Optimization of vehicle handling performance by increasing the ARB effectiveness

Date :- 22 June 2010

BY

Dr. A K Jindal, M.G. Belsare and T. M. Arun Prakash

Contents

- Vehicle Specifications
- Suspension System Configuration
- Subjective Appraisal and Problem Statement
- Concept Evaluation
- Concept Finalization
- Modified Component List and System Configuration
- Design Of Experiments
- Summary
- Subjective Evaluation
- Conclusions
- References

Contents

- Vehicle Specifications
- Suspension System Configuration
- Subjective Appraisal and Problem Statement
- Concept Evaluation
- Concept Finalization
- Modified Component List and System Configuration
- Design Of Experiments
- Summary
- Subjective Evaluation
- Conclusions
- References


GRANDE MK II
More than meets the eye
TATA MOTORS

Vehicle Specifications

Sr.	System	Details
1	**Engine**	2.2 L 16 Valve DOHC DICOR and 2179 CC
2	**Steering**	RCBT steering gear box with power steering and collapsible with tilt steering column
3	**Suspension**	
	Front	Double wishbone type with coil spring
	Rear	Solid Axle (Hotchkiss drive) with parabolic leaf spring
4	**Tyres**	235 / 70 R 16 Tubeless tires
5	**Brake**	
	Actuation	Hydraulic brakes with Vacuum Assisted
	Foundation	Ventilated disc with twin pot caliper at front and Auto adjusted drum brake on rear

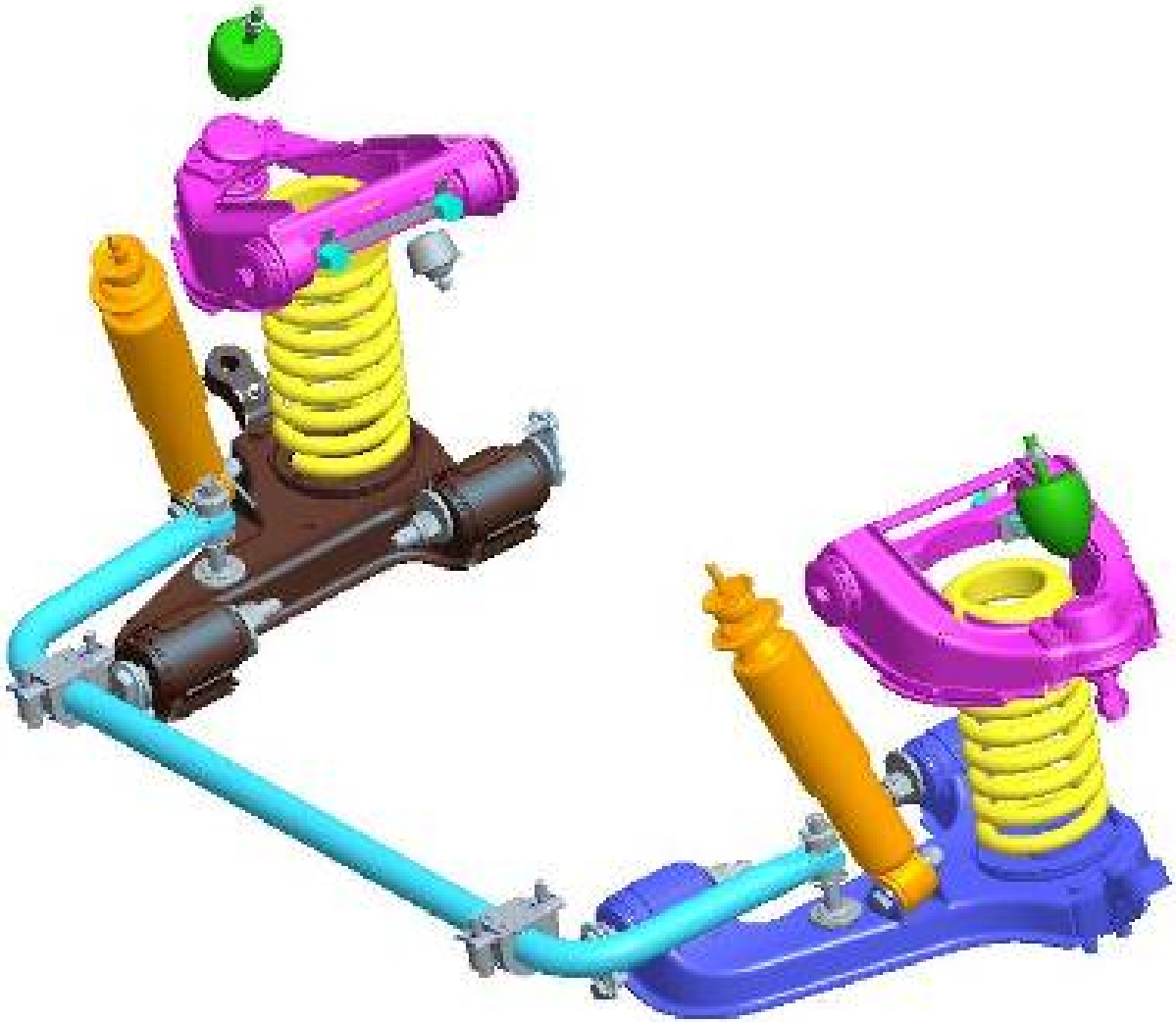
Chassis Dimension

Sl No	Details	Unit	Front	Rear
1	Unladen weight	Kg	1000	950
2	Track	mm	1496	1490
3	Overall length	mm	4421	
4	Max Width	mm	1780	
5	Overall Height	mm	1940	
6	Ground Clearance	mm	180	
7	Turing Radius	m	5.25	
8	Wheel Base	mm	2550	

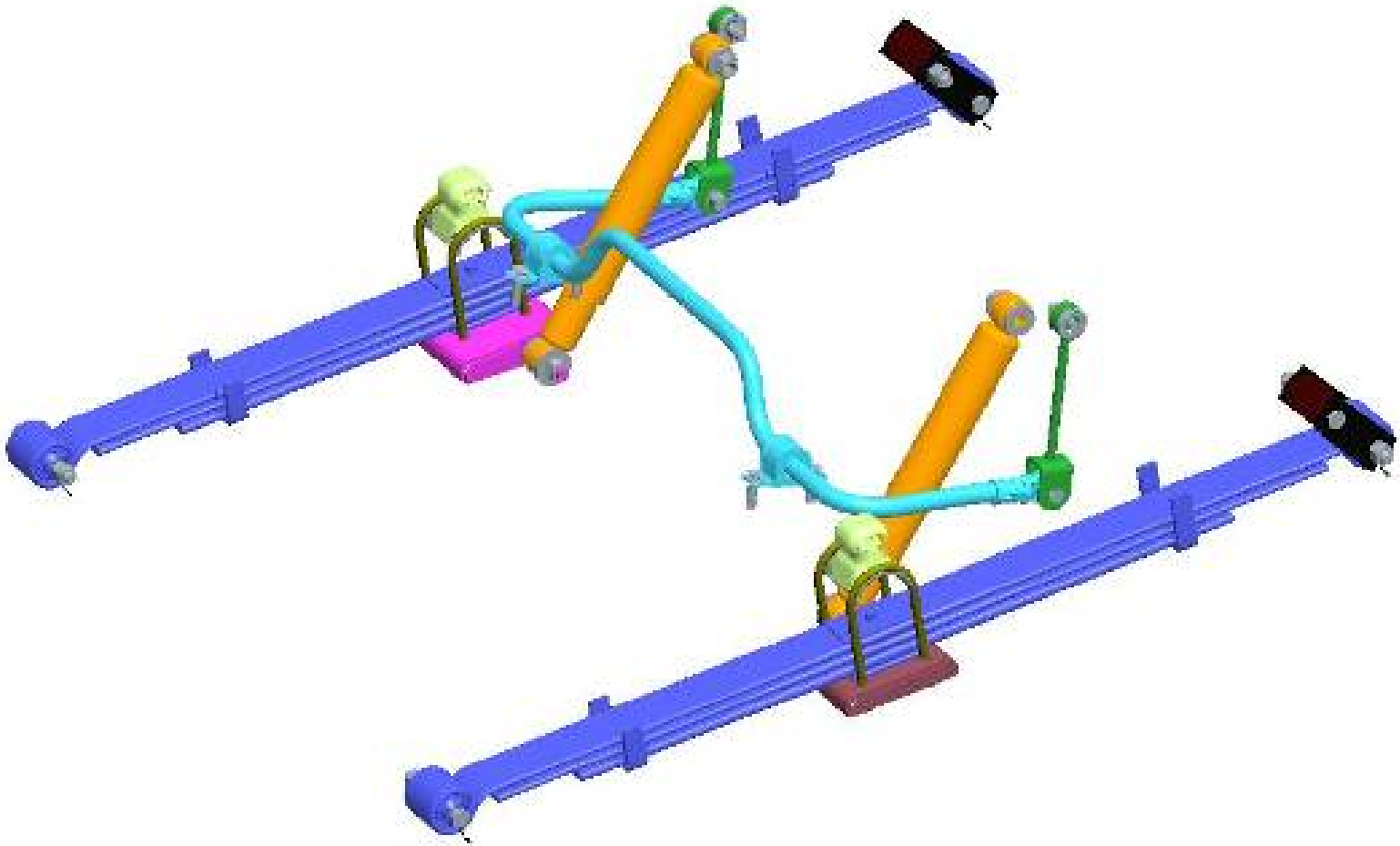
Contents

- Vehicle Specifications
- Suspension System Configuration
- Subjective Appraisal and Problem Statement
- Concept Evaluation
- Concept Finalization
- Modified Component List and System Configuration
- Design Of Experiments
- Summary
- Subjective Evaluation
- Conclusions
- References

Front Suspension View



Rear Suspension View



Demands of SUV from the suspension system

- To minimize the low frequency motions of the sprung masses (i.e.) bouncing, rolling, pitching ground 1 Hz.
- To avoid compiling between suspension resonances and chassis vibrations.
- rolling of the body ↓
- corner stability ↑
- braking stability ↑

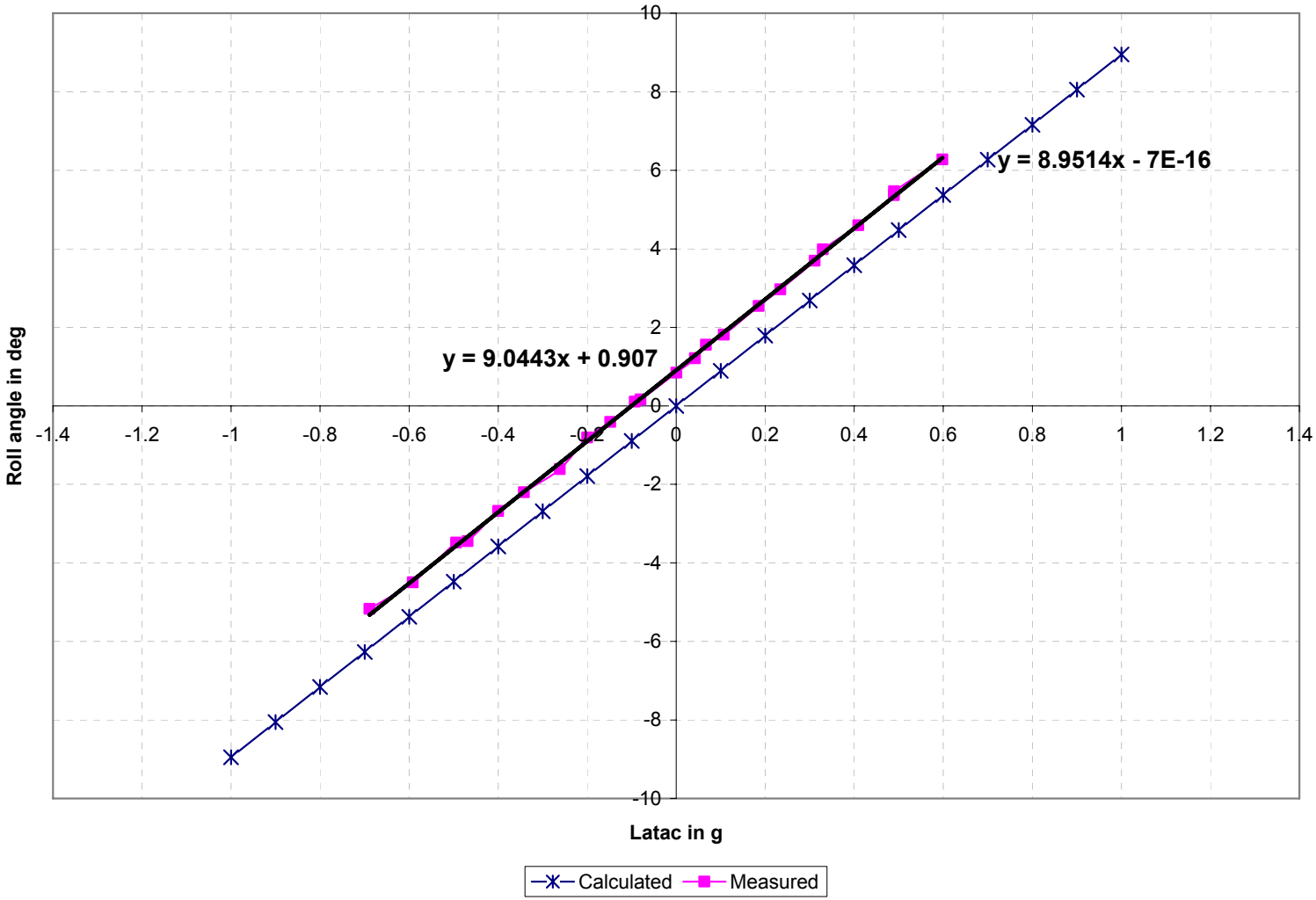
Demands of SUV from the suspension system

- force at the steering wheel ↓
- effects due to loading variations between one driver & full load ↓
- Strong package boundaries ↑
- ground clearance ↑

Suspension System Configuration

Sl. No	Description	Unit	Front	Rear
1	Ride Frequency	Hz	1.5	1.6
2	Unladen Ride Travel	mm	45	84
3	Roll Center Height	mm	26	242
4	CG from the ground	mm	725	
5	ARB Dia	mm	32	22
6	ARB Stiffness	Kg m/deg	177	26
7	ARB Effectiveness at the wheels	Kg m/deg	24	13
8	Total Roll stiffness of the vehicle	Kg m/deg	97	61
9	% of ARB Contribution in the roll stiffness	%	16.5	16.4

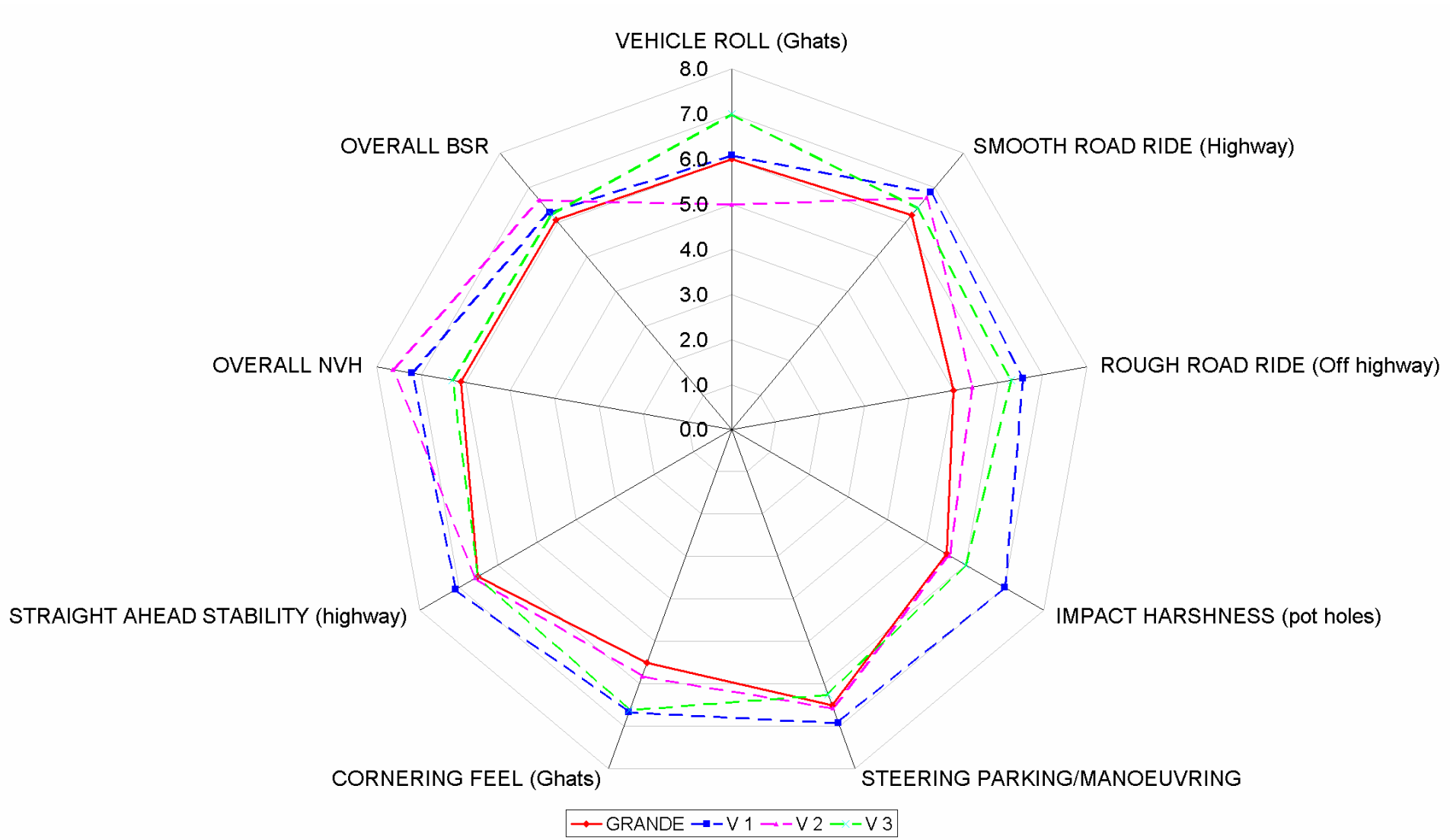
Roll Gradient Measured and Calculated



Contents

- Vehicle Specifications
- Suspension System Configuration
- Subjective Appraisal and Problem Statement
- Concept Evaluation
- Concept Finalization
- Modified Component List and System Configuration
- Design Of Experiments
- Summary
- Subjective Evaluation
- Conclusions
- References

Subjective Appraisal of GRANDE MK-I with Benchmarks



Problem Statement

- Roll of the vehicle is high when compared with benchmark vehicle
- Ride is Harsh
- Pitching
- Poor Cornering feel at the Hilly regions

Contents

- Vehicle Specifications
- Suspension System Configuration
- Subjective Appraisal and Problem Statement
- Concept Evaluation
- Concept Finalization
- Modified Component List and System Configuration
- Design Of Experiments
- Summary
- Subjective Evaluation
- Conclusions
- References

Concept Evaluation

- Roll gradient of the vehicle to be reduced without changing the suspension hard points

- Options to reduce the roll gradient of the vehicle

  1. front roll stiffness ↑

  2. rear roll stiffness ↑

Design options

- Options for Roll stiffness ↑

1) spring stiffness ↑
2) diameter of the ARB ↑
3) spring track ↑
4) Change the geometry of the ARB

Design option Finalization

1) spring stiffness ↑ ----Ride Comfort

2) diameter of the ARB ↑ ----weight and effectiveness

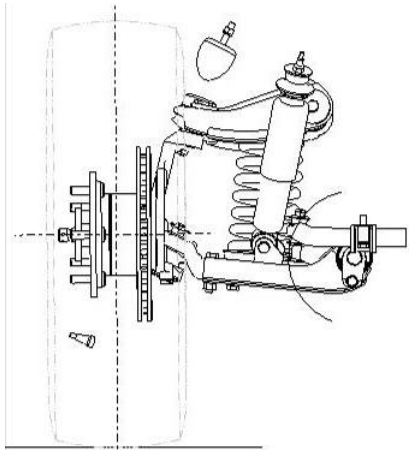
3) spring track ↑ ----Packaging constraint and hard point change

4) Change the geometry of the ARB

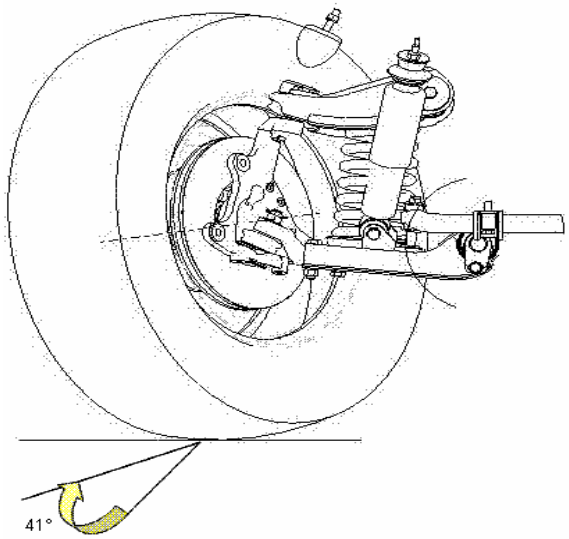
Existing ARB Details

- Mounted on the wishbone --single degree of freedom
- End link is conventional (Bush- Bush)
- effectiveness is less
- 16% of its total roll stiffness

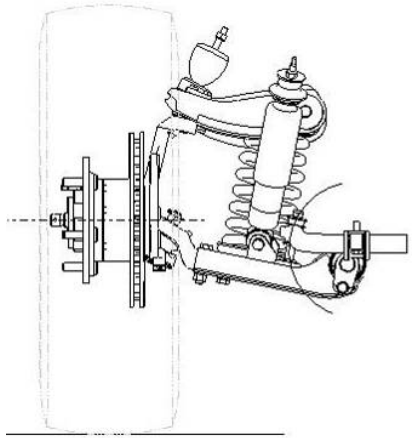
Existing ARB movement in Different Conditions



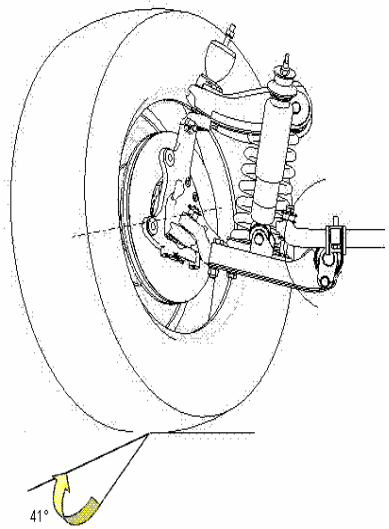
Unladen Straight Ahead



Unladen Full Inner turn

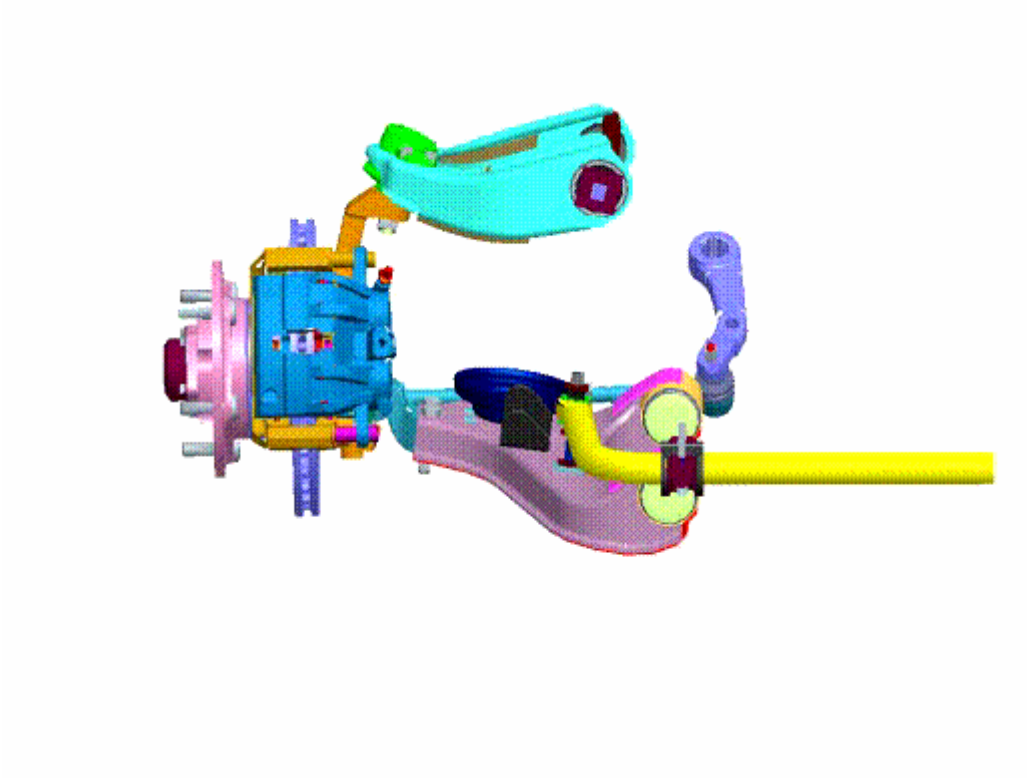


Bump Straight Ahead



Bump Full Inner Turn

Steering and Suspension Motion Clip



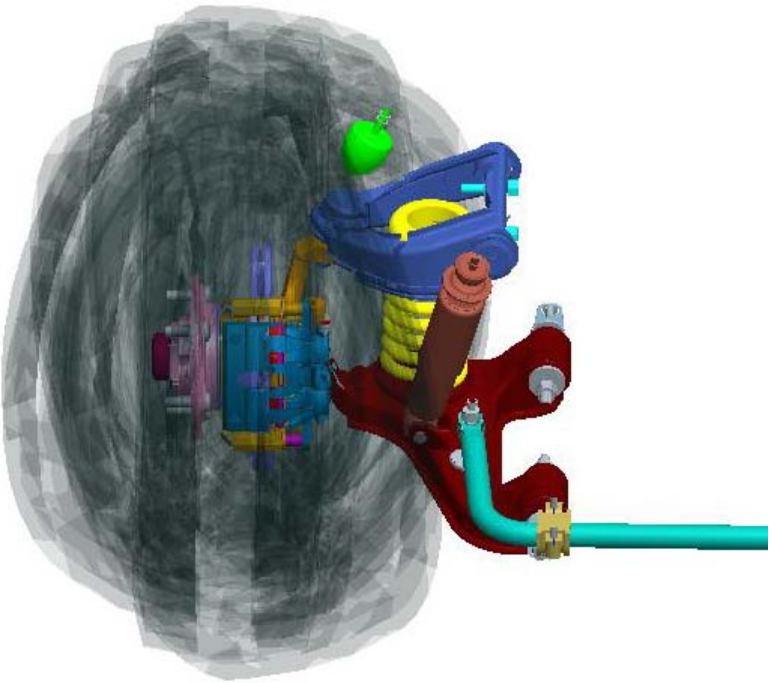
Contents

- Vehicle Specifications
- Suspension System Configuration
- Subjective Appraisal and Problem Statement
- Concept Evaluation
- Concept Finalization
- Modified Component List and System Configuration
- Design Of Experiments
- Summary
- Subjective Evaluation
- Conclusions
- References

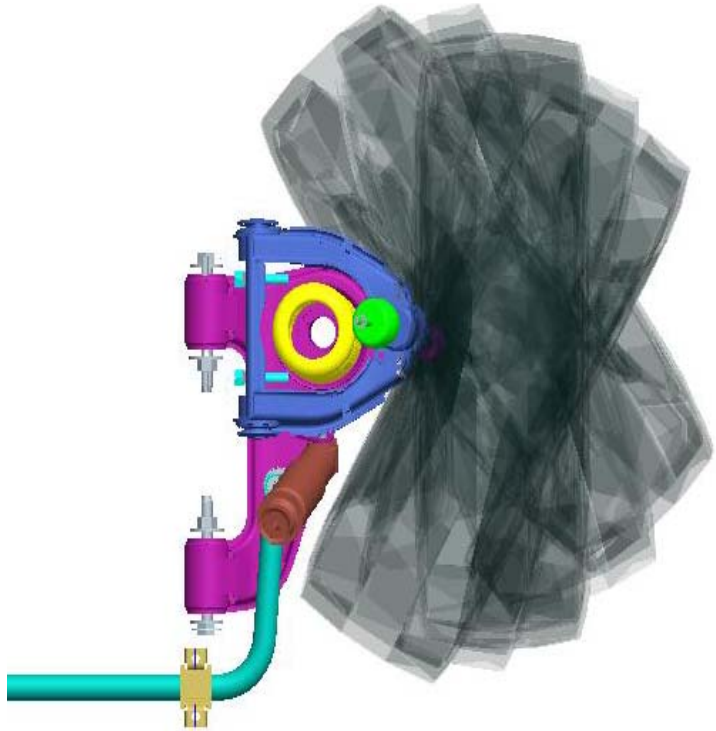
Concept Finalization

- Relocation is critical due to the wheel envelope clearance.

Rotated Front View



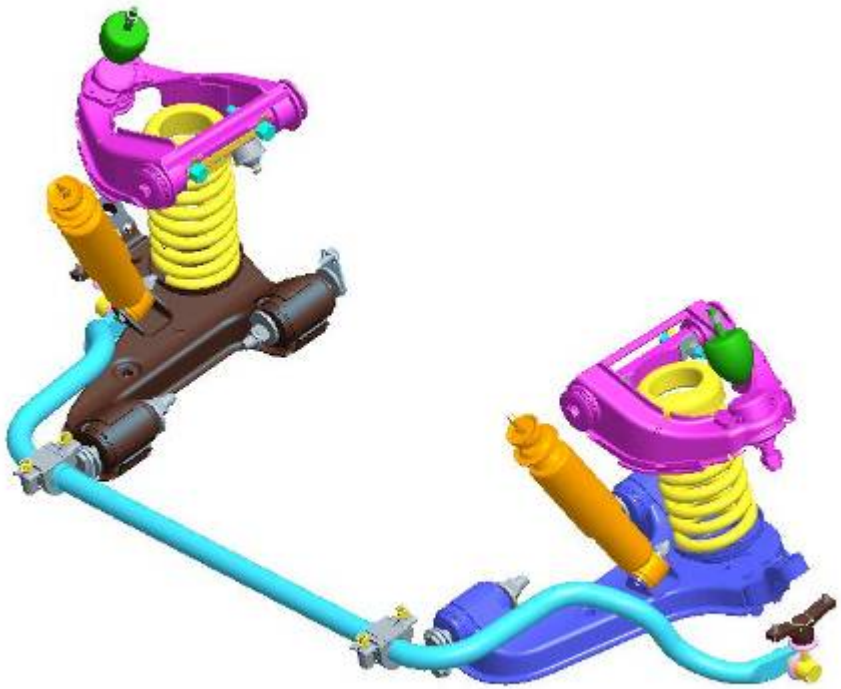
Top View



Cont…

- Joining the ARB in the stub Axle which has two degrees of the freedom
  - ➢vertical motion (Up and Down for the bump and the rebound)
  - ➢the rotational movement along the KPI
- Mounting location of the ARB is optimized on the bottom of the stub Axle along the KPI Axis
- New Ball joint designed

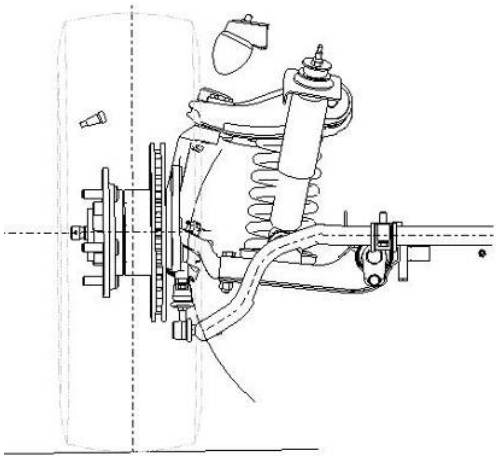
Modified ARB with Suspension System



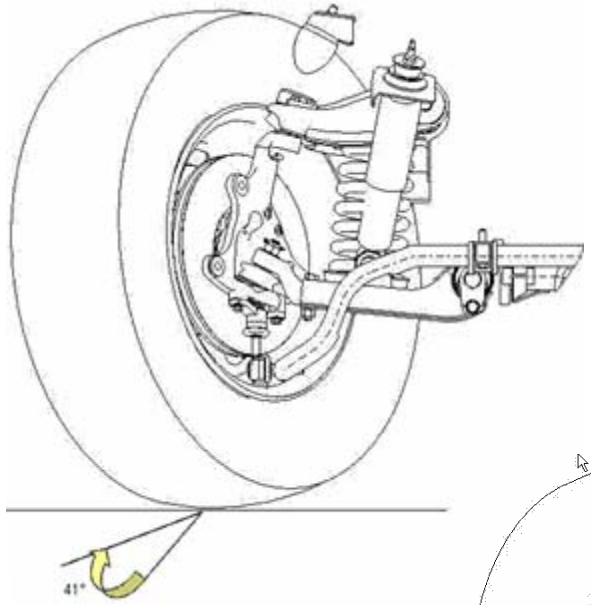
Ball Joint

Suspension System with the Wheel envelope

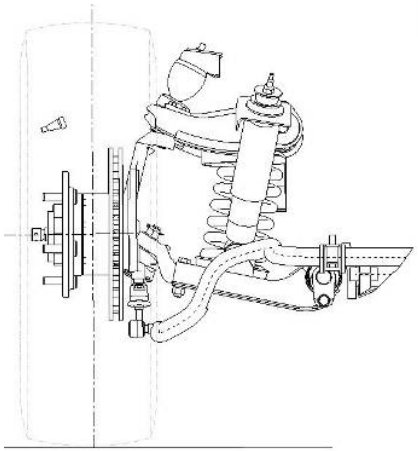
ARB Movement in Different Conditions



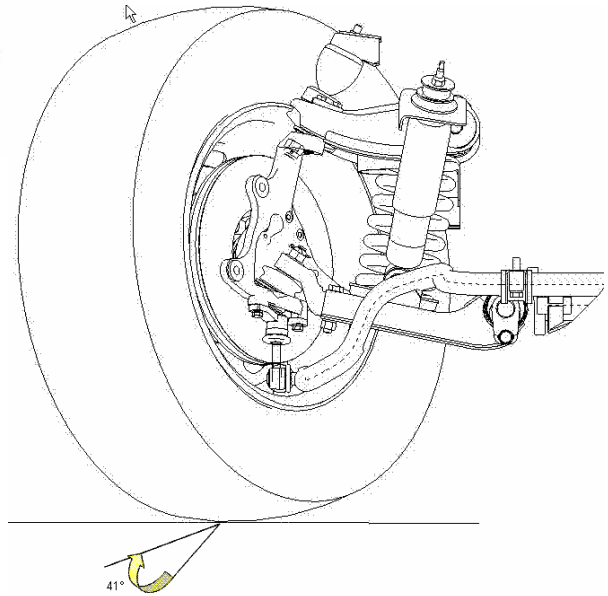
Unladen Straight Ahead



Unladen Full Inner turn

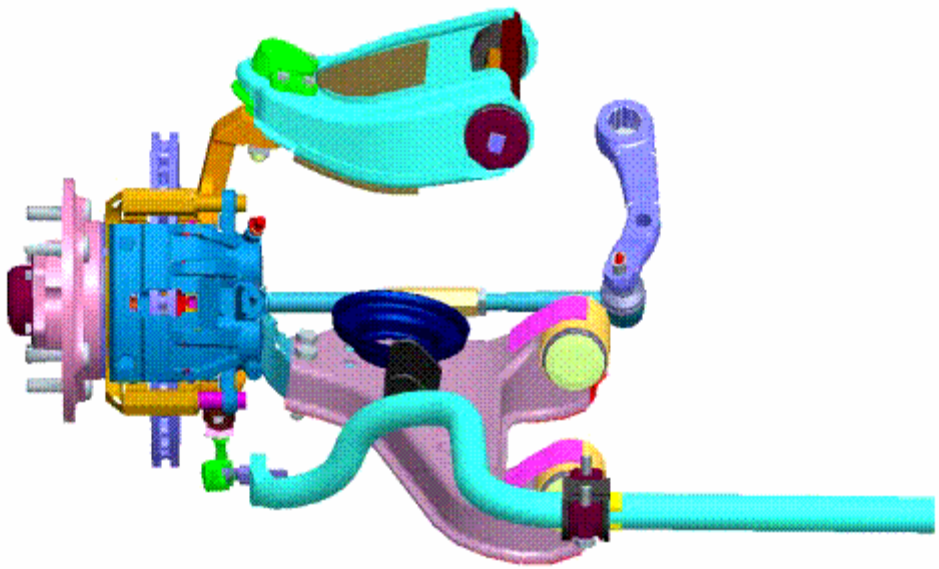


Bump Straight Ahead



Bump Full Inner Turn

Steering and Suspension Motion Clip for Modified ARB



Contents

- Vehicle Specifications
- Suspension System Configuration
- Subjective Appraisal and Problem Statement
- Concept Evaluation
- Concept Finalization
- Modified Component List and System Configuration
- Design Of Experiments
- Summary
- Subjective Evaluation
- Conclusions
- References

Modified Component List

1. Stub Axle

2. ARB

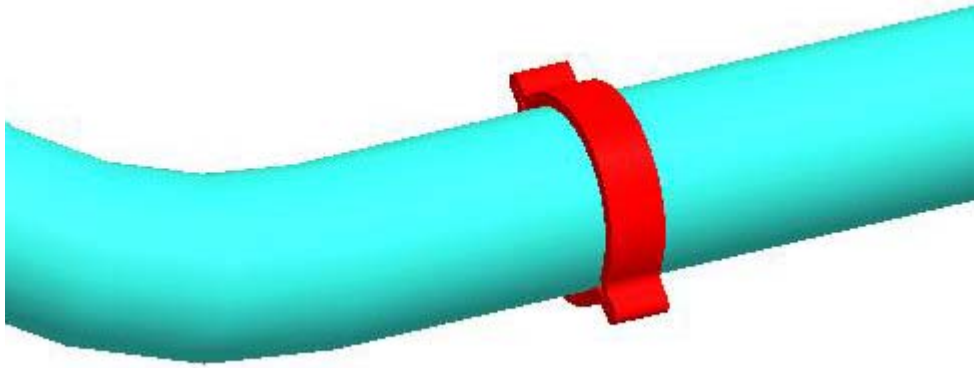
3. ARB Ball Joint

4. Lower wishbone

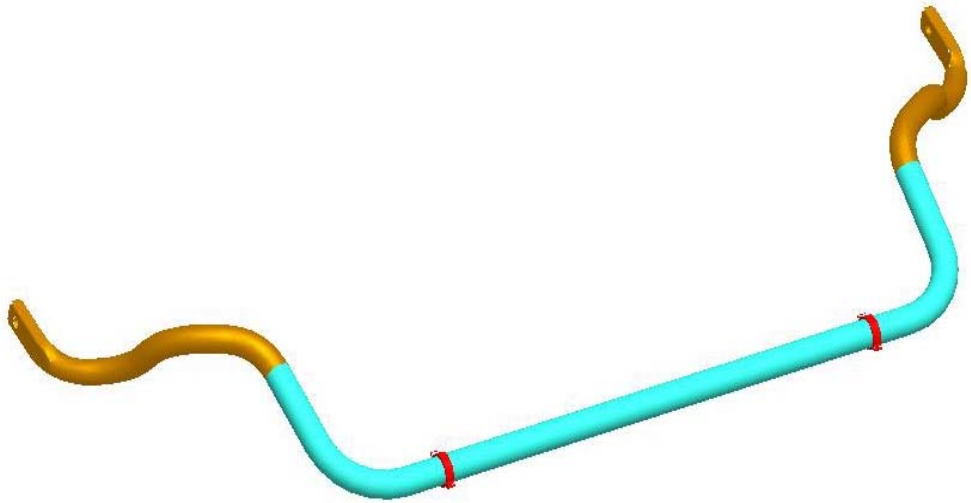
5. Shock Absorber mounting bracket Top and Bottom

Implementation Difficulties

- Crimping



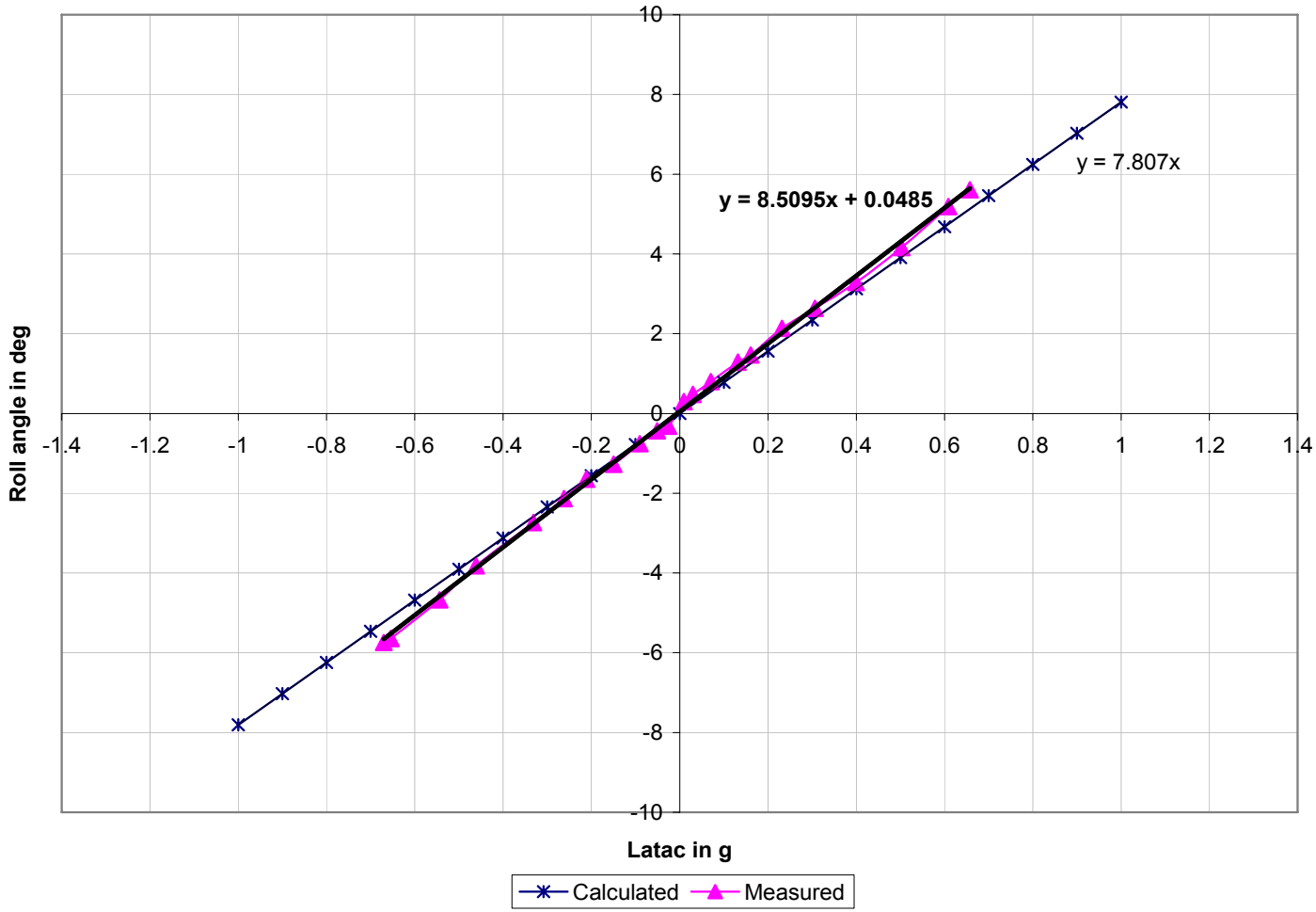
- Tapered ARB



Modified Suspension System Configuration

Sl. No	Description	Unit	Front Existing	Front Modified	Rear
1	Ride Frequency	Hz	1.5	1.5	1.6
2	Unladen Ride Travel	mm	45	45	84
3	Roll Center Height	mm	26	26	242
4	CG from the ground	mm	725	725	
5	ARB Dia	mm	32	30	22
6	Bar Rate	Kg m/deg	177	78	26
7	ARB Effectiveness at the wheels	Kg m/deg	24	57	13
8	Total Roll stiffness of the vehicle	Kg m/deg	97	117	61
9	% of ARB Contribution in the roll stiffness	%	16.5	30.8	16.4

Roll angle Vs Latac with wider front 30mm dia ARB and rear 22 mm dia ARB



Significance of Achievements

- Roll stiffness ↑ from 97 Kgm/ deg to 117 Kgm/deg
- 30.8 % of the total roll stiffness
- Roll of the vehicle ↓

Contents

- Vehicle Specifications
- Suspension System Configuration
- Subjective Appraisal and Problem Statement
- Concept Evaluation
- Concept Finalization
- Modified Component List and System Configuration
- Design Of Experiments
- Summary
- Subjective Evaluation
- Conclusions
- References

Criteria for optimizations

- Balance between front and rear roll stiffness

- Higher overall levels of roll stiffness result in reduced body roll angles.

- To increase the effectiveness and to balance front and rear roll stiffness the following are the options

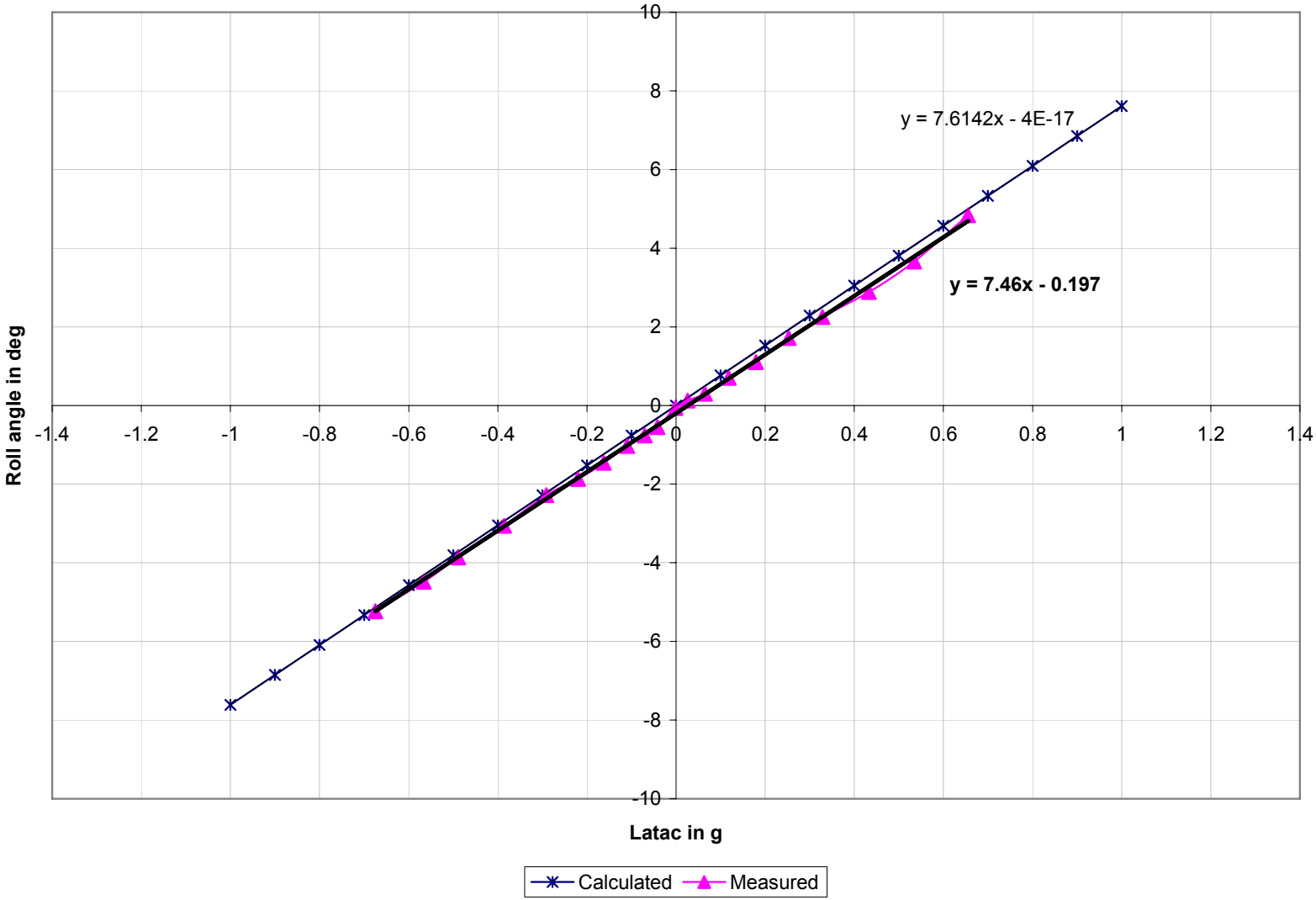
DOE

Options	A	B	C	D	E
Coil Spring Stiffness in kg/mm	14.4	14.4	14.4	14.4	12.8
Front ARB Dia in mm	30	32	32	32	32
Leaf Spring stiffness in kg/mm	4.7 / 7.8	4.7 / 7.8	4.7 / 7.8	4.7 / 7.8	4 / 7.5
Rear ARB Dia in mm	24	22	24	28	24

(A) Front ARB 30 mm diameter and Rear 24 mm diameter

Sl. No	Description	Unit	Front	Rear
1	ARB Dia	mm	30	24
2	Bar Rate	Kg m/deg	78	37
3	ARB Effectiveness at the wheels	Kg m/deg	57	18
4	Total Roll stiffness of the vehicle	Kg m/deg	117	65
5	% of ARB Contribution in the roll stiffness	%	30.80	21.50

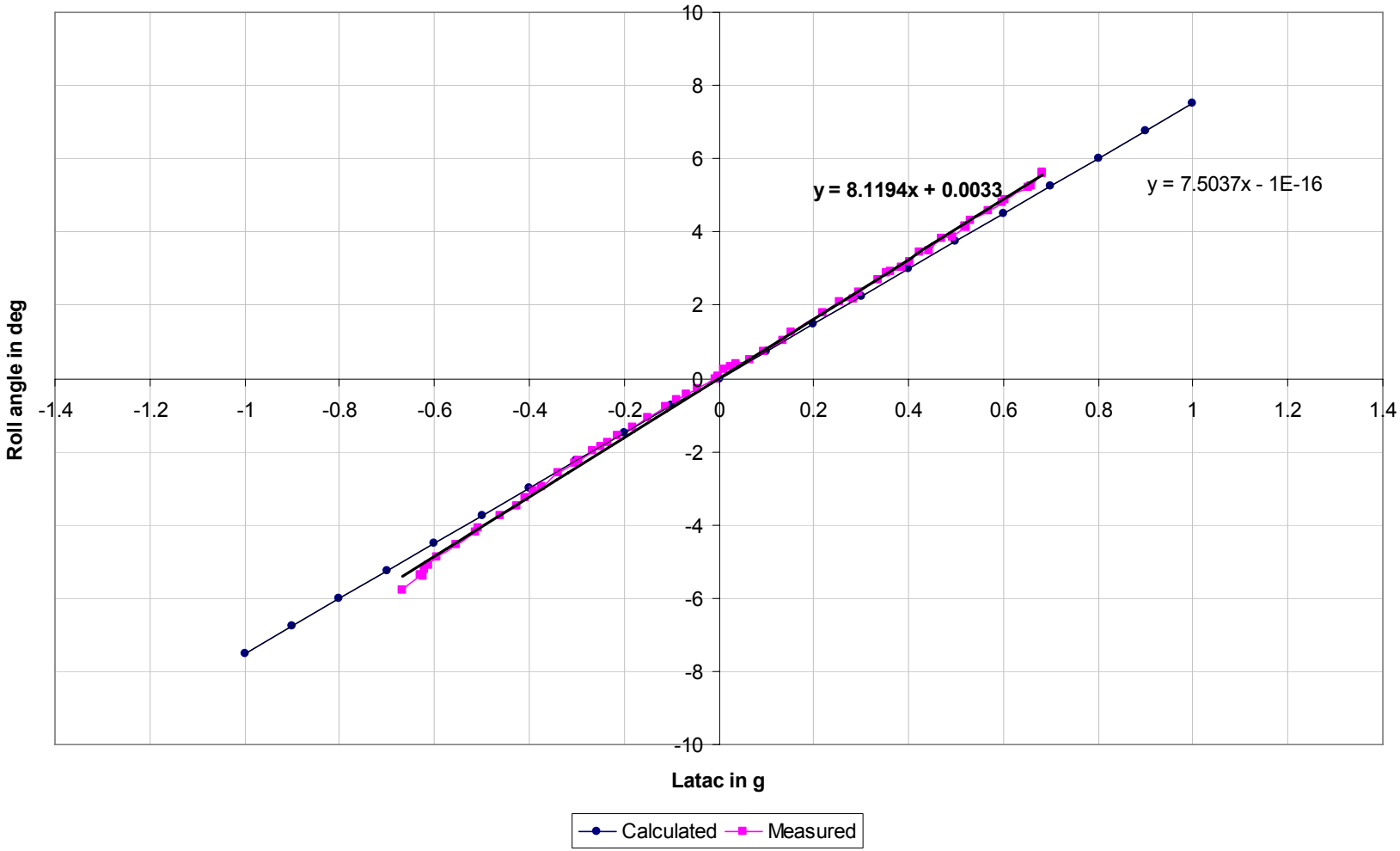
(A) Front ARB 30 mm diameter and Rear 24 mm diameter



(E) Front ARB 32 mm diameter and Rear 24 mm diameter with modified Spring Characteristics

Sl. No	Description	Unit	Front	Rear
1	Ride Frequency	Hz	1.45	1.51
2	Unladen Ride Travel	mm	45	89
3	Roll Center Height	mm	26	246
4	CG from the ground	mm	725	
5	ARB Dia	mm	32	24
6	Bar Rate	Kg m/deg	101	37
7	ARB Effectiveness at the wheels	Kg m/deg	74	18
8	Total Roll stiffness of the vehicle	Kg m/deg	123	58
9	% of ARB Contribution in the roll stiffness	%	38.2	24.13

(E) Front ARB 32 mm diameter and Rear 24 mm diameter with modified Spring Characteristics



Contents

- Vehicle Specifications
- Suspension System Configuration
- Subjective Appraisal and Problem Statement
- Concept Evaluation
- Concept Finalization
- Modified Component List and System Configuration
- Design Of Experiments
- Summary
- Subjective Evaluation
- Conclusions
- References

Summary of DOE

Sr.	Front Suspension				Rear Suspension		Calculated	Measured	
	Coil Spring Stiffness in kg/mm	ARB Dia in mm	ARB end Mtg	ARB Link Arrangement	Leaf Spring Stiffness in Kg/mm	ARB Dia in mm	Roll gradient in deg/g	Roll gradient in deg/g	U/S in deg/g
Base	14.4	32	Wishbone	Bush- Bush	4.7 / 7.8	22	**8.95**	**9.04**	**3.5**
modi	14.4	30	Stub Axle	Ball- Ball	4.7 / 7.8	22	**7.81**	**8.51**	**5.55**
A	14.4	30	Stub Axle	Ball- Ball	4.7 / 7.8	24	**7.61**	**7.46**	**4.74**
B	14.4	32	Stub Axle	Ball- Ball	4.7 / 7.8	22	**7.36**	**7.01**	**3.86**
C	14.4	32	Stub Axle	Ball- Ball	4.7 / 7.8	24	**7.19**	**7.16**	**4.17**
D	14.4	32	Stub Axle	Ball- Ball	4.7 / 7.8	28	**7.06**	**7.33**	**2.91**
E	12.8	32	Stub Axle	Ball- Ball	4.0 / 7.5	24	**7.5**	**8.12**	**3.8**

Contents

- Vehicle Specifications
- Suspension System Configuration
- Subjective Appraisal and Problem Statement
- Concept Evaluation
- Concept Finalization
- Modified Component List and System Configuration
- Design Of Experiments
- Summary
- Subjective Evaluation
- Conclusions
- References

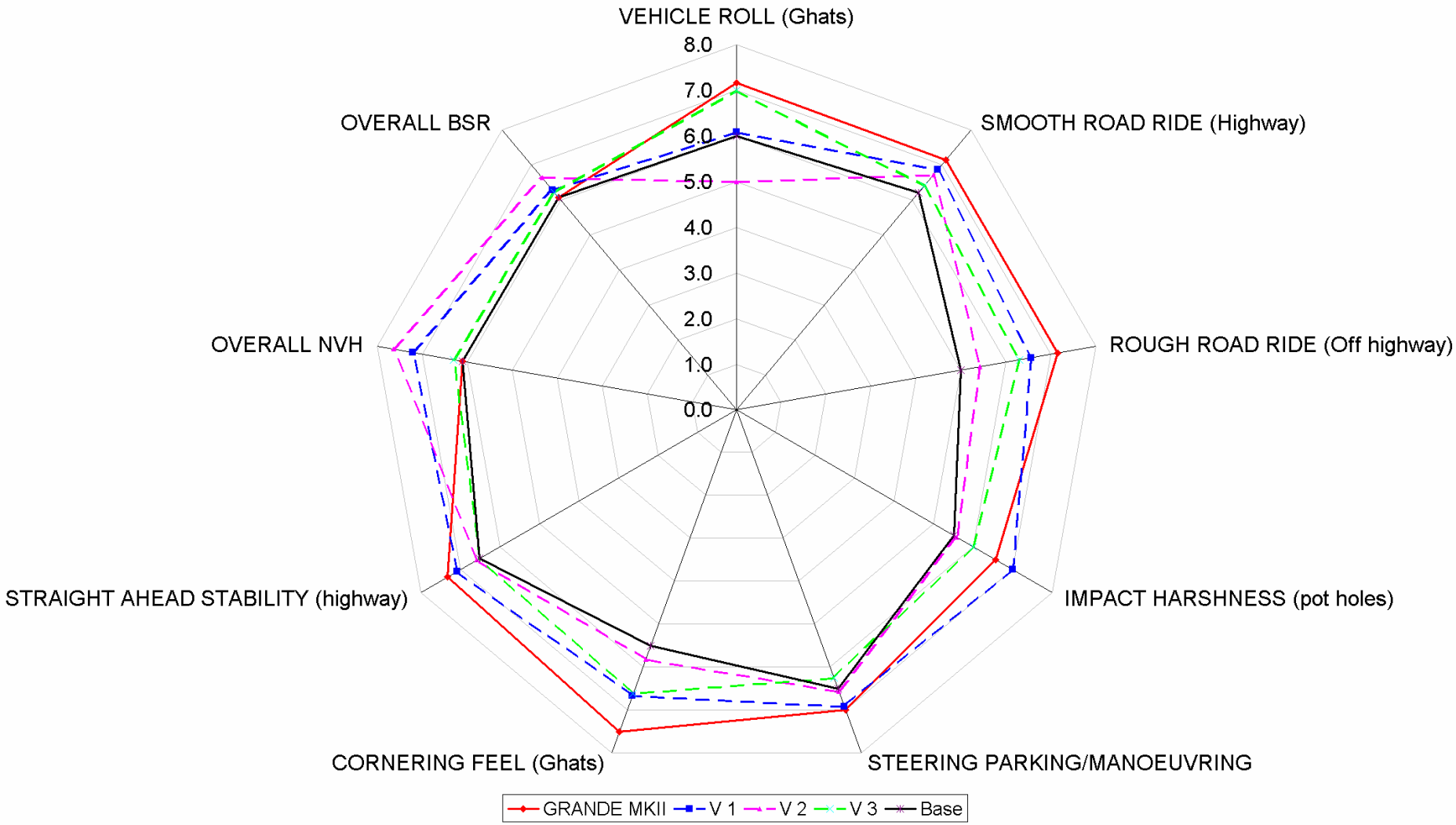
Subjective Evaluation

- always the final judgment
  - it is practical
  - account many different conditions of the vehicle use.

- Parameters evaluated subjectively for the DOE configurations.
  - Straight running Stability
  - Lane change maneuverability
  - Cornering Stability
  - Steering effort.
  - Ride Comfort

- Option (E) holds good in the subjective evaluation for the above parameters.

Subjective Appraisal of GRANDE MK-II with Benchmarks



Contents

- Vehicle Specifications
- Suspension System Configuration
- Subjective Appraisal and Problem Statement
- Concept Evaluation
- Concept Finalization
- Modified Component List and System Configuration
- Design Of Experiments
- Summary
- Subjective Evaluation
- Conclusions
- References

Conclusions

- By joining the ARB along the KPI Axis
  - Steering Kinematics is isolated from the ARB motion path
  - Articulation of the Ball joint is optimized- (No side load)
- The effectiveness of the ARB is increased
- By mounting the ARB end to Stub axle 100 % motion ratio is achieved.

Contents

- Vehicle Specifications
- Suspension System Configuration
- Subjective Appraisal and Problem Statement
- Concept Evaluation
- Concept Finalization
- Modified Component List and System Configuration
- Design Of Experiments
- Summary
- Subjective Evaluation
- Conclusions
- References

References

1. J.Ed Maltinez and Richard J. Schlvetes, “A Primes on the Reconstruction Presentation of Rollover Accidents “ SAE 960647.
2. C.B.Winkler, S.M.Karamihas & S.E.Bogard “Roll Stability Performance of Heavy Vehicle Suspensions “SAE 922426
3. Aleksander Hac, “Rollover Stability Index Including Effects of Suspension Design “ SAE 2002-01-0965
4. Thomas J.Wielenga,” A Method for Reducing On-Road Rollovers Anti-Rollover Braking”, SAE 1999-01-0123
5. Micky C. Marine, Jeffrey L.Wirch & Terry M. Thomas, “Characteristics of On Road Rollover“, SAE 1999-01-0122
6. Manfred Fremberger, Florian Wolf, Gerd Scholpp & Juergen Schmidt, “Influences of Parameters at Vehicle Rollover “SAE 2000-01-2669.
7. H.Fred Chan & Dennis A. Gventher, “The Effects of Suspension Stiffness on Handling Responses “, SAE 911928.
8. P.M.Beuzit, “Ride & Handling of a European Car: The Renault 9 “ SAE 830981.
9. Peter Holdmann & Frank Berger, “Kinematics & Compliance of Sports Utility Vehicles “SAE 2001-01-0491.

Cont….

10. Akifumi Matsushita, Katsuji Takanami, Nobuyoshi Takeda & Masaro Takahashi, “ Subjective Evaluation & Vehicle Behavior in Lane Change Maneuvers “ , SAE 800845.
11. Thomas J.Wielenga,” Tire Properties Affecting Vehicle Rollover”, SAE 1999-01-0126.
12. Friedrich Jaksch,” Handling and Stability Volvo’s Experimental Safety Car’, SAE 730591.
13. D. A. Crolla, G. R. Firth and D. N. L. Horton, “Independent Vs Axle Suspension for On/Off Road Vehicles”, SAE 921662.
14. Nilson Barbieri,”Suspensions Optimization”, SAE 921491.
15. Thomas D. Gillespie, “Fundamentals of Vehicle Dynamics”, Society of Automotive Engineers, Inc.

Discussions

?

Thank You