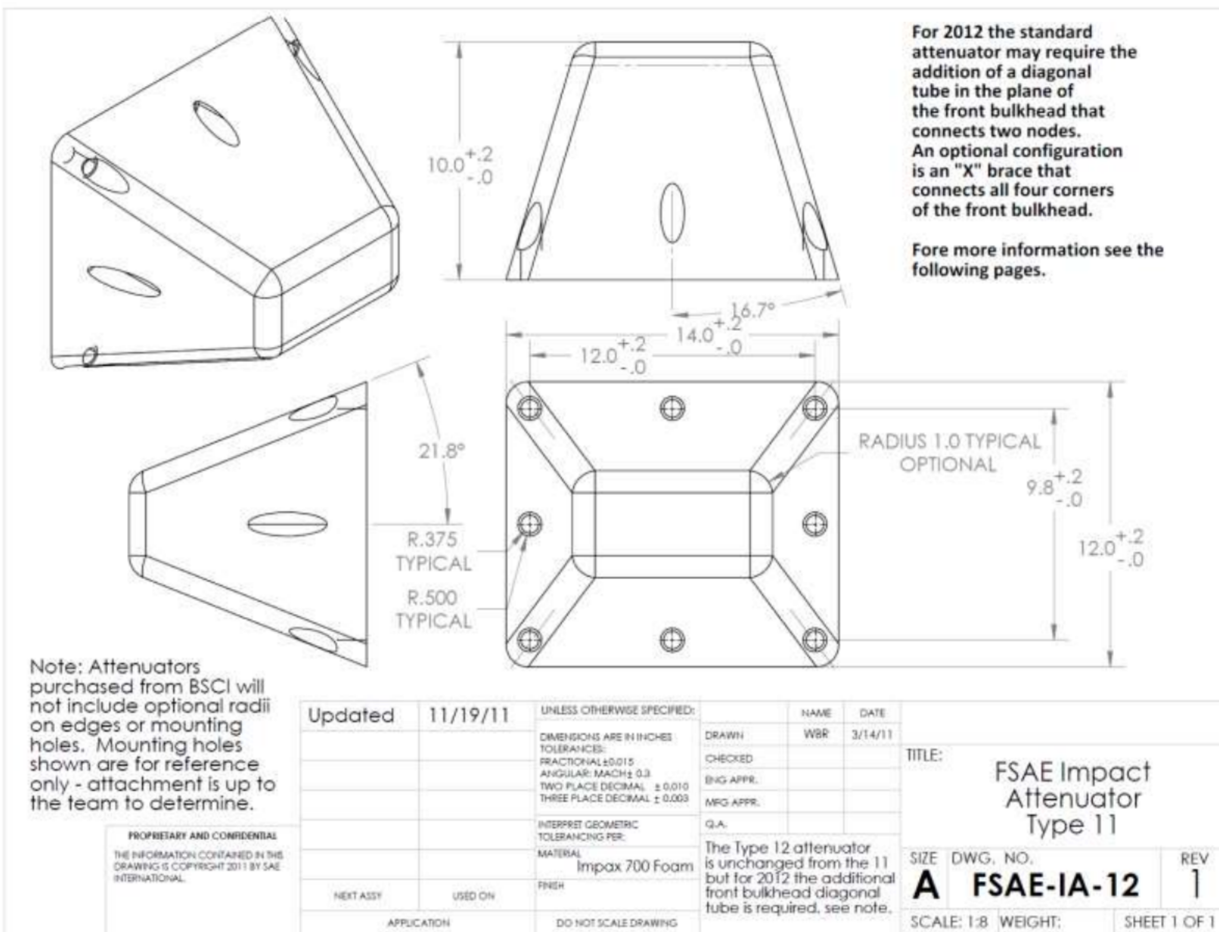


Figure 1: Seen above is the drawing for the standard impact attenuator specified by the 2017 rules. This impact attenuator has not changed since 2013 and uses high energy absorbing foam.

See above, is the standard impact attenuator that will be used by the team. It will be secured following rule T3.20.4 with eight, grade 8.8 bolts. This method, compared to gluing it with epoxy, allows for removable during transport and will prevent damage being done to the foam.

3 Problem Formulation

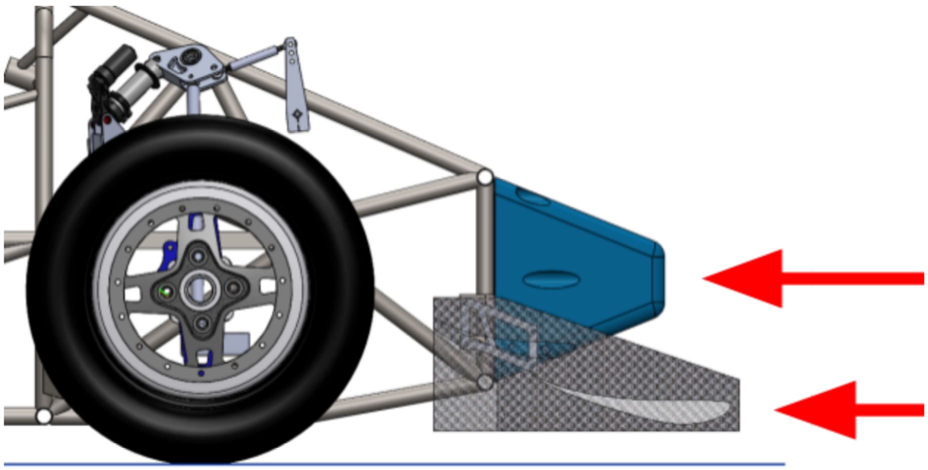


Figure 2: Above is the impact scenario that we will be preforming analysis on. The force will be applied to the front of the vehicle to both the wing and standard impact attenuator.

The FSAE rules specify the assumptions that should be made for the crash scenario. We have a 300kg vehicle that needs to have an average deceleration of 20g's, with a peak deceleration of 40g's. We can preform the following simple calculation to find the specified 120kN of maximum force exerted:

$$\begin{aligned} F &= m * a \\ &= (car\ mass) * (peak\ g's) * (gravity) \\ &= (300kg) * (40g's) * (9.81m/s^2) \\ &= 117kN \approx 120kN \end{aligned} \tag{1}$$

We know from rule T3.21.6 that the standard impact has a max force of 95kN. We want preform analysis in the worst-case scenario, and thus we assume that both the front wing and the standard impact attenuator are being struck at the same time instant. This means that the standard impact attenuator will be taking 95kN from the total max of 120kN at this time instant. Thus the mounting bolts of the wing cannot exceed 25kN peak force. Knowing the force we can now determine the geometry of the system. We define everything in reference to the origin of the mount and get the following values:

Table 1: Geometry taken from the solidworks model of the front aerodynamic wing assembly. All distances are denoted in meters.

Description	**X Direction (m)**	**Y Direction (m)**
Mount Bolt Hole 1	0.00762	0.06858
Mount Bolt Hole 2	0.00762	0.00762
Location of Force on Wing	0.41630	-0.12192

4 Bolt Analysis

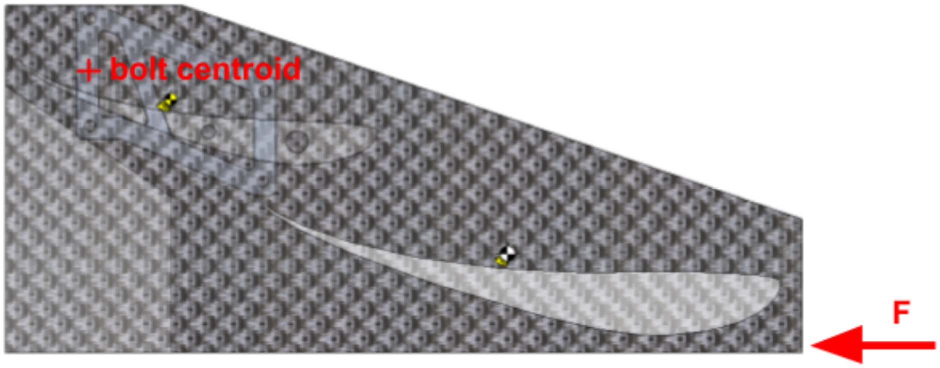


Figure 3: We can see above where we assume the force is applied, and the location of the bolts centroid.

Following the approach by *Budynas and Nisbett* in *Shigley's Mechanical Engineering Design, Ninth Edition*, we first calculate the location of the bolt centroid through symmetry. After calculating the centroid we find the resultant distance for each mounting hole and the force on the wing. Add dimensions where taken from the solidworks model of the front wing assembly.

Description	**X Direction (m)**	**Y Direction (m)**
Bolt Centroid	0.00762	0.03810

$$resultant = (mount\ hole\ location) - (centroid) \tag{2}$$

Description	**X Direction (m)**	**Y Direction (m)**
Mount Bolt Hole 1 (r_1)	0.00000	0.03048
Mount Bolt Hole 2 (r_2)	0.00000	-0.03048
Location of Force on Wing (r_f)	0.40869	-0.16002

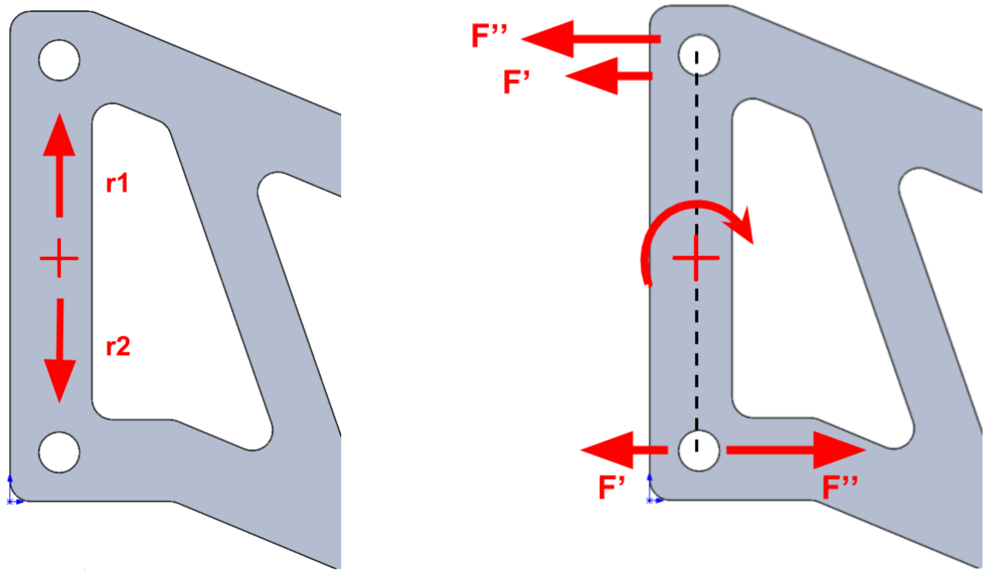


Figure 4: The distance diagram of the calculated resultants (left). Force diagram of the forces acting on the bolt holes (right)

The total force (F) applied to the wing is the 25kN at peak load. Since there are two mounts holding the front wing up on either side of the car we half this total force to get an applied force of 12.5kN on a single mount. We can now calculate the primary shear caused by this force on a single mount

$$F' = -\frac{F}{num\ bolts} = -\frac{12.5kN}{2\ bolts} = -6.25kN \tag{3}$$

We can now calculate the secondary shear caused by the moment of the force being offset vertically. The moment at the bolt centroid is the following:

$$M = F * r_f = (12.5kN) * (-0.16002) = -2kNm \tag{4}$$

Now we can calculate the secondary shear caused by this moment. Give by the weighted distance fraction of shear that each bolts gets, is given as the following for each bolt in the mount:

$$F_1'' = -\frac{M * r_1}{(r_1)^2 + (r_2)^2} = -32.8kN \tag{5}$$

$$F_2'' = -\frac{M * r_2}{(r_1)^2 + (r_2)^2} = 32.8kN \tag{6}$$

Taking the combined magnitude of these resulting forces, we have the following for the total force on bolt 1 and bolt 2.

$$\boxed{F_1 = -39.0kN \qquad F_2 = 26.6kN} \tag{7}$$

Now that we have the magnitude of shear force experience by the bolt, we can compute the average shear stress felt in each bolt. To do so we need the cross sectional area that the force is being applied through. We will be using fully threaded fine thread bolts, and thus can attain the cross sectional areas of the smallest diameter in the bolt. See Appendix A for the full table that was referenced.

$$\tau = \frac{F}{A_{shear}} \tag{8}$$

Bolt Name	Bolt Area Fine (in^2)	Bolt 1 Shear (ksi)	Bolt 2 Shear (ksi)
1/4-28	0.03260	269.37	183.17
5/16-24	0.05240	167.59	113.96
3/8-24	0.08090	108.55	73.81

We can now select what grade bolt we should use for a given size. We define the max allowable shear stress through the bolt as 0.577 times the yield strength as specified by distortion energy theory. Using the table in Appendix B we have the following for each bolt:

Bolt Name	Yield Strength (ksi)	Shear Strength (ksi)	Max SAE Grade
1/4-28	130	75.0	Grade 8
5/16-24	130	75.0	Grade 8
3/8-24	115	66.4	Grade 7

Thus, to conclude, the design team has selected the use of four fully threaded 1/4-28 bolts that are grade 8. These bolts will fail at a lower force magnitude then the maximum allowable force of 25kN. This ensures that the front wing element will **not** cause the maximum deceleration of 40g's.

Appendix A: Bolt Diameter Table

Table 8–2

Diameters and Area of Unified Screw Threads UNC and UNF*

		Coarse Series—UNC			Fine Series—UNF		
Size Designation	Nominal Major Diameter in	Threads per Inch N	Tensile-Stress Area A_t in^2	Minor-Diameter Area A_r in^2	Threads per Inch N	Tensile-Stress Area A_t in^2	Minor-Diameter Area A_r in^2
0	0.0600				80	0.001 80	0.001 51
1	0.0730	64	0.002 63	0.002 18	72	0.002 78	0.002 37
2	0.0860	56	0.003 70	0.003 10	64	0.003 94	0.003 39
3	0.0990	48	0.004 87	0.004 06	56	0.005 23	0.004 51
4	0.1120	40	0.006 04	0.004 96	48	0.006 61	0.005 66
5	0.1250	40	0.007 96	0.006 72	44	0.008 80	0.007 16
6	0.1380	32	0.009 09	0.007 45	40	0.010 15	0.008 74
8	0.1640	32	0.014 0	0.011 96	36	0.014 74	0.012 85
10	0.1900	24	0.017 5	0.014 50	32	0.020 0	0.017 5
12	0.2160	24	0.024 2	0.020 6	28	0.025 8	0.022 6
$\frac{1}{4}$	0.2500	20	0.031 8	0.026 9	28	0.036 4	0.032 6
$\frac{5}{16}$	0.3125	18	0.052 4	0.045 4	24	0.058 0	0.052 4
$\frac{3}{8}$	0.3750	16	0.077 5	0.067 8	24	0.087 8	0.080 9
$\frac{7}{16}$	0.4375	14	0.106 3	0.093 3	20	0.118 7	0.109 0
$\frac{1}{2}$	0.5000	13	0.141 9	0.125 7	20	0.159 9	0.148 6
$\frac{9}{16}$	0.5625	12	0.182	0.162	18	0.203	0.189
$\frac{5}{8}$	0.6250	11	0.226	0.202	18	0.256	0.240
$\frac{3}{4}$	0.7500	10	0.334	0.302	16	0.373	0.351
$\frac{7}{8}$	0.8750	9	0.462	0.419	14	0.509	0.480
1	1.0000	8	0.606	0.551	12	0.663	0.625
$1\frac{1}{4}$	1.2500	7	0.969	0.890	12	1.073	1.024
$1\frac{1}{2}$	1.5000	6	1.405	1.294	12	1.581	1.521

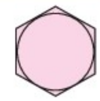
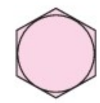
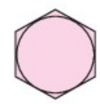
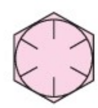
*This table was compiled from ANSI B1.1-1974. The minor diameter was found from the equation $d_r = d - 1.299\,038p$, and the pitch diameter from $d_p = d - 0.649\,519p$. The mean of the pitch diameter and the minor diameter was used to compute the tensile-stress area.

Figure 5: Table taken from *Budynas' and Nisbett's* textbook (*Shigley's Mechanical Engineering Design, Ninth Edition*).

Appendix B: Bolt Grade Table

Table 8–9

SAE Specifications for Steel Bolts

SAE Grade No.	Size Range Inclusive, in	Minimum Proof Strength,* kpsi	Minimum Tensile Strength,* kpsi	Minimum Yield Strength,* kpsi	Material	Head Marking
1	$\frac{1}{4}$–$1\frac{1}{2}$	33	60	36	Low or medium carbon	
2	$\frac{1}{4}$–$\frac{3}{4}$	55	74	57	Low or medium carbon	
	$\frac{7}{8}$–$1\frac{1}{2}$	33	60	36		
4	$\frac{1}{4}$–$1\frac{1}{2}$	65	115	100	Medium carbon, cold-drawn	
5	$\frac{1}{4}$–1	85	120	92	Medium carbon, Q&T	
	$1\frac{1}{8}$–$1\frac{1}{2}$	74	105	81		
5.2	$\frac{1}{4}$–1	85	120	92	Low-carbon martensite, Q&T	
7	$\frac{1}{4}$–$1\frac{1}{2}$	105	133	115	Medium-carbon alloy, Q&T	
8	$\frac{1}{4}$–$1\frac{1}{2}$	120	150	130	Medium-carbon alloy, Q&T	
8.2	$\frac{1}{4}$–1	120	150	130	Low-carbon martensite, Q&T	

*Minimum strengths are strengths exceeded by 99 percent of fasteners.

Figure 6: Table taken from *Budynas' and Nisbett's* textbook (*Shigley's Mechanical Engineering Design, Ninth Edition*).

Appendix C: FSAE Rules

T3.20.2 The Impact Attenuator must be

- At least 200 mm (7.8 in) long, with its length oriented along the fore/aft axis of the Frame.
- At least 100 mm (3.9 in) high and 200 mm (7.8 in) wide for a minimum distance of 200 mm (7.8 in) forward of the Front Bulkhead.
- Attached securely to the Anti-Intrusion Plate or directly to the Front Bulkhead.

T3.20.3 The Anti-Intrusion Plate must

- Be a 1.5 mm (0.060 in) solid steel or 4.0 mm (0.157 in) solid aluminum plate, or an approved alternative as per T3.38.
- Attach securely and directly to the Front Bulkhead.
- Have an outer profile must extend at least to the centerline of the Front Bulkhead tubes on all sides (note that this is for welded attachment of the impact plate).

T3.20.4 Attaching the Impact Attenuator

- Welding, where the welds are either continuous or interrupted. If interrupted, the weld/space ratio must be at least 1:1. All weld lengths must be greater than 25 mm (1 in).
- Bolted joints, using a minimum of eight (8) 8 mm Metric Grade 8.8 (5/16" SAE Grade 5) bolts with positive locking. The distance between any two bolt centers must be at least 50 mm (2 in).

T3.21.2 Impact Attenuator Data Requirement

- Teams using the standard Impact Attenuator are not required to submit test data with their IAD Report, but all other requirements must be included. In addition, photos of the actual attenuator and evidence that it meets the design criteria in Appendix T-3 must be appended to the report.

T3.21.6 Impact Attenuator Data Requirement

Teams with any non-crushable object(s) that do not meet the requirements of T3.22.2(c) must prove the combination of their Impact Attenuator Assembly and non-crushable object(s) do not exceed the peak deceleration of 40g (rule T3.21.2). Any of the following methods may be used to prove the design does not exceed 120kN:

(a) Physical testing of the Impact Attenuator Assembly including any required non-crushable object(s). See fsaeonline.com FAQs for an example of the structure to be included in the test for wings and wing mounts

(b) Combining the peak force from physical testing of the Impact Attenuator Assembly with the failure load for the mounting of the non-crushable object(s), calculated from fastener shear and/or link buckling.

(c) Combining the "standard" Impact Attenuator peak load of 95kN with the failure load for the mounting of the non-crushable object(s), calculated from fastener shear and/or link buckling.