2015-2016 SAE Baja

By

Fahad Alajmi, Sean Collins, Peng Li,

Auston Solway, Maximilian Whipple and Jingyuan Zhang

Section 3 Team 13

Final Report

Document

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Northern Arizona University

Flagstaff, AZ 86011

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1. Introduction

1.1 Client and Background

The Society of Automotive Engineers (SAE) club at NAU is part of the SAE International organization, which is an organization dedicated to students interested in automotive or aeronautical career fields. The club, advised by Dr. John Tester is interested in competing in an SAE competition but does not have an operational vehicle.

1.2 Project Needs and Goals

The Baja vehicle to be finished must be operational, reliable and satisfies all competition rules. The goal of this project is to build an operational Baja vehicle through engineering practice and teamwork. This project is to help students develop the professional skills such as communication ability and design experiences.

1.3 Project Objectives

There are many objectives of this project. The first object is to make sure the weight of the Baja vehicle is as light as possible. A lighter weight Baja will cause higher maximum velocity and save the fuel. The second objective is quickness, the Baja needs to have a high acceleration. The third objective is the safety, which is measured as factor of safety. This objective is mainly decided by the reliability of frame. The frame of Baja vehicle must have the ability to withstand a powerful impact without break. The fourth objective is the endurance, the Baja vehicle must have the ability to run for a long time without any fatigue issue occurs. The last objective is ergonomic cockpit, the Baja vehicle must have enough room for the driver, which means the driving space must be big and comfortable for the driver.

1.4 Project Constraints

There are 5 constraints for this project. The first constraint is that the frame must be less than 2 years old, which is required by the SAE Baja competition rules. If the frame is more than 2 years old, the team must build a new frame rather than use the old frame. The second constraint is that the Baja vehicle must have at minimum 2 forward gears and 1 reverse gear. The third constraint is about the dimensions, the length of vehicle must be less than 108 inch and the width must be less than 64 inch. The fourth constraint is about the weight, the weight of the Baja must be less than 800 pounds. The last constraint is about the engine, the engine must be a 10 horse-power Briggs and Stratton engine.

1.5 Issues from Last Year

These issues left from last semester have to be fixed and finished in this semester. The first issue is to verify the safety of the frame. This issues is mainly solved by the FEA software, and the team must make sure the factor of safety of frame is higher than the expectation. The second issues is the rear suspension, the allowed deflection of rear suspension is too much, and the team is going to limit the deflection in this semester. The third issues is the transmission, the shift fork's size in incorrect and must to be modified. The shift fork must be in the right size to be fixed on the shifting rod and works well. The fourth issue is the shifter, it is necessary for the team to design a shifting mechanism for the transmission. The last issue is the clutch, the clutch is interfered with the travel of the suspension and it could not be disengaged. The team must figure a way to solve this problem and make sure the clutch works well.

2. Function Diagram

The function diagram (figure 1) shows the correlation of different main parts of the Baja and the energy flow between those parts. From the diagram, energy flow in is provided by human, gasoline and battery power. The engine transfer the chemical energy gained from combusting gasoline into mechanical energy. After that, the energy goes into clutch, transmission, differential and finally the wheels. The wheels support the suspensions and the frame. In addition, the power provided by battery goes to reverse light and brake light which are used for informing others.

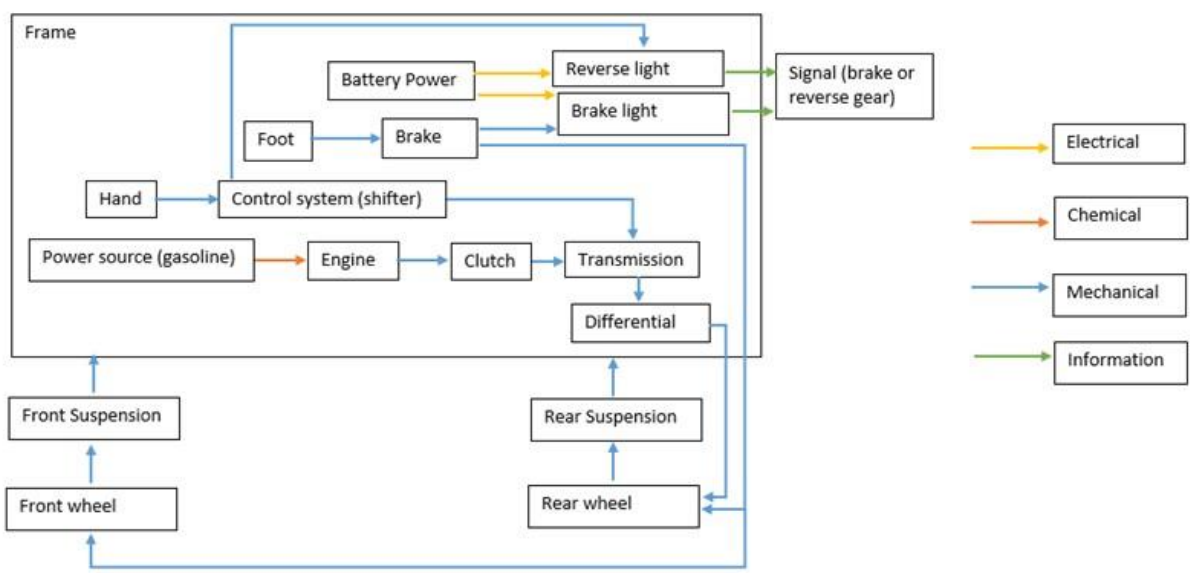

Figure 1: Functional Diagram

3. Criteria Analysis

When selecting important components to incorporate into the construction of the Baja, multiple criteria should be chosen for each component based on the part's functionality. These criteria should then be weighted based on their importance to the operation of the system. The overall weight of each criterion is then used for the final calculation of the decision matrix. When analyzing the criteria for each concept, the analytical hierarchy process was used, an example of this is shown in the tables below. Each group member individually rated criteria, this was done by deciding if the criteria in the row was more important than the criteria in the column, if so a whole numeric value from Table 1 was selected based on the objective opinion of each member. If it was determined that the column is more important than the row, a fraction was inserted into the cell. The final result is then normalized to express the weight of the criteria, the entire process is shown in Table 2. Since each group member analyzed the criteria for each concept, only the average weighted values for each subsection of criteria analysis are shown. Table 2 only demonstrates how each team member weighted the criteria.

Table 1: Criteria Preference Rating

Preference	Rating
Extremely Preferred	9
Very Strongly Preferred	7
Strongly Preferred	5
Moderately Preferred	3
Equally Preferred	1

Table 2: Example Analytical Hierarchy

Criteria	Durability	Main. /Repair	Weight	User Friendly	Cost	Total	Norm. Weight
Durability	1	7	3	1/5	3	14.20	0.28
Maint./Repair	1/7	1	1/5	1/3	3	4.68	0.09
Weight	1/3	5	1	3	1/5	9.53	0.18
User Friendly	5	3	1/3	1	1/7	9.48	0.18
Cost	1/3	1/3	5	7	1	13.67	0.27
Total	6.81	16.33	9.53	11.53	7.34	51.55	1.00

3.1 Rear Suspension

The team chose multiple criteria to analyze for the selection of a rear suspension for the Baja vehicle. In order for the vehicle to be competitive in a racing setting, multiple factors must be taken into account, the factors chosen for analysis are: length of travel, deflection, durability, cost, and maintenance/repair.

Length of travel in this context refers to the amount the rear suspension is able to move along the y-axis when combined with shock absorption. In race competitions such as the endurance race and suspension test, length of travel is an important factor because it helps to protect the safety of the driver and the vehicle from jarring impacts. Additionally, when traversing over uneven terrain, jumps, and drops, length of travel also affects the handling of the vehicle.

Deflection is another important factor to consider regarding suspension selection. Deflection refers to the maximum amount of movement in the x-axis. Since the transmission of power between the differential and the wheels occurs through CV axles, the amount of deflection should be as limited as possible. When too much deflection occurs in this system, the CV joints and the bearings that connect them to the transmission experience stresses unintended for their application, ultimately causing failure in the CV axle or the bearing connecting them to the transmission.

In the context of a racing environment, durability is measured in the amount of hours the suspension should be able to withstand constant abuse before critical failure occurs. Since the race involves traversing rough terrain for a long period of time, durability was chosen as an important factor for analysis. Another factor closely associated with durability is maintenance and repair, referring to the ideal amount of time required to fix a minor malfunction in the suspension during a race.

The final criterion for analysis is the cost associated for building the rear suspension. Cost takes into account the amount of money required to purchase materials and the labor involved in building the suspension.

Table 3 shows the average final weighted criteria for the suspension.

Table 3: Weighted Suspension Criteria

Criteria Weight	
Criteria	**Average Weight**
Travel	0.14
Deflection	0.13
Durability	0.37
Cost	0.12
Maint./Repair	0.24
Total	**1.00**

3.2 Clutch

Providing the transmission of power between the engine and the transmission, the clutch serves a very important role in the drivetrain system. The criteria chosen for analysis include: durability, maintenance/repair, starting torque, user friendly, and cost.

Similarly to the durability for suspension, durability in this context refers to the predicted amount of hours the clutch should be able to withstand before failure. Additionally, maintenance and repair also refers to the amount of time needed to replace components and get the clutch in working order during a race.

The next important criterion to analyze is the torque the clutch is able to withstand, especially when a vehicle is at a dead stop. If the output torque is too high when engaging with the transmission, the clutch could potentially break. Thus, determining a clutch that will withstand the required starting torque is necessary when purchasing.

One of the most limiting factors regarding clutches is the cost associated with the various types of clutches. Based on the type of clutch and the quality, will determine what kind of clutch will be reasonable to purchase, this is important due to the limited budget the team has access to.

The final criteria to analyze is how user friendly the clutch is, this limitation mostly applies to the driver. Depending on the clutch that is chosen will depend on the ease of use the user will experience when operating the clutch. In the setting of a race, when gear shifts occur often, this is important so that the driver does not stall the vehicle, causing the vehicle to stop mid-race.

Table 4 shows the group final weighted criteria for the clutch.

Table 4: Weighted Clutch Criteria

Criteria Weight	
Criteria	**Average Weight**
Durability	0.30
Maint./Repair	0.12
Torque	0.21
User Friendly	0.13
Cost	0.24
Total	**1.00**

3.3 Shifter

The current transmission in the Baja vehicle possesses four forward gear and one reverse gear; however, the main limitation with the current set-up is that the transmission is unable to shift between gears. As a result, it is the responsibility of this year's Baja team to design and develop a working shifting mechanism for the transmission to operate to full capacity. The following criteria for the shifter we have chosen to analyze are: degrees of throw, shifting speed, shifting force, cost, and simplicity.

Degrees of throw refers to the amount degrees from the shifting handle required to shift the transmission one position in the gear box. Due to the physical restraints the driver will be experience while in the cockpit of the vehicle, the degrees per shift should be as limited as possible.

Shifting speed is an important factor since the driver will have to shift between gears often, especially when the driver is forced to a dead stop and must transition the gearbox back to the beginning gear. This is especially important since the type of gearbox on the vehicle is a sequential gearbox, meaning gears must be shifted in order and none can be skipped; for example, when shifting from fourth gear to first gear, the driver must shift through third and then second. Shifting force is a criterion that affects the speed at which the driver can shift. The amount of torque required to turn the shifting rod on the transmission will determine how the shifting mechanism will be designed thus determining the force required from the driver to shift the rod one position.

Like the suspension and the clutch, cost is another important factor in the selection of a shifting mechanism. Depending on if the shifter can be built using raw materials or if the group must purchase a prefabricated shifter will also play an important role in the selection and overall cost of the shifter.

The final criterion to consider is the simplicity of the shifting mechanism, ideally the team would like to design and build, or buy a shifting mechanism with as many little parts as possible. Not only does simplicity reduce the amount of time required to maintain/repair the mechanism, it also reduces the complexity involved in the building of the mechanism if the group chose to construct their own shifter.

Table 5 shows the average final weighted criteria for the shifting mechanism.

Table 5: Weighted Shifter Criteria

Shifter	
Criteria	**Normalized Weight**
Degrees of Throw	0.18
Shifting Speed	0.13
Shifting Force	0.45
Cost	0.15
Simplicity	0.09
Total	**1.00**

4. Concept Generation

4.1 Suspension

The rear suspension of the Baja is a focal point due to its failure with its current design. Currently there is an issue with the amount of movement that the arm has in the x direction. After narrowing down the design possibilities of the rear suspension, the team has concluded on three possibilities for further assessment. The possible suspension designs include a single trailing arm, control arm (A-Arm), and a three link system. Each system has their own positive and negative attributes which will be further evaluated using decision matrices. These matrices average out each team member's opinion of how influential each design pro/con is. With our current drivetrain design, the Baja has an independent rear suspension. This means that there is no fixed link between the two rear wheel hubs which allows for each side to move independently of the other. This is in comparison to a straight axle design that utilizes a fixed member between the hubs to cause them to move independently of each other. With the independent suspension design both sides and the suspension mirror each other.

The first design choice is referred to as the single trailing arm. The single trailing arm is best described as a single member attached to the rear of the frame connecting the frame to the wheels' hub. This member runs roughly the last third of the overall length and is attached to the frame using a simple bolt through bushing attachment. This attachment design allows for the trailing arm to freely move in the y-direction while the shock absorber, which is attached to the end of the trailing arm, absorbs all of the force acting on the wheel. A large benefit of this design is that it allows for maximum suspension travel. One issue with this design is that it allows max deflection in the x-direction due to lack of restricting linkages. This means that any force acting in the x direction on the wheel of the Baja, would cause the trailing arm to act as a cantilever with only the fixed bushing to absorb the torsional force. Through experimentation, it was found that these forces cause the attaching bracket to bend and therefore causing the overall alignment of the rear wheels to fall out of tolerance.

Figure 2: Single Trailing Arm

Another design possibility is the Control Arm style suspension. This style can also be referred to as an A-Arm style suspension due to the shape of each control arm. A control arm suspension utilizes an upper and lower control arm to attach the wheels hub to frame. The upper and lower control arms both attach to the frame using the same bolt through bushing design. Each control arm has two connecting junctions totaling to four per wheel. Due to the increased amount of connections to the frame the reduction of deflection due to the cantilever movement is assumed to decrease. One positive aspect to this design is that it also takes into consideration the vertical angle of the wheel in comparison to the surface it is driving on. This means that the wheel is able to be stay vertical, in reference to a ground, longer due to the utilization of ball joints. Ball joints are joints that work similar to a ball and socket joint found on a human being. A ball joint is located at the end of each control arm to connect the hub and allows for the wheel to have a slight change of angle as the wheel moves up and down with the terrain. Another positive feature to this design is the cost of manufacturing. The manufacturing cost of each control arm is relatively low in comparison to other styles. A negative feature of this design is that it does not have the same suspension travel capabilities as other designs.

Figure 3: Control Arm

The third design that the team has narrowed down to is the Three Link style suspension. The three link suspension style is named in reference to the amount of members connecting the hub, or in other cases the axle, to the frame of the Baja. In our case of the independent rear suspension, one of the three links in the system is the trailing arm. As previously mentioned the trailing arm connects the frame of the Baja but in this case utilizes a different connection style.

The previous explanation of the a trailing arm system uses a bolt through bushing style as the connection while the three link system utilizes a hemi joint in order to allow for a slight rotation in the trailing arm as the suspension contracts. A hemi joint is pivot style bearing and is placed at the end of each link. Other than the adjustment in connection style the three link system also adds two members between the hub and the frame in order to minimize the deflection in the x-direction. The additional two linkages are placed perpendicular to the trailing arm. A downfall to this suspension style is that its geometry causes the wheel to change its vertical orientation as the suspension contracts. This suspension will allow for the max suspension travel which is beneficial to the Baja design.

Figure 4: Three Link

4.2 Clutch

For the concept generation we narrowed the clutch selection down to a dry basket clutch and a centrifugal clutch. The dry clutch is a user activated clutch that disengages power from the motor to the transmission.

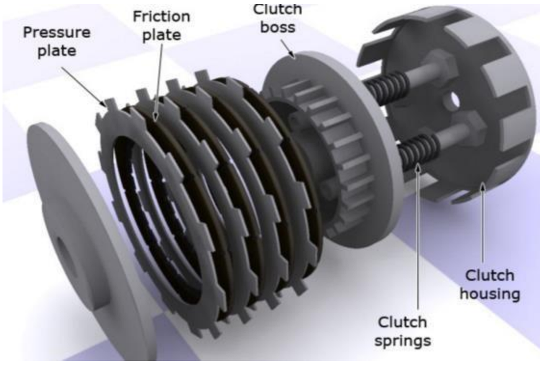

Figure 5: Dry Basket Clutch

The centrifugal clutch is an automatic style disengaging clutch. It uses the motors decrease in rotations per minute to automatically disengage power from the motor to the transmission.

Figure 6: Centrifugal Clutch

4.3 Shifter

For the concept generation of the shifter we narrowed it down to a ratchet shifter and a gate shifter. The ratchet shifter uses a ratcheting mechanism to shift one gear position with each full throw of the shifter.

Figure 7: Ratchet Shifter

The gate shifter using precise gates to regulate each shift of the transmission. One full throw of the shifter hits all gears on the transmission.

Figure 8: Gate Shifter

5. Concept Selection

When ranking criteria for each concept, we used a scale from 1-10 in relation to quantifiable values for each criteria. The raw scores for each criteria in each design option is then multiplied by the weighted criteria values shown in section 3. The criteria ranking and decision matrices are shown in their respective subsections.

5.1 Suspension

Table 6 shows the criteria ranking based on quantifiable values for the following criteria for the suspension: travel, deflection, durability, cost, and maintenance/repair.

Table 6: Criteria Ranking

Rear Suspension						
Level	**Rating**	**Travel (in)**	**Deflection (in)**	**Durability (hours)**	**Cost**	**Maint./Repair (min)**
Perfect	**10**	20	0	30	≤ $150	≤ 15
Excellent	**9**	18	0.25	27	$300	30
Very Good	**8**	16	0.5	24	$450	45
Good	**7**	14	0.75	21	$600	60
Satisfactory	**6**	12	1	18	$750	75
Adequate	**5**	10	1.25	15	$900	90
Tolerable	**4**	8	1.5	12	$1,050	105
Poor	**3**	6	1.75	9	$1,200	120
Very Poor	**2**	4	2	6	$1,350	135
Inadequate	**1**	2	2.25	3	$1,500	150
Useless	**0**	0	≥ 2.5	0	> $1500	> 150

The team as a whole objectively ranked the criteria for each design option, creating raw scores for each criteria (Table 7), these raw scores were then multiplied by the weighted values, resulting in the final weighted score for the suspension options (Table 8).

Table 7: Raw Score and Criteria Weights

Criteria	Three Link	Single Trailing Arm	A-Arm
Travel	10(0.14)	10(0.14)	6(0.14)
Deflection	8(0.13)	0(0.13)	8(0.13)
Durability	7(0.37)	3(0.37)	7(0.37)
Cost	6(0.12)	10(0.12)	7(0.12)
Maint./Repair	6(0.24)	8(0.24)	5(0.24)

Table 8: Finalized Weighted Score

Criteria	Three Link	Single Trailing Arm	A-Arm
Travel	1.4	1.4	0.84
Deflection	1.04	0	1.04
Durability	2.59	1.11	2.59
Cost	0.72	1.2	0.84
Maint./Repair	1.44	1.92	1.2
Total	**7.19**	**5.63**	**6.51**

Based on the information presented in table 8, the Baja team determined that the three-link suspension is the best option.

5.2 Clutch

Table 9 shows the criteria ranking based on quantifiable values for the following criteria for the clutch: durability, maintenance/repair, starting torque, and cost.

Table 9: Criteria Ranking

Clutch					
Level	**Rating**	**Durability**	**Maint./Repair**	**Torque (ft-lb)**	**Cost**
Perfect	**10**	100 hrs.	≤ 15 min.	≥ 30	≤ $150
Excellent	**9**	90 hrs.	30 min.	28.5	$300
Very Good	**8**	80 hrs.	45 min.	27	$450
Good	**7**	70 hrs.	60 min.	25.5	$600
Satisfactory	**6**	60 hrs.	75 min.	24	$750
Adequate	**5**	50 hrs.	90 min.	22.5	$900
Tolerable	**4**	40 hrs.	105 min.	21	$1,050
Poor	**3**	30 hrs.	120 min.	19.5	$1,200
Very Poor	**2**	20 hrs.	135 min.	18	$1,350
Inadequate	**1**	10 hrs.	150 min.	16.5	$1,500
Useless	**0**	0 hrs.	> 150 min.	≤ 15	> $1500

The team as a whole objectively ranked the criteria for each design option, creating raw scores for each criteria (Table 10), these raw scores were then multiplied by the weighted values, resulting in the final weighted score for the clutch options (Table 11).

Table 10: Raw Score and Criteria Weights

Criteria	Centrifugal	Basket Clutch
Durability	7(0.30)	10(0.30)
Maint./Repair	10(0.12)	2(0.12)
Torque	10(0.21)	10(0.21)
User Friendly	10(0.13)	5(0.13)
Cost	9(0.24)	3(0.24)

Table 11: Finalized Weighted Score

Criteria	Centrifugal	Basket Clutch
Durability	2.1	3
Maintenance/Repair	1.2	0.24
Torque	2.1	2.1
User Friendly	1.3	0.65
Cost	2.16	0.72
Total	**8.86**	**6.71**

Based on the information presented in table 11, the Baja team determined that the centrifugal clutch is the best option.

5.3 Shifter

Table 12 shows the criteria ranking based on quantifiable values for the following criteria for the shifting mechanism: rating, degrees of throw, shifting speed, shifting force, and cost.

Table 12: Criteria Ranking

Shifter					
Level	**Rating**	**Deg. of Throw**	**Shifting Speed (s)**	**Shifting Force (lb)**	**Cost**
Perfect	**10**	<10	1	<4	≤ $100
Excellent	**9**	10	2	4	$125
Very Good	**8**	20	3	6	$150
Good	**7**	30	4	8	$175
Satisfactory	**6**	40	5	10	$200
Adequate	**5**	50	6	12	$225
Tolerable	**4**	60	7	14	$250
Poor	**3**	70	8	16	$275
Very Poor	**2**	80	9	18	$300
Inadequate	**1**	90	10	20	$325
Useless	**0**	>90	> 10	>20	>$325

The team as a whole objectively ranked the criteria for each design option, creating raw scores for each criteria (Table 13), these raw scores were then multiplied by the weighted values, resulting in the final weighted score for shifting mechanism options (Table 14).

Table 13: Raw Score and Criteria Weights

Criteria	Rachet	Gate
Degrees of Throw	4(0.18)	8.5(0.18)
Shifting Speed	5(0.13)	5(0.13)
Shifting Force	7(0.45)	4(0.45)
Cost	3(0.15)	10(0.15)
Simplicity	4(0.09)	8(0.09)

Table 14: Finalized Weighted Score

Criteria	Rachet	Gate
Degrees of Throw	0.72	1.53
Shifting Speed	0.78	0.65
Shifting Force	3.15	1.8
Cost	0.45	1.5
Simplicity	0.36	0.72
Total	**5.46**	**6.2**

Based on the information presented in table 14, the Baja team determined that the gate shifter is the best option. However, further tests and analyses will need to be performed later to verify this selection.

6. Design Modification

6.1 Rear Suspension

The rear suspension design needed to address problems from the previous design. The previous design of the rear suspension was a single trailing arm with a bolt-through-bushing connecting style. With this style of mounting the suspension has no reinforcing members that can hold the horizontal load created while turning. As the vehicle turns the single trailing arm acted as a cantilever with the mounting side being over a foot away than the load. This loading force not only cause the trailing arm mount to bend but also caused the axles to attempt to pull out of the transmission as the deflection increased. To counteract these forces, additional members were added between the rear hubs and the frame of the transmission, which can be seen in Figure 9. The initial design included two members to be added to each side but after analysis, it was determined that there was only enough room for a single member to be added which can be seen in Figure 10. After the implementation of the single additional linkage, the updated design proved to be efficient at holding the horizontal forces while allowing for full travel of the suspension.

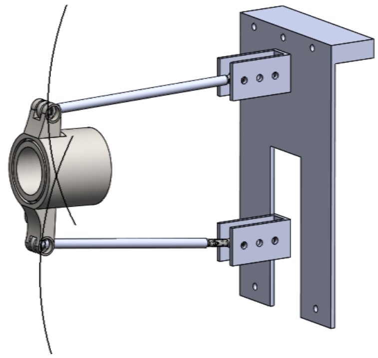

Figure 9: Dual Link Design

Figure 10: Updated Suspension Design

6.2 Transmission:

The transmission for this project is a continuation of the design from last year, it is a sequential gearbox with a reverse gear, neutral, and three forward gears with potential for a fourth. During the initial familiarization with this transmission, it was discovered that the shift forks made by last year's team were of inconsistent size and were each made of two pieces, as shown in figure 11 below. The inconsistent size caused issues with the fitment of the transmission components which did not allow the shift forks to move properly with input from the shift shaft.

Figure 11: Old Shift Fork Design

These issues resulted in redesigning the shift forks to be made out of one solid piece of material, as shown in figure 12.

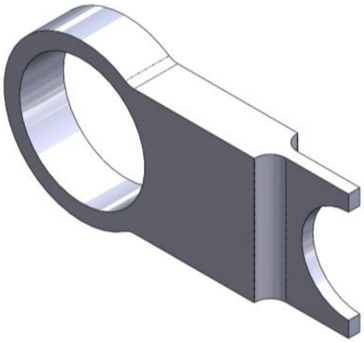

Figure 12: Design Modification

In order to ensure fitment, two shift forks were 3D printed and incorporated into the assembly of the transmission. Once it was verified that the forks fit, the three steel forks were milled. When testing the new forks a new issue resulted, when attempting to shift a bending moment would result on the shift shaft when attempting to move the collars that engage the gears causing the forks to bind along the shift shaft rendering them immobile, this depiction is shown in figure 13.

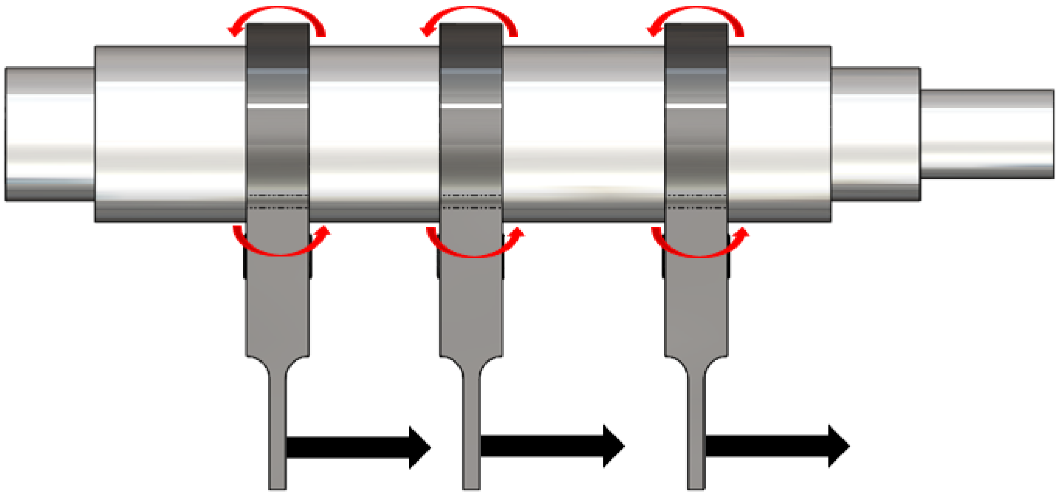

Figure 13: Bending Moments Caused by Shifting Forces

As a result of this issue, a guide rod was implemented into the design of the shift forks, shown in figure 14. The theory behind the addition of this guide rod was that the bending moment would be eliminated from each shift fork by distributing the load among all of the forks. The result of the addition of the bearings and guide rod was a smooth shifting transmission. The improvement in the shifting capability due to this addition eliminated the need for a force analysis required to shift between gears.

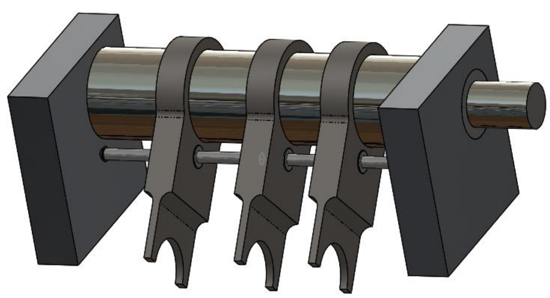

Figure 14: Addition of Guide Rod to Shifting Fork Design

6.3 Clutch

The original clutch concept chosen for implementation was a centrifugal clutch; however, after further consideration a dry basket clutch became the preferred clutch to implement on the vehicle. When researching clutches for our application, the team was unable to find an inexpensive dry basket clutch to mount to our vehicle. As a result, a design was created to convert a wet clutch to a dry clutch. Figure 15 below shows the Yamaha YZ250 wet clutch chosen by the team last year, the rotating parts on this clutch failed since they were not constantly lubricated.

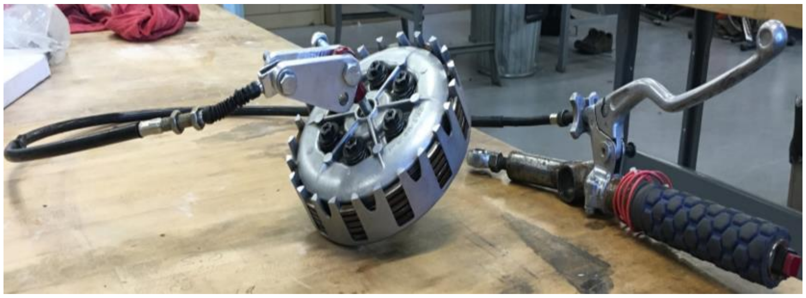

Figure 15: Yamaha YZ250 Wet Basket Clutch

In order to address this issue a new design was created which consisted of a bearing hub and a machined sprocket for containing a bearing, by implementing a sealed bearing to the design, the clutch basket is able to rotate without needing constant lubrication like the bushing on the wet clutch. The design and physical components are shown below.

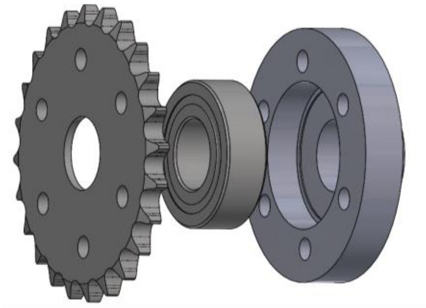

Figure 16: Wet to Dry Clutch Conversion

Figure 17: Machined Parts

In addition, the clutch had to be relocated to a new area due to interference issues with the suspension and the shifting mechanism, this resulted in relocating the clutch onto an idler shaft which mounted to the same mounts as the engine, shown in figure 18.

Figure 18: Location of Clutch

6.4 Shifter

The mini baja utilizes a sequential transmission that was machined in the NAU machine shop. The sequential transmission shifts between gears by rotating the shift shaft in figure 19. The shift shaft requires a 60 degree rotation to disengage one gear and engage into another gear.

Figure 19: Shift Shaft

With the requirements for the shift shaft's rotational needs, the model in figure 20 was developed in Solidworks that would allow for 60 degree rotations in either direction, at the operator's desired time. The model was put through a motion analysis to verify proper rotation of the shift shaft, and once complete was ready for prototype development. The model was sent to the rapid prototyping lab in building 98c on campus to be 3D printed, as shown in figure 21 to allow for testing and modifications of the model before the final machining was done.

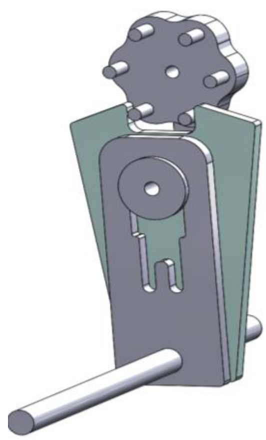

Figure 20: Solidworks Model

Figure 21: 3D Print of Shifter

After completed testing of the prototype, the final shifter mechanism was manufactured and machined at the NAU machine shop. The design consist of the shifting slide and the shifting flower, which mounts directly to the shift shaft as shown in figure 22.

Figure 22: Shifting Flower

The shifting mechanism is mounted with two pillow block bearings that mount on the transmission mount rails. The shifter is located in between the firewall and the front of the transmission as shown in figure 23.

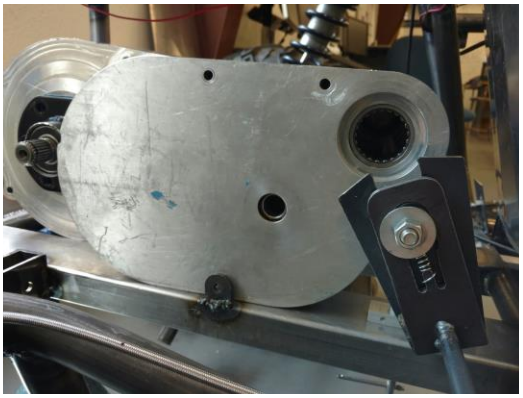

Figure 23: Shifter Location

6.5 Frame FEA Analysis

The FEA for the frame are applied in the design. The objective of FEA is to make sure the frame is reliable and has enough strength to work without break. Four FEA are applied, and they are front impact test, side impact test, rear impact test and rollover test. Different tests are based on different assumptions. For front impact, side impact, rear impact tests, it is assumed that the tested Baja vehicle is hit by another vehicle at the same weight and a speed of 25 miles per hour. For the rollover test, it is assumed that the tested Baja vehicle drops from a height of 6 feet. It is also assumed the impact time for from impact, side impact and rollover impact is 0.2 second. But it is assumed that the impact time for rear impact is 0.5 second, because rear impact is different from the other three test. For rear impact, the tested Baja will be pushed forward from the back when get hit, which increase the impact time and decrease the force. All the factors of safety are shown below, the factor of safety for side impact and rear impact seems small, but the assumptions of 25 miles per hour are made as an extremely situation. So a factor of safety merely over than 1 is accepted (Table 15: FEA Result).

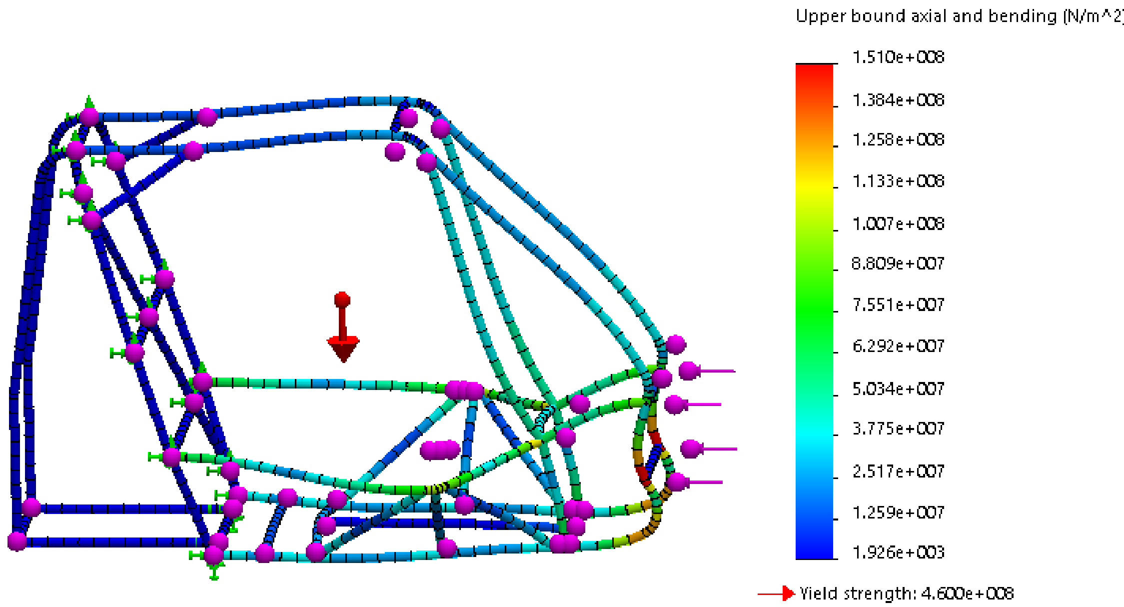

Figure 24: Front Impact FEA

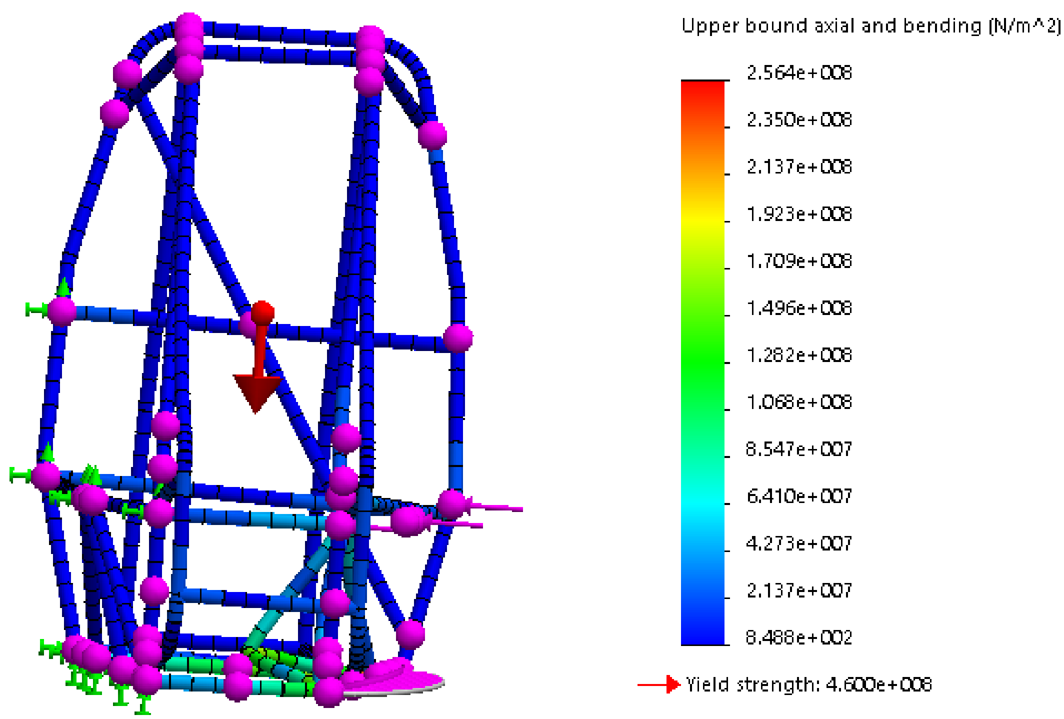

Figure 25: Side Impact FEA

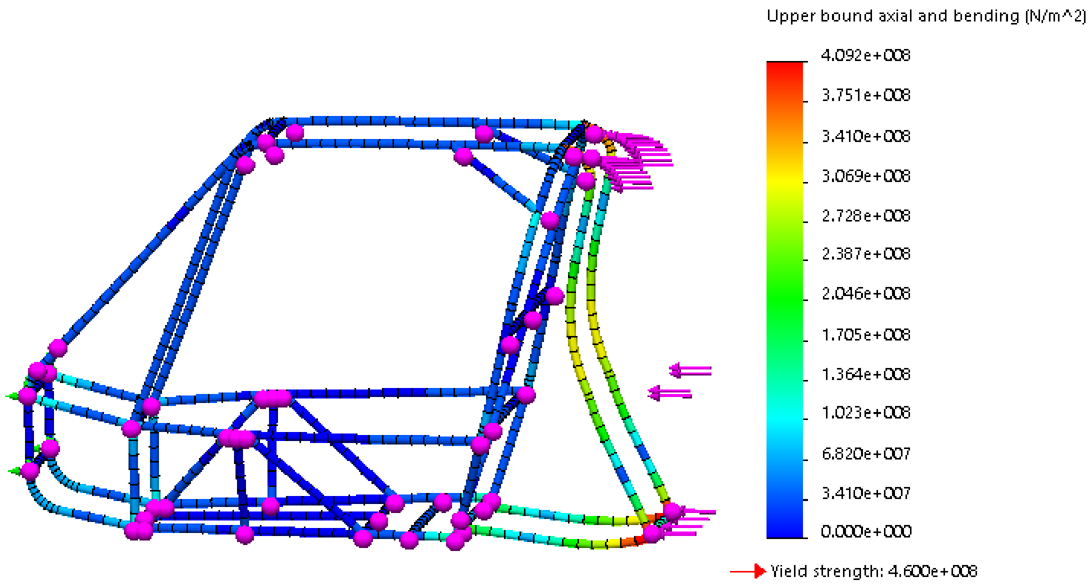

Figure 26: Rear Impact FEA

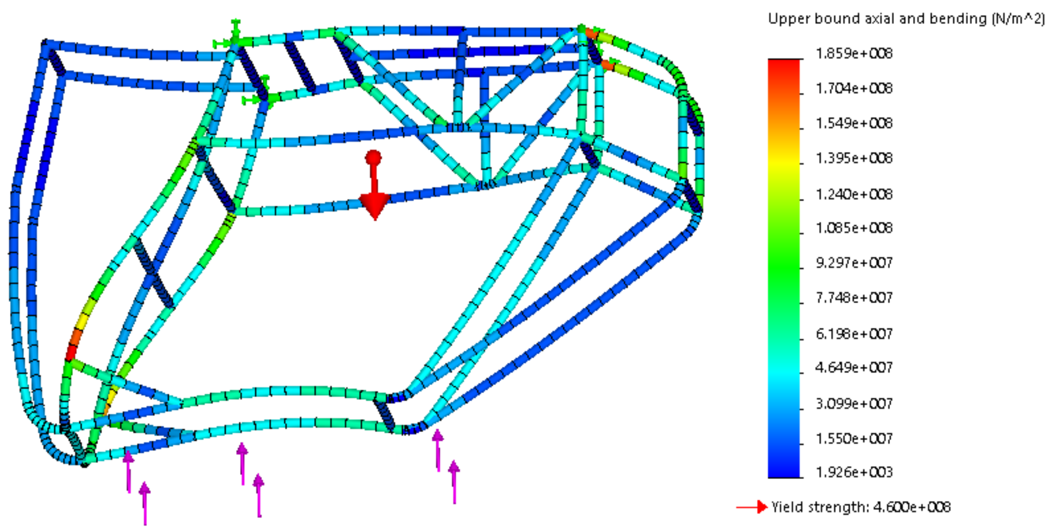

Figure 27: Roll Over FEA

Table 15: FEA Results

	Yield Stress $*10^8$ Pa	Maximum Stress $*10^8$ Pa	Factor of Safety	Factor of Safety Requirement
Front impact	4.60	1.55	2.96	1
Side impact	4.60	3.97	1.16	1
Rear impact	4.60	4.09	1.12	1
Roll over	4.60	1.86	2.47	1

6.6 Muffler

The previous design of the muffler did not meet the requirements set by SAE. The requirements mention that the muffler must not exceed any part of the frame from the mini baja. The previous design had had two major issues, the muffler exceeded the boundary of the frame, and had improper flow characteristics two pipes that were sharply angled together as seen in figure 28.

The design modification made to the muffler uses a shorter mandrel bent pipe to allow for proper flow of the exhaust gases. The shorter pipe also meets the SAE requirement that the muffler must reside within the frame. The new design is displayed in figure 29.

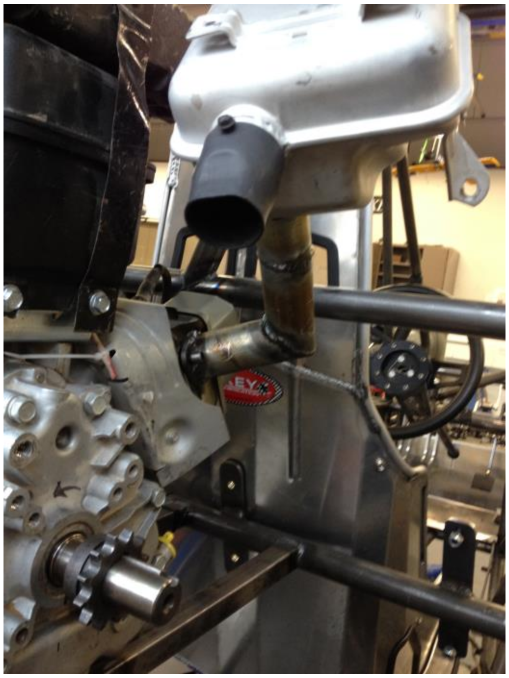

Figure 28: Old Muffler

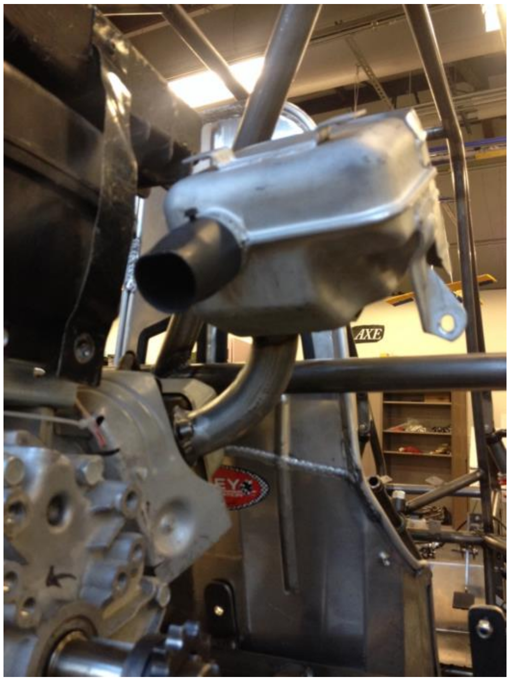

Figure 29: Current Muffler

6.7 Steering and Throttle

The previous steering shaft consisted of a three part design. The three part design shown in figure 30, allowed for various points of failure.

Figure 30: Broken Steering Shaft

The steering shaft broke at the welds holding the three pieces together and required a new design that would endure the demand of competition. The new design for the steering shaft consisted of a one piece shaft to eliminate points of failure. The new design is shown in figure 31.

Figure 31 New Steering Shaft

The throttle cable mount had poor welding penetration and broke off while testing the gas pedal. The mount was moved and rewelded, as shown in figure 32, to help withstand the forces of the gas pedal.

Figure 32: Throttle Cable Mount

7. Performance Testing and Results

7.1 Performance Testing

The first iteration of performance testing was the process verifying the modifications to the suspension yielded positive results. This was performed by disconnecting the shock from the trailing arm and checking the amount of travel in the suspension. In total the suspension was able to provide ten inches of travel while maintaining a consistent arc for the wheel hub to travel, thus eliminating the horizontal deflection through the link.

The next component we tested was the clutch, this was tested by putting the rear end of the baja on jack stands to take the load off of the tires. We then started the engine and released the clutch handle, thus successfully transferring power from the engine to the wheels of the vehicle, verifying the wet to dry conversion of the clutch was successful.

The final iteration of performance testing was verifying that the vehicle drove. This was performed similar to the clutch test except the vehicle was on the ground, the driver for this test was able to successfully start the vehicle with the clutch disengaged and fully engaging the clutch with the transmission in gear thus allowing the vehicle to move. The vehicle was able to travel a total of 100 yards before a sprocket in the inside of the transmission broke for a second time, thus no other testing was able to be performed for the remainder of the project.

7.2 Results

After performance testing the transmission suffered from internal parts failure. The drive sprocket that delivers the power from the transmission to the output sprocket suffered from a shear failure upon testing. The sprocket sheared along the corner of the key way as seen in figure 33. Under the assumption that the sprocket may have encountered a manufactured defect, a new sprocket was purchased and the transmission was rebuilt. Upon another test run the sprocket failed the same way in the same place as shown in figure 34.

Figure 33: First Broken Chain Sprocket

Figure 34: Second Broken Chain Sprocket

Other damage within the transmission was with the pins on the engagement collars. Since the transmission does not have synchronizers, there is no way to bring the selector gear to the same velocity as the engagement collar. As a result the collars are subjected to a large dynamic bending moment that has bent the pins beyond elastic deformation as shown in figure 35.

Figure 35: Bent Engagement Pins

8. Conclusions

In conclusion the SAE club, advised by Dr. John Tester, needed a completed mini baja that was competition ready. The structural integrity of the frame was verified with an FEA in Solidworks. The rear suspension was modified and redesigned. The shift forks were redesigned and machined to allow for proper shifting in the transmission. Modification were made to the previously supplied wet basket clutch, to convert it to a dry basket clutch. A shifting mechanism was designed, prototyped, and manufactured for the sequential transmission. Miscellaneous design modifications were needed to make the baja operational for testing. These design modifications included manufacturing a new one piece steering shaft and also rewelding the throttle cable mount that had previously broken off due to penetration lacking welds.

After the performance testing there were major issues with the transmission. Vital internals can't withstand the forces within the transmission. To resolve the shearing of the drive sprocket and the bent engagement collar pins, the rest of the transmission must be designed around these parts. The design would need a factor of safety to ensure longevity of the internals of the transmission. With these needs, it is not economical to redesign the transmission. With the hours, labor, and material cost put into the transmission, the purchase of a manufactured transmission would be more economical. A purchased transmission would put the focus on further testing the rest of the mini baja and achieving a competition ready build.

9. Reference

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