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Vehicle Structures - Redesigned and Analyzed a Suspension System for a Mitsubishi 3000GT

Abstract:

The suspension is a system of shocks, springs and linkages that connects the vehicle’s chassis to the wheels. Suspension systems serve a dual purpose - contributing to the car's handling and braking for good active safety and driving pleasure, and keeping vehicle occupants comfortable and reasonably well isolated from road noise, bumps, and vibrations. These goals are generally at odds, so the tuning of suspensions involves finding the right compromise. In the sports car scenario, a compromise between comfort and cornering stability will be made in order to optimize racing performance.

Introduction:

A Brief Introduction on Lowering Suspension:

Most people lower their cars by installing shorter springs. This is the easiest way to achieve lowering. An alternative, more expensive way of lowering a car is to relocate the hubs and spindles upwards. In our analysis, we decided to lower the car by simply installing shorter springs.

Advantages:

- Lowering the car also lowers its center of gravity (CG) which decreases "weight transfer" to help improve handling. And it may also lower the car's "roll center" and change other aspects of the car's suspension geometry in ways that help handling. But sometimes these changes hurt.
- Lowering the car improves aerodynamics at high speeds.
- Lowering the car looks cool.

Disadvantages:

- Lowering the car makes it more susceptible to "bottoming out." This is when the suspension compresses enough, usually over bumps (and especially bumps in turns), to cause the suspension's "bump stops" to contact. This pounding can damage the car's suspension and chassis if it is excessive. It can also cause the car to "skip" over bumps in fast turns, or even increase the likelihood of the car flipping over! This can be dangerous and isn't the way to win races either.

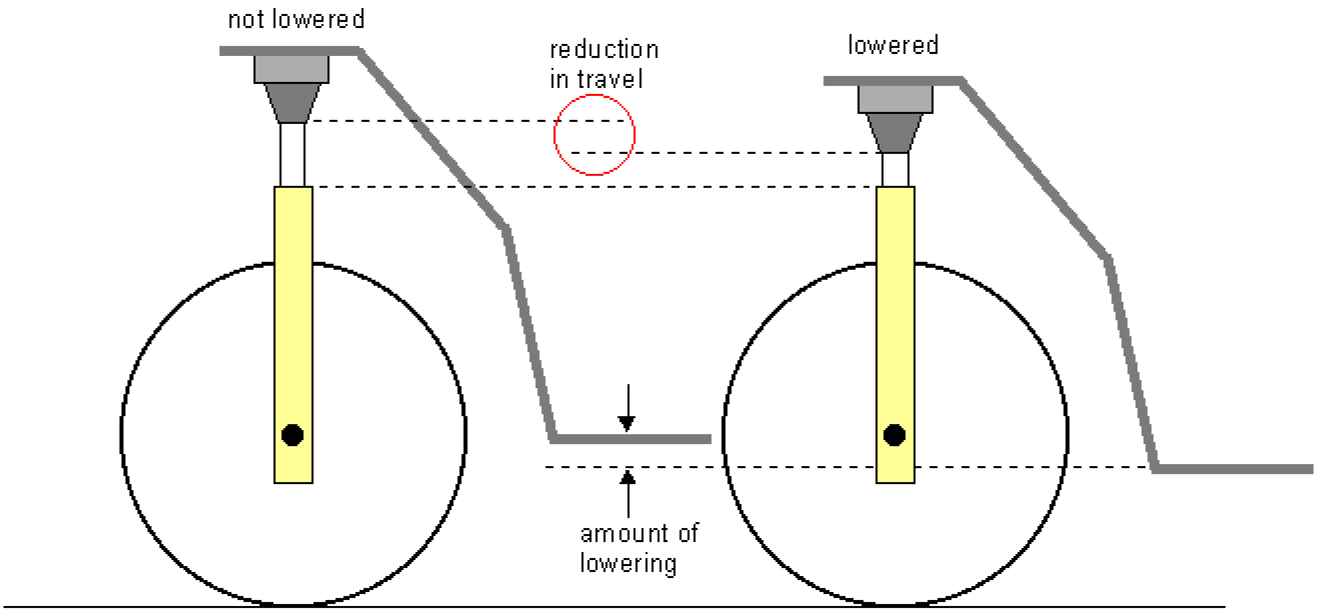


Figure 1

Figure 1 displays a schematic of a car with front strut suspension. Caster is set to zero to aid visualization. Note the reduction in suspension travel that occurs when the car is lowered (shown by the red circle). This happens because using a shorter spring brings the upper strut bearing (or camber plate) closer to the top of the strut housing. This pushes the bump stop down and since travel is defined as the distance between the bump stop and the top of the strut housing, travel is reduced. The only way around this is to either use shortened strut housing or to cut the bump stop.

- Lowering changes the car's wheel alignment. Usually the car's "negative camber" and "toe-in" are increased. Extra negative camber may be a handling advantage.

- The lower ride height can also cause your car to scrape "speed bumps," and when crossing over sidewalks into driveways and parking lots, and to bump into curbs when parking.

Objective/Goal:

Lowering the Car Reduces Weight Transfer

After analyzing the advantages and disadvantages, we figured out that our team will go ahead and lower the car but replacing the stock springs with shorter springs. The ultimate goal here is to reduce the weight transfer of the vehicle. Reducing weight transfer just makes the car corner better.

A lower center of gravity is good because it reduces weight transfer during cornering. Reducing weight transfer is good because a pair of tires can create the greatest lateral grip when the weight they carry is evenly distributed. When the car corners, a centripetal force acts on its center of gravity (CG). This centripetal force acts as a lever arm to transfer some of the vehicle weight from the inside tires to the outside tires.

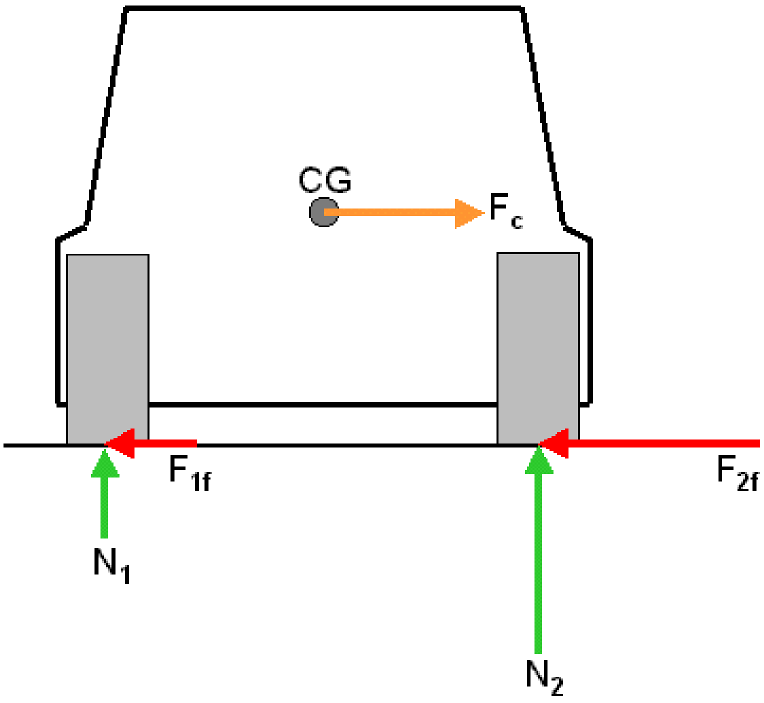
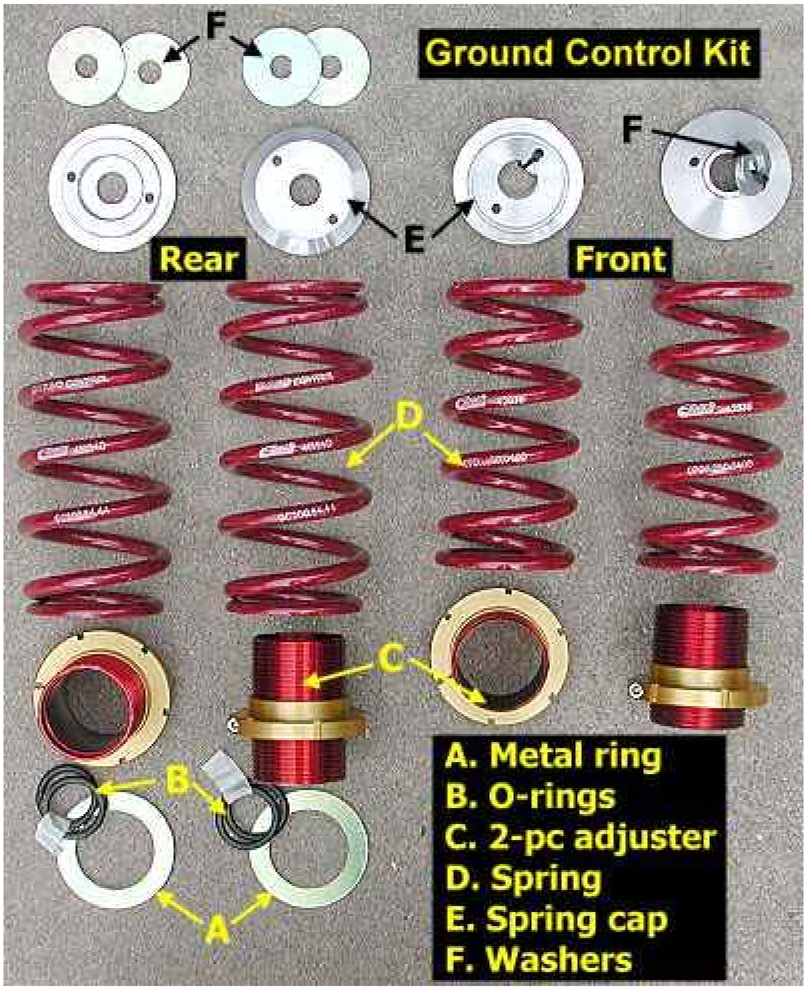


Figure 2

This figure shows the forces involved in creating weight transfer. The car is cornering towards the left and some of its weight has been transferred to the right-side tires. Since the outside tires are loaded more heavily, they can create a greater lateral grip then the inside tires. But the key point to remember is that the tires would generate the most grip if they were evenly loaded (N1 = N2). This is due to "load sensitivity". Tires do not create friction like blocks of wood on a smooth surface (or like brake pads on a rotor). During cornering, the loss of grip experienced by the inside tires is *not* made up for by the increase in grip of the outside tires. Thus the overall cornering power of a pair of tires is reduced due to weight transfer. There are only two ways that you can make a significant reduction in weight transfer. One is by lowering the center of gravity and the other is by increasing the track width. In our analysis, we are going to reduce the weight transfer only by lowering the center of gravity.

Assessment:

In order to achieve the results we wanted, all four springs of the vehicle had to be changed. A shorter and thicker coil springs were chosen. The team decided to go with the Eibach spring kit. Picture 1 below shows the new spring system for both the front and rear suspension system.



Picture 1: Eibach GC Springs

This set is a perfect bolt on set. No major modifications are required in order to install these springs. The table below compares the specifications of the stock springs and the aftermarket springs. The aftermarket springs are basically shorten and is much stiffer compared to the stock springs.

	Aftermarket (Front)	**Stock (Front)**	**Aftermarket (Rear)**	**Stock (Front)**
Total Spring Length	6”	7.3”	8”	9.3”
Spring Stiffness	500 lb/in	218 lb/in	360 lb/in	157 lb/in

Table 1: Aftermarket vs. Stock Springs

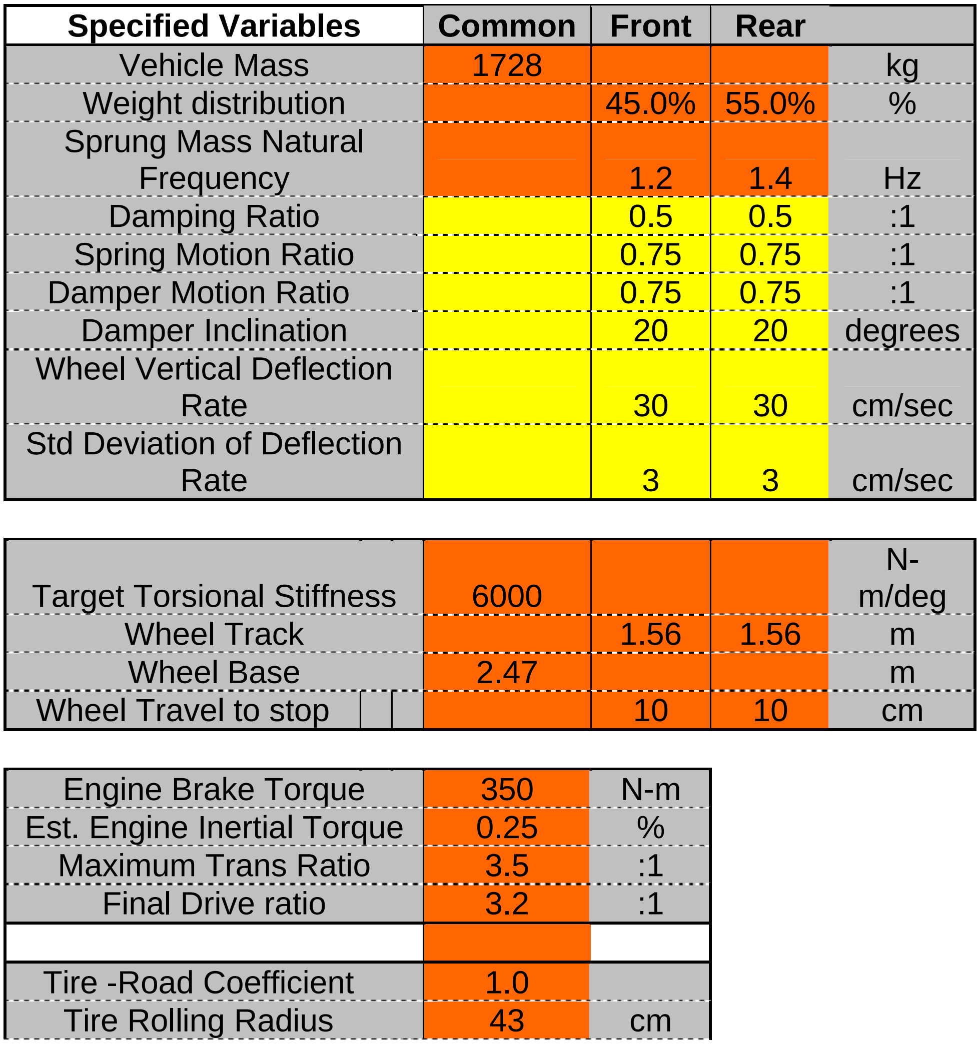
It is obvious that when the power and performance of a car is increased, the stability and ground control also have to be increased. This will help to get better handling and a good suspension system will allow the car to be setup to optimum performance. We spent a lot of time on this section, as the safety of the car on the road is very important. We ran through several calculations to do the forces analysis on the vehicle for various cases. A detail description of the analysis is given. Below is a picture comparing the new suspension and the old suspension.

Picture 2:New springs (red) vs Stock Springs (black)

Note: The new springs are shorter. This is to reduce the ride height of the vehicle to improve stability.

Analysis/Results:

Table 2 below basically shows us the constants used for the calculations in the analysis. Most of the constant values were obtained from the official Mitsubishi 3000-GT website. There were several assumptions that the team had to make in order to go ahead with the analysis. The assumptions are represented by yellow shaded columns in the table below and the orange columns represent the actual constants obtained.



Specified Variables	Common	Front	Rear	
Vehicle Mass	1728			kg
Weight distribution		45.0%	55.0%	%
Sprung Mass Natural Frequency		1.2	1.4	Hz
Damping Ratio		0.5	0.5	:1
Spring Motion Ratio		0.75	0.75	:1
Damper Motion Ratio		0.75	0.75	:1
Damper Inclination		20	20	degrees
Wheel Vertical Deflection Rate		30	30	cm/sec
Std Deviation of Deflection Rate		3	3	cm/sec

Target Torsional Stiffness	6000			N-m/deg
Wheel Track		1.56	1.56	m
Wheel Base	2.47			m
Wheel Travel to stop		10	10	cm

Engine Brake Torque	350	N-m
Est. Engine Inertial Torque	0.25	%
Maximum Trans Ratio	3.5	:1
Final Drive ratio	3.2	:1
Tire -Road Coefficient	1.0	
Tire Rolling Radius	43	cm

Table 2: List of Constants Used for Analysis

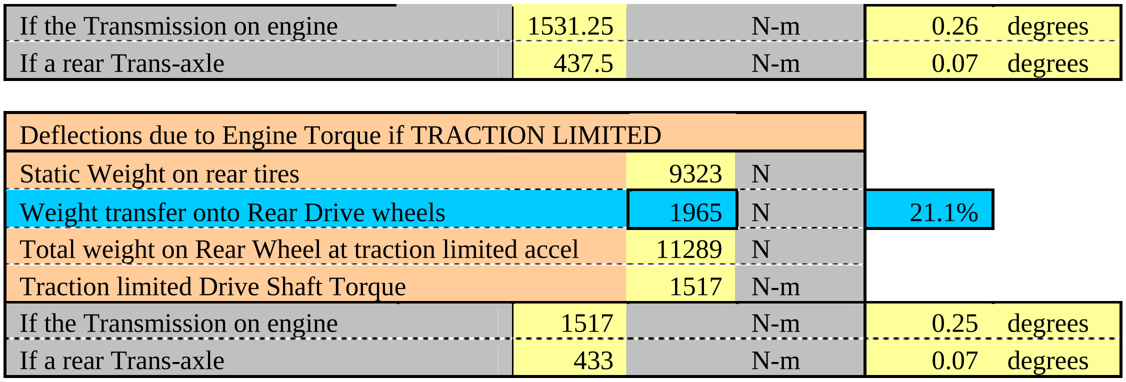
Table 3 shows a list of calculations done in order to analyze the stock suspension configuration. In this analysis, the original center of gravity height of 43cm was used. The calculated value of the weight transfer onto the rear drive wheels was 1965N which is shown in the blue color box in the table below. This force yields a deflection due to the engine torque (traction limited) of 21.1%.

Center of Gravity Ht	43	cm

Calculated Variables	Total	Combined		per wheel		
		Front	Rear	Front	Rear	
Vehicle Mass distribution	1728	778	950	389	475	kg
Vehicle Weight distribution	16952	7628	9323	3814	4662	N
Spring Rate @ wheel	117626	44161	73465	22080	36733	N/m
Required Spring Rate		78508	130605	39254	65302	N/m
Spring Static Deflection		17.27	12.69	cm		
Maximum roll to bottom susp.		7.35	7.35	Degrees		
Critical Damping		11720	16712	5860	8356	N-s/m
Damping @ wheel	14216	5860	8356	2930	4178	N-s/m
Required Damper Rate	25273	10418	14855	5209	7427	N-s/m
Mean of Damping Force @ whl		1758	2507	879	1253	N
Mean Damping Force @ frame		2344	3342	1172	1671	N
Std Dev of Damp Force @ whl		176	251	88	125	N
Std Dev of Damp Force @ frame		234	334	117	167	N

Spring Anti-Roll Stiffness		469	780	N-m/deg	
Anti Roll Bar Stiffness		135	0	N-m/deg	Add to balance W.T.
Total Stiffness (Front/Rear)		604	780	N-m/deg	
% anti Roll Stiffness		43.6%	56.4%	N-m/deg	
Total Anti-Roll Stiffness	1384	N-m/deg			

Deflections due to suspension loads				Angular Deflection of specified Frame
Max applied moment @ max wheel travel	4436.28	5730.3	N-m	0.96 degrees
If vehicle is supported diagnoally	5950.04	7272.3	N-m	1.21 degrees
Damper moment @ 3 sigma	1783	2542	N-m	Below excessive
Total potential thru suspension	6219	8272	N-m	1.38 degrees
Deflections due to Engine Torque if TORQUE LIMITED				



If the Transmission on engine	1531.25	N-m	0.26	degrees
If a rear Trans-axle	437.5	N-m	0.07	degrees

Deflections due to Engine Torque if TRACTION LIMITED				
Static Weight on rear tires	9323	N		
Weight transfer onto Rear Drive wheels	1965	N	21.1%	
Total weight on Rear Wheel at traction limited accel	11289	N		
Traction limited Drive Shaft Torque	1517	N-m		
If the Transmission on engine	1517	N-m	0.25	degrees
If a rear Trans-axle	433	N-m	0.07	degrees

Table 3: Calculated Results for the Stock Suspension Setup

Table 3 is a comparison of table 4 in which the car was lowered using the aftermarket suspension system. This resulted in a lower center of gravity height which was 38cm. Due to the lesser height of the center of gravity; the weight transfer onto the rear drive wheels was also reduced significantly. The weight transfer reduced from 1965N to 1695N. a weight transfer of 1695N resulted in a 18.2% deflection due to the engine torque (traction limited). A weight reduction of 13.74% was obtained after switching to the new suspension system. This calculation is shown below.

$$\% \text{ Weight Reduction} = \frac{1965\text{N} - 1695\text{N}}{1965\text{N}} \times 100\%$$

$$= \mathbf{13.74\%}$$

Center of Gravity Ht	38	cm

Calculated Variables	Total	Combined		per wheel		
		Front	Rear	Front	Rear	
Vehicle Mass distribution	1728	778	950	389	475	kg
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Total Stiffness (Front/Rear)		604	780	N-m/deg	
% anti Roll Stiffness		43.6%	56.4%	N-m/deg	
Total Anti-Roll Stiffness	1384	N-m/deg			

Deflections due to suspension loads				Angular Deflection of specified Frame	
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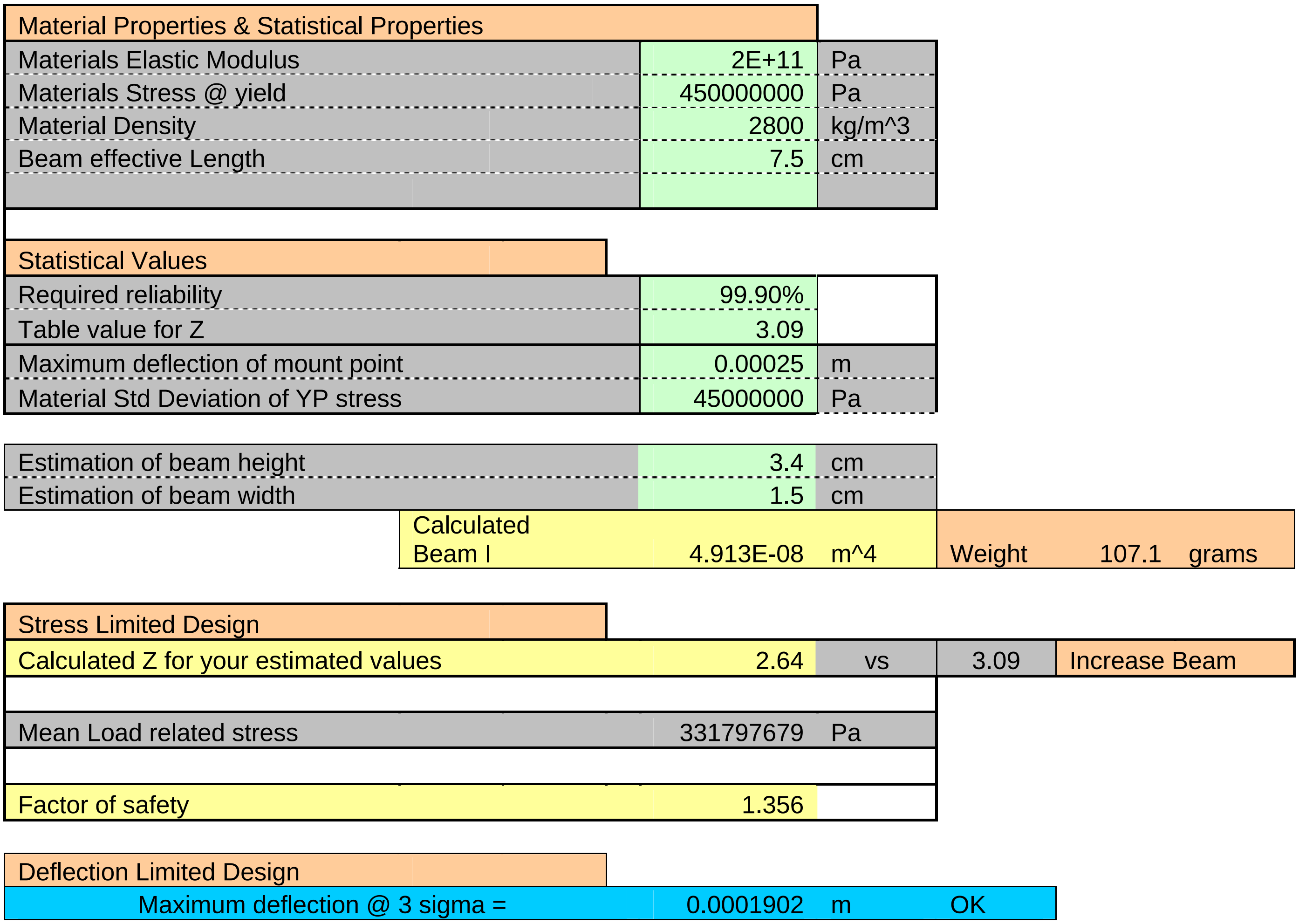
Damper moment @ 3 sigma	1783	2542	N-m	Below excessive	
Total potential thru suspension	6219	8272	N-m	1.38	degrees
Deflections due to Engine Torque if TORQUE LIMITED					
If the Transmission on engine	1531.25		N-m	0.26	degrees
If a rear Trans-axle	437.5		N-m	0.07	degrees

Deflections due to Engine Torque if TRACTION LIMITED					
Static Weight on rear tires		9323	N		
Weight transfer onto Rear Drive wheels		1695	N	18.2%	
Total weight on Rear Wheel at traction limited accel		11019	N		
Traction limited Drive Shaft Torque		1481	N-m		
If the Transmission on engine	1481		N-m	0.25	degrees
If a rear Trans-axle	423		N-m	0.07	degrees

Table 4: Calculated Results for the Aftermarket Suspension Setup

The final table of calculations, table 5 analyzes the vehicle deflection limit analysis. In this a maximum deflection @ 3 sigma of 0.00019015m was obtained. This value is an acceptable value as the maximum deflection @ 3 sigma is greater than the material deflection of mount point.



Material Properties & Statistical Properties		
Materials Elastic Modulus	2E+11	Pa
Materials Stress @ yield	450000000	Pa
Material Density	2800	kg/m^3
Beam effective Length	7.5	cm

Statistical Values		
Required reliability	99.90%	
Table value for Z	3.09	
Maximum deflection of mount point	0.00025	m
Material Std Deviation of YP stress	45000000	Pa

Estimation of beam height	3.4	cm			
Estimation of beam width	1.5	cm			
Calculated Beam I	4.913E-08	m^4	Weight	107.1	grams

Stress Limited Design				
Calculated Z for your estimated values	2.64	vs	3.09	Increase Beam
Mean Load related stress	331797679	Pa		
Factor of safety	1.356			

Deflection Limited Design			
Maximum deflection @ 3 sigma =	0.0001902	m	OK

Table 5: Vehicle Deflection Limit Analysis

Recommendations:

By changing the stock springs to the Eibach aftermarket springs, the team is convinced with the stability and the frame deflection results. However given more time and money, there were several other modifications that would be considered in the future. These include:

- Front and rear stability/ strut bar (for extra cornering stability)
- TEIN Electronic Damper System (control the ride height and the shock stiffness with the touch of a button)
- *Falken* Racing Tires (for extra road grip)
- Ground control/Body kit (to minimize aerodynamic drag)
- Rear Carbon Fiber wing (to improve aerodynamic flow)