Design and Integration of Suspension, Brake and Steering Systems for a Formula SAE Race Car

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Final Report

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MAE 340/440

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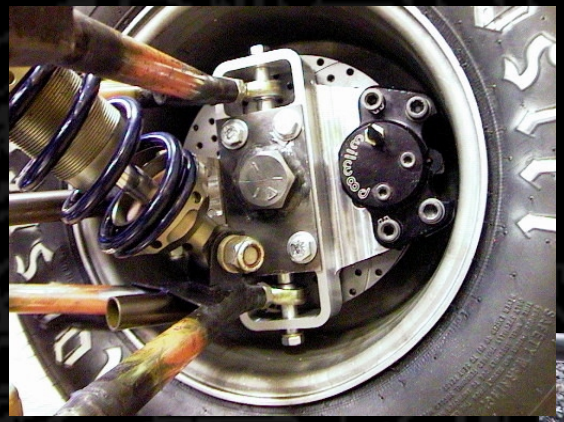
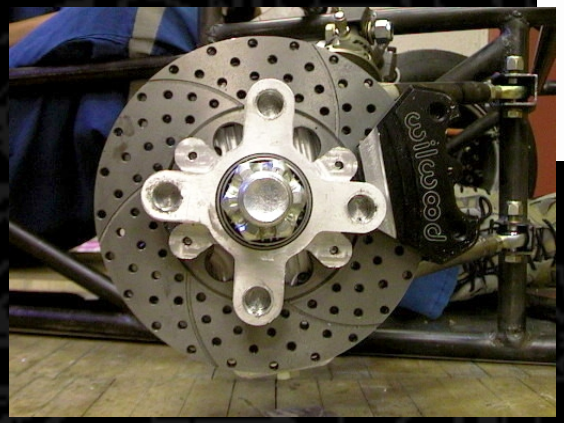
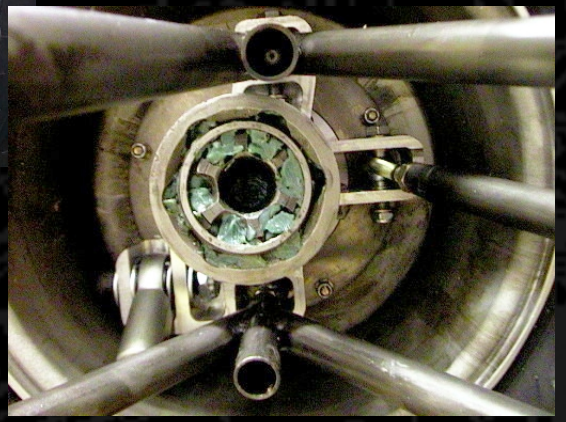
"Behind the Wheels"

- Intro/Update
- Front axle
- Rear axle
- Specifications
- The Future







Vehicle Control Systems

Intro/Update
Front axle
Rear axle
Specifications
The Future

- **Suspension System**
  - Fall semester's focus
  - Kinematics (motion of wheel)
  - Dynamics (behavior of the wheel and car)
- **Steering System**
  - Control, stability, consistency
- **Brake System**
  - Control, efficiency, effectiveness
- **Philosophies: Reliability, adjustability…**

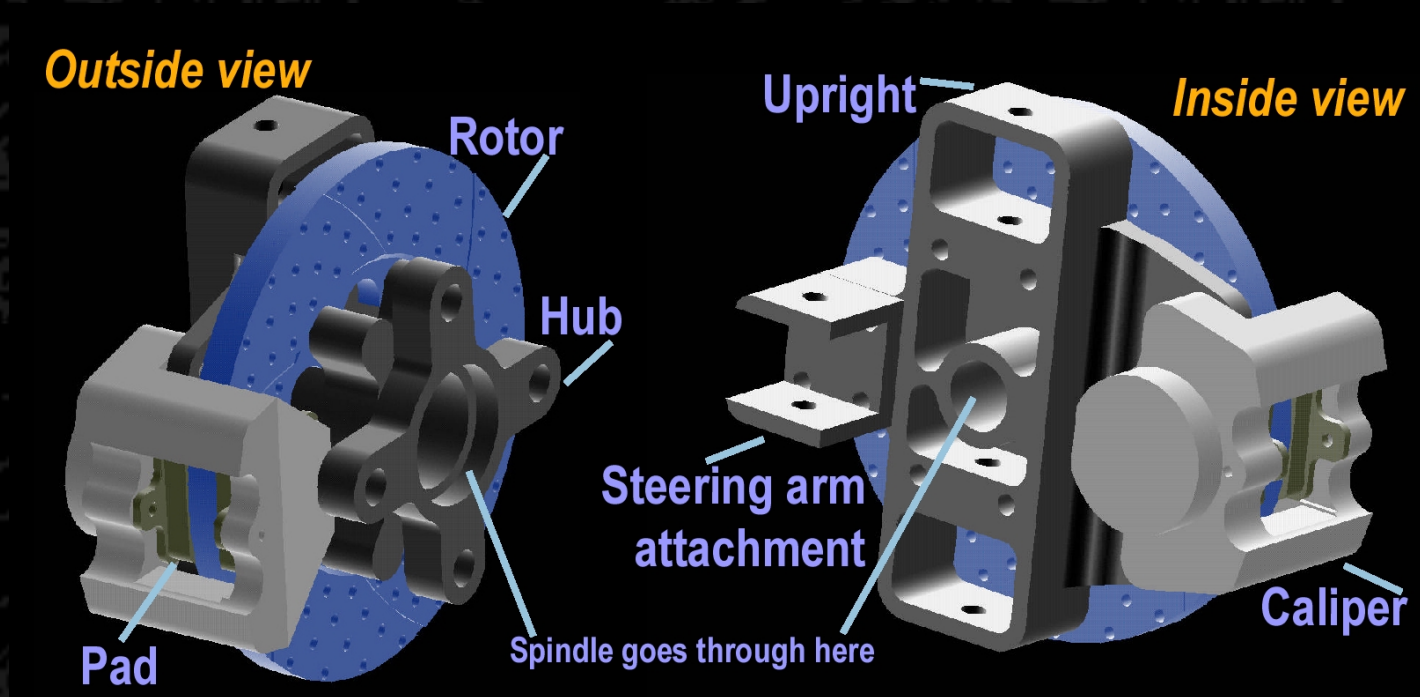
Suspension Update

Intro/Update
Front axle
Rear axle
Specifications
The Future

- Repositioned all shock absorber attachment points for reduced bending loads and optimized load paths
- Grounded rear track rod/toe link for strength
- Completed final parts for all corners of the car
- Rethought items for reliability and adjustability

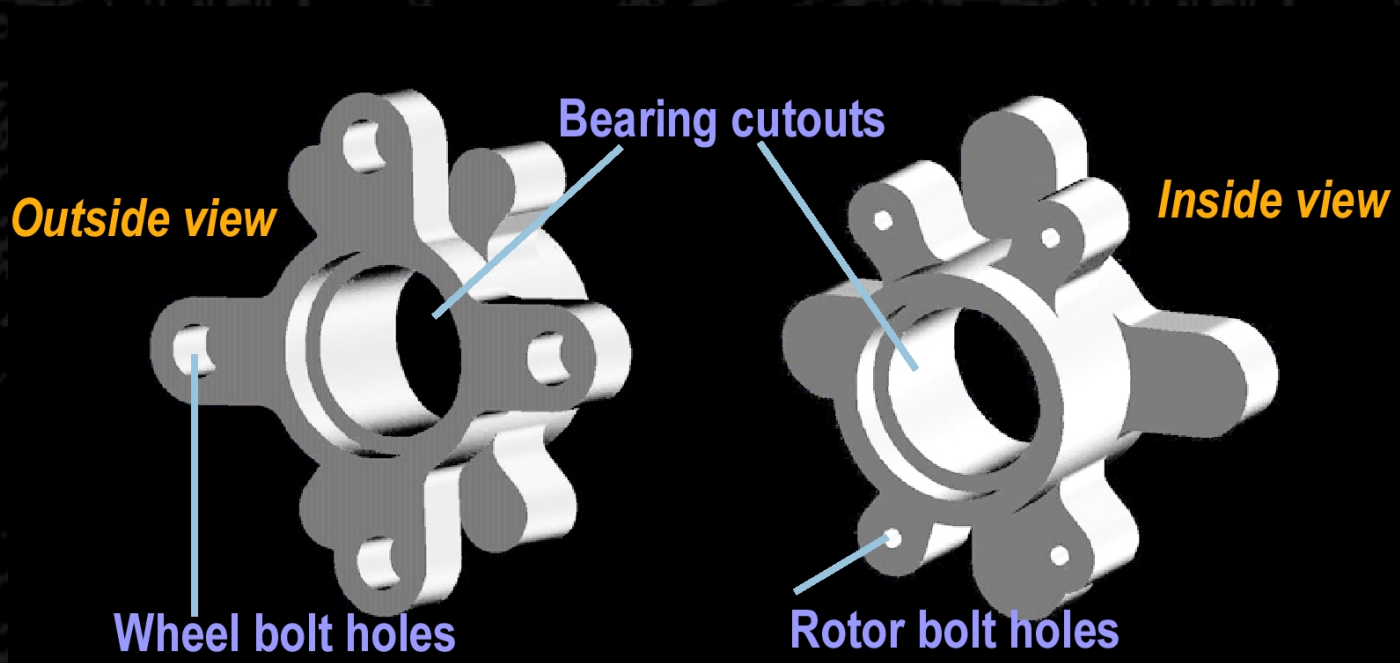
Front Axle

Intro/Update
Front axle
Rear axle
Specifications
The Future



Hub

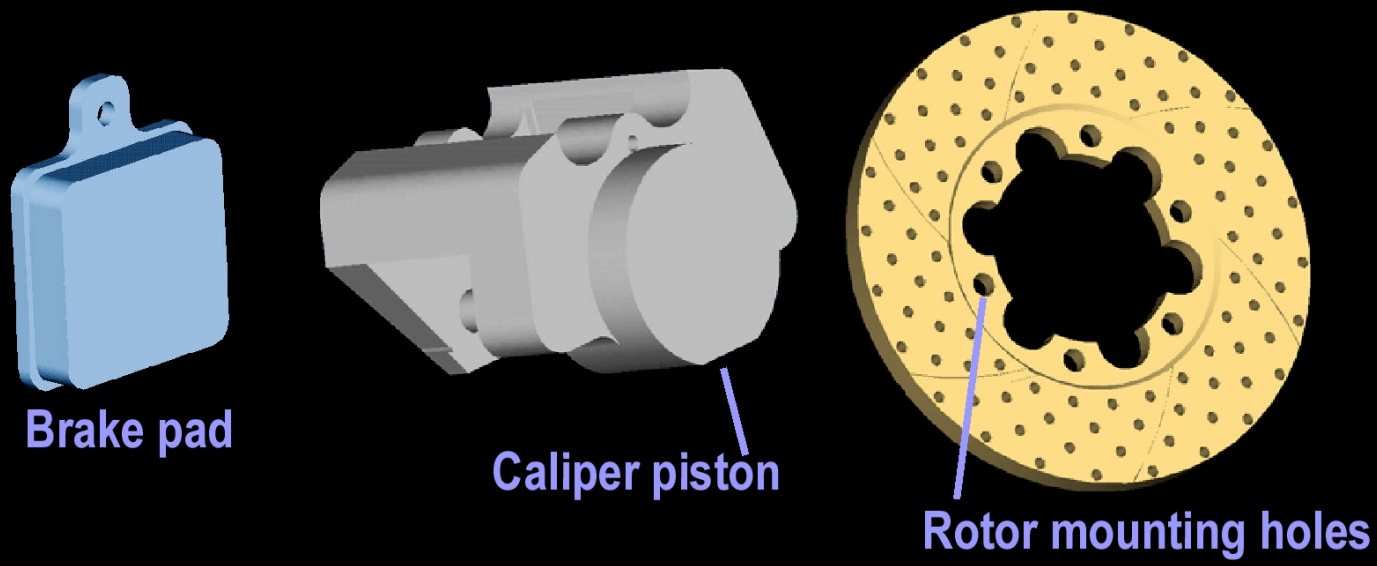
Intro/Update
Front axle
Rear axle
Specifications
The Future



Front Brakes

Intro/Update
Front axle
Rear axle
Specifications
The Future

- Wilwood 1.75” single piston floating calipers
- 7.5” diameter vented, cross-drilled, slotted, cast-iron rotors



Brake Considerations

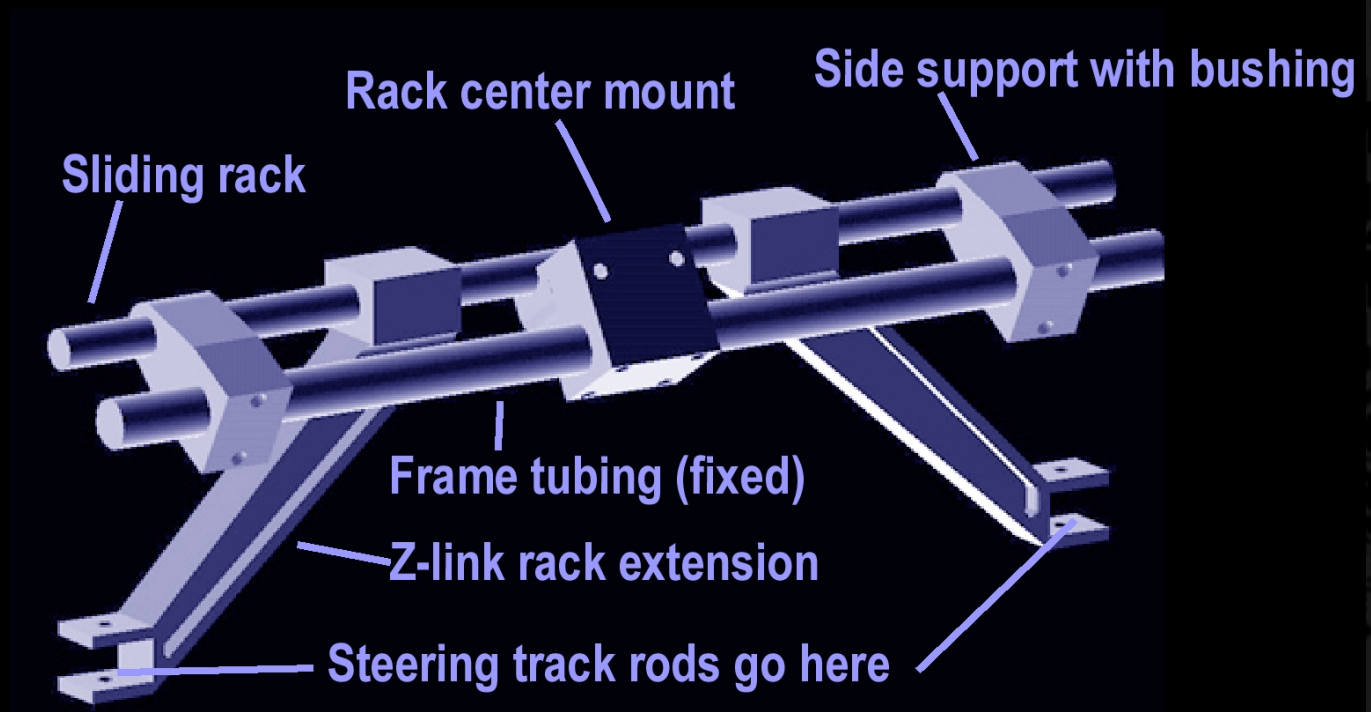
Intro/Update
Front axle
Rear axle
Specifications
The Future

- Deceleration (1.2G design)
  - dependent on fluid pressure, relative piston sizes, tire traction...
- Brake bias (60/40 design)
  - balance brake torque between front and rear tires
  - adjustable balance bar
- Cooling
  - 45 kJ of energy from 50 mph to 10 mph
  - about 20ºC rise in rotor temperature per stop

Steering System

Intro/Update
Front axle
Rear axle
Specifications
The Future

- Stiletto steering rack
- Alpha steering wheel (quick release)
- Various mounting components



Steering Considerations

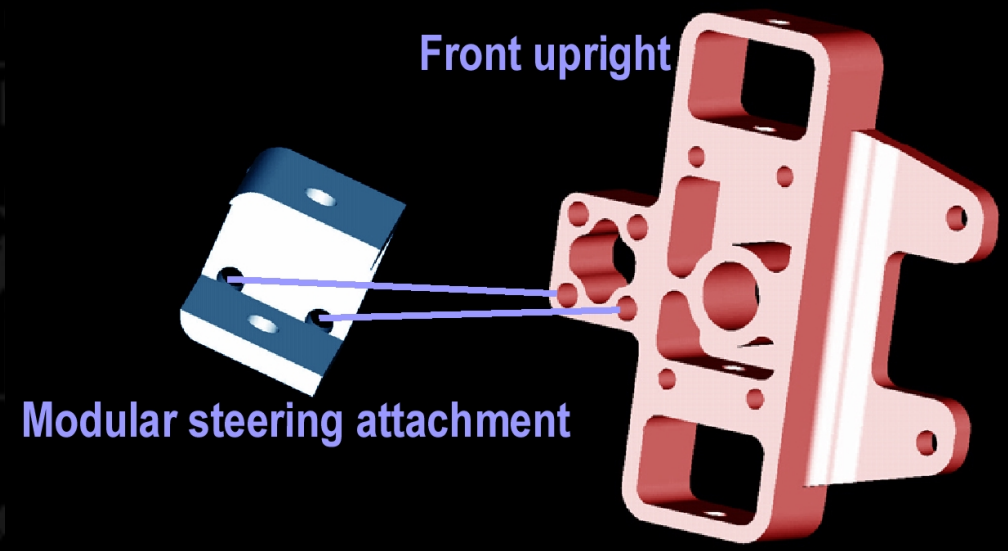
Intro/Update
Front axle
Rear axle
Specifications
The Future

- Ratio
  - 3.6:1 to 3.3:1, less than 1 turn lock to lock
- Ackermann geometry
  - difference in steering angle between inside and outside tires
  - inside tire turns more (smaller radius)
- Bump and compliance steer
  - wheels don't change direction over bumps or under load
  - determined by relative locations of suspension and steering points

Steering Outer Track Rod Attachment

Intro/Update
Front axle
Rear axle
Specifications
The Future

- **Modular attachment**
  - allows changes in steering geometry (Ackermann, bump steer, ratio) without refabricating the entire upright
  - reduces material usage



Reynard Kinematics

Intro/Update
Front axle
Rear axle
Specifications
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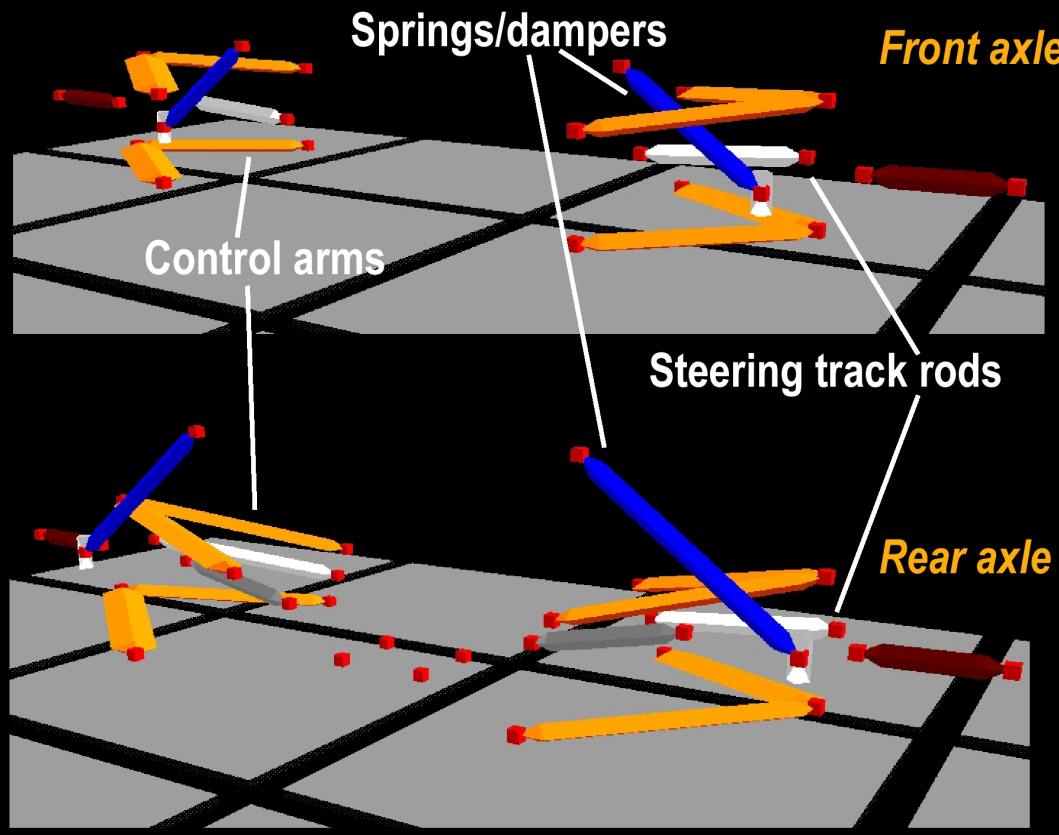
- Used to determine suspension and steering locations in pitch and roll



Rear Axle

Intro/Update
Front axle
Rear axle
Specifications
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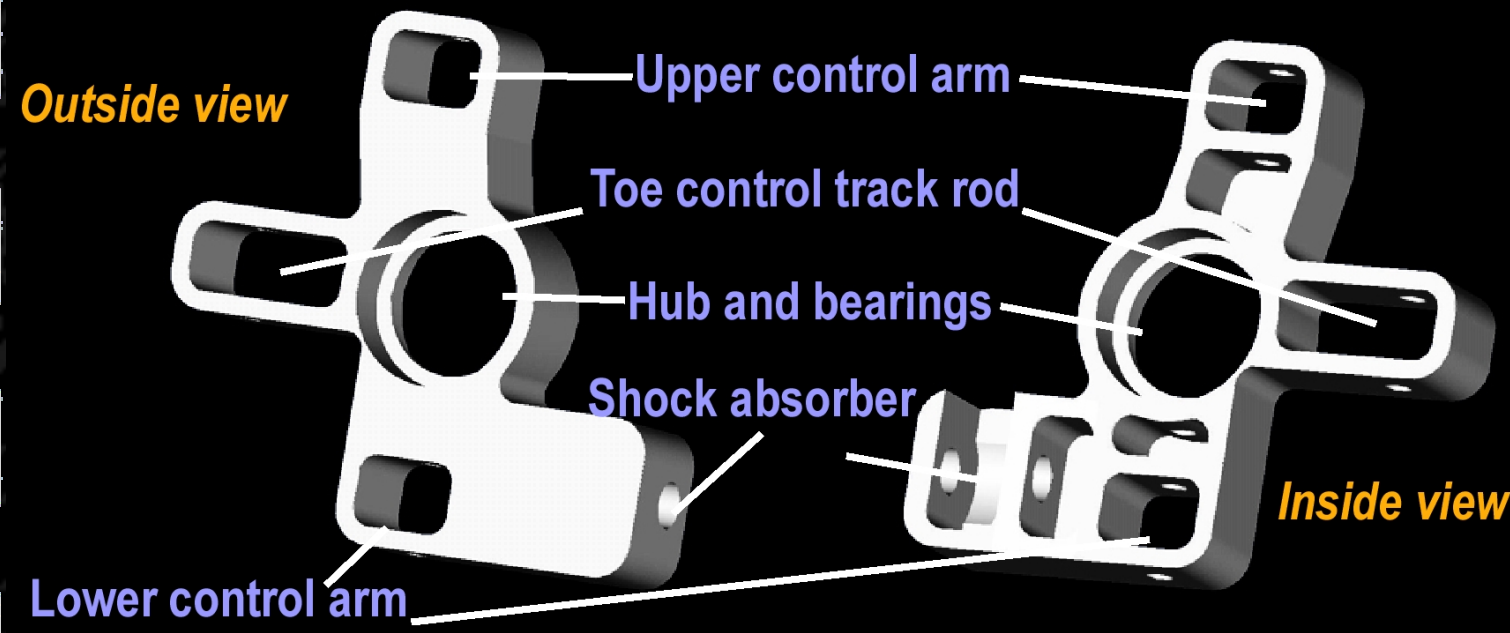

Rear Shock Extension

Intro/Update
Front axle
Rear axle
Specifications
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- Replaces lower spring perch and spherical bearing to gain adjustable length and flexibility

Rear Shock Mounting Points

Intro/Update
Front axle
Rear axle
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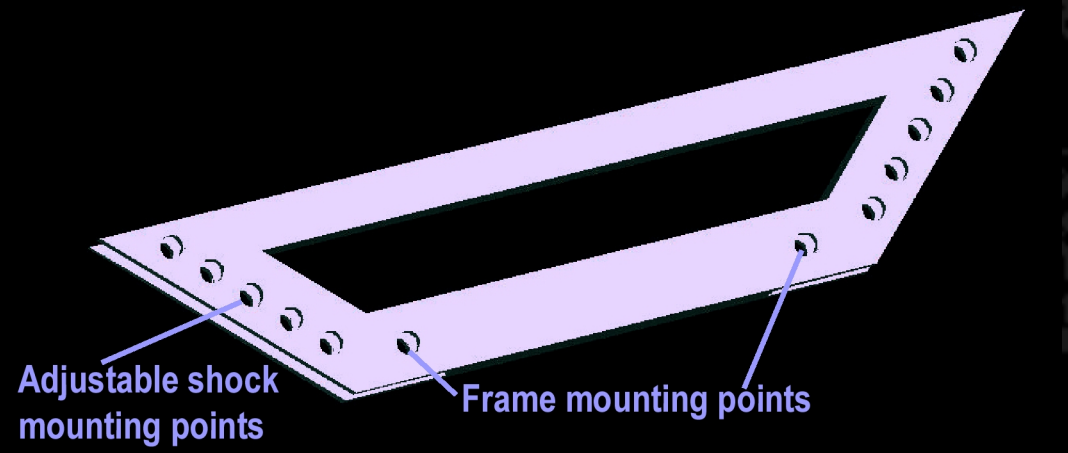
- Adjustable mounting points to balance car through corners
- Rear ride rate: 45 lb/in to 115 lb/in
- Use of locked spool axle requires different characteristics



Rear Axle Mount

Intro/Update
Front axle
Rear axle
Specifications
The Future

- Single inboard brake system
- Adjacent to drive chain and sprocket
- Adjustable position for chain tensioning

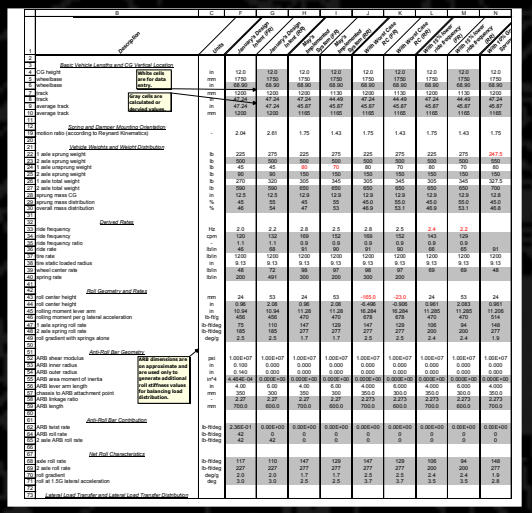
Rear axle plate for
axle bearings and caliper

Hub for
rear rotor

Suspension Specifications

Intro/Update
Front axle
Rear axle
Specifications
The Future

- Track: 1200mm / 1130mm
- Tire size: 18x7.5x10
- Camber: -1º / -1.5º
- Caster: 8.1º
- Scrub radius: 51.5 mm
- Motion ratios: 1.75 / adjustable
- Roll gradient: 1.6º per G nominal
- Ride frequencies: 2.2 Hz / 2.8 Hz nominal
- Anti-dive/squat: 12%



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Steering Specifications

Intro/Update
Front axle
Rear axle
Specifications
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- Steering System
- Ratio: 3.6:1 to 3.3:1
- Caster: 8.1º
- Scrub radius: 51.5 mm
- Steering wheel diameter: 250 mm
- Perfect Ackermann until 26º of inside wheel steering

Brake Specifications

Intro/Update
Front axle
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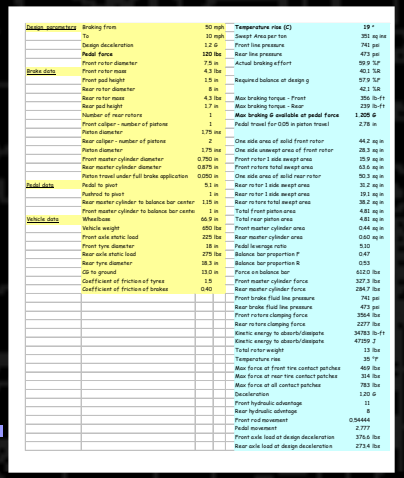
- Design deceleration: 1.2G
- Design pedal force: 120 lb.
- Swept area: 350 sq. in. / ton
- Rotor diameter: 7.5 in. / 8.0 in.
- Hydraulic advantage: 11:1 / 8:1
- Mechanical advantage: 5.1:1
- Fluid line pressure: 750 psi / 500 psi
- Brake bias: 40 / 60 nominal



Design parameters	Braking from	50 mph		Temperature rise (C)	19 °
	To	10 mph		Swept Area per ton	351 sq ins
	Design deceleration	1.2 G		Front line pressure	741 psi
	Pedal force	**120 lbs**		Rear line pressure	473 psi
	Front rotor diameter	7.5 in		Actual braking effort	59.9 %F
Brake data	Front rotor mass	4.3 lbs			40.1 %R
	Front pad height	1.5 in		Required balance at design g	57.9 %F
	Rear rotor diameter	8 in			42.1 %R
	Rear rotor mass	4.3 lbs		Max braking torque - Front	356 lb-ft
	Rear pad height	1.7 in		Max braking torque - Rear	239 lb-ft
	Number of rear rotors	1		**Max braking G available at pedal force**	**1.205 G**
	Front caliper - number of pistons	1		Pedal travel for 0.05 in piston travel	2.78 in
	Piston diameter	1.75 ins			
	Rear caliper - number of pistons	2		One side area of solid front rotor	44.2 sq in
	Piston diameter	1.75 ins		One side unswept area of front rotor	28.3 sq in
	Front master cylinder diameter	0.750 in		Front rotor 1 side swept area	15.9 sq in
	Rear master cylinder diameter	0.875 in		Front rotors total swept area	63.6 sq in
	Piston travel under full brake application	0.050 in		One side area of solid rear rotor	50.3 sq in
Pedal data	Pedal to pivot	5.1 in		Rear rotor 1 side swept area	31.2 sq in
	Pushrod to pivot	1 in		Rear rotor 1 side swept area	19.1 sq in
	Rear master cylinder to balance bar center	1.15 in		Rear rotors total swept area	38.2 sq in
	Front master cylinder to balance bar centre	1 in		Total front piston area	4.81 sq in
Vehicle data	Wheelbase	66.9 in		Total rear piston area	4.81 sq in
	Vehicle weight	650 lbs		Front master cylinder area	0.44 sq in
	Front axle static load	225 lbs		Rear master cylinder area	0.60 sq in
	Front tyre diameter	18 in		Pedal leverage ratio	5.10
	Rear axle static load	275 lbs		Balance bar proportion F	0.47
	Rear tyre diameter	18.3 in		Balance bar proportion R	0.53
	CG to ground	13.0 in		Force on balance bar	6120 lbs
	Coefficient of friction of tyres	1.5		Front master cylinder force	327.3 lbs
	Coefficient of friction of brakes	0.40		Rear master cylinder force	284.7 lbs
				Front brake fluid line pressure	741 psi
				Rear brake fluid line pressure	473 psi
				Front rotors clamping force	3564 lbs
				Rear rotors clamping force	2277 lbs
				Kinetic energy to absorb/dissipate	34783 lb-ft
				Kinetic energy to absorb/dissipate	47159 J
				Total rotor weight	13 lbs
				Temperature rise	35 °F
				Max force at front tire contact patches	469 lbs
				Max force at rear tire contact patches	314 lbs
				Max force at all contact patches	783 lbs
				Deceleration	1.20 g
				Front hydraulic advantage	11
				Rear hydraulic advantage	8
				Front rod movement	0.54444
				Pedal movement	2.777
				Front axle load at design deceleration	376.6 lbs
				Rear axle load at design deceleration	273.4 lbs

Future Work

Intro/Update
Front axle
Rear axle
Specifications
The Future

- Successfully implemented suspension, steering, brake systems
- Short term work:
  - brake hydraulics
  - rear axle items
- Long term work:
  - testing
  - reliability vs. weight assessment
  - re-evaluate many technical details to optimize the car

Recommendations

Intro/Update
Front axle
Rear axle
Specifications
The Future

- Full car model to resolve clearance details
- Larger wheel diameter

Acknowledgments

- The entire MAE department
  - too many people to list
- Other Formula SAE teams

Questions

Intro/Update

Front axle

Rear axle

Specifications

The Future