



## **Synthetic Steering Torque Feedback**

**Dan Williams, Ph.D., P.E.**

**Chief Engineer, Global Advanced Engineering**

**TRW Commercial Steering Systems**

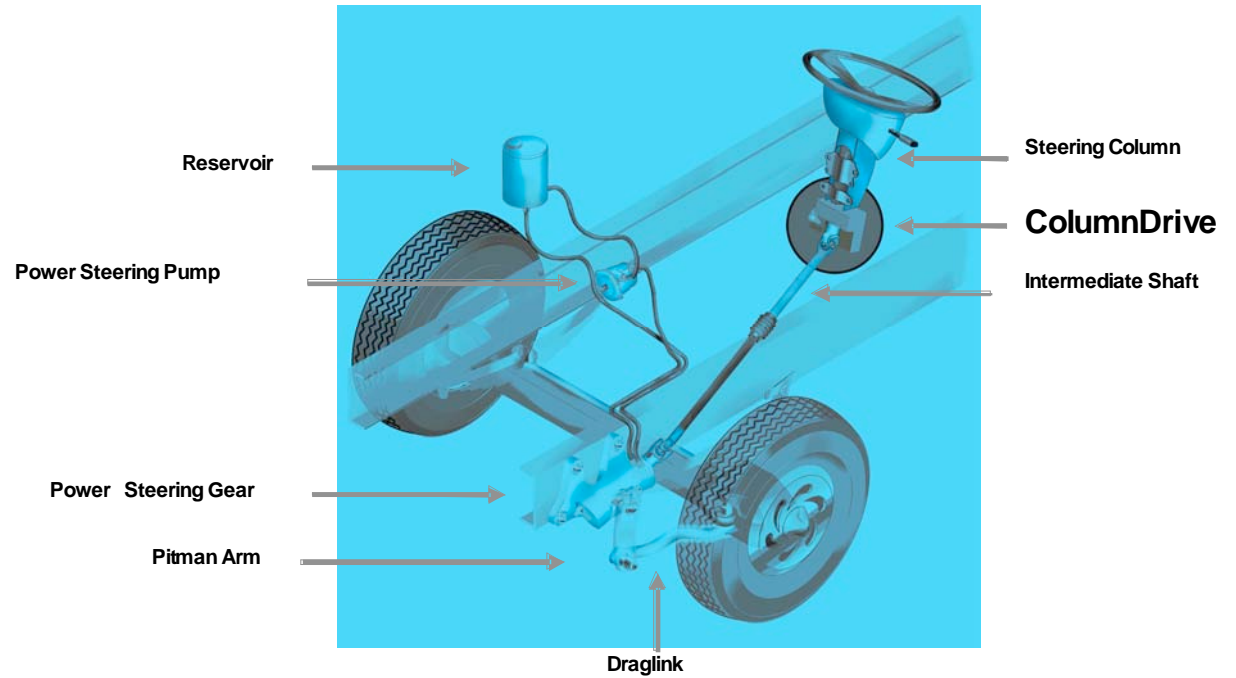
**Lafayette, IN**

**[dan.williams@trw.com](mailto:dan.williams@trw.com)**

*safety.*

# Background

# ColumnDrive Installation



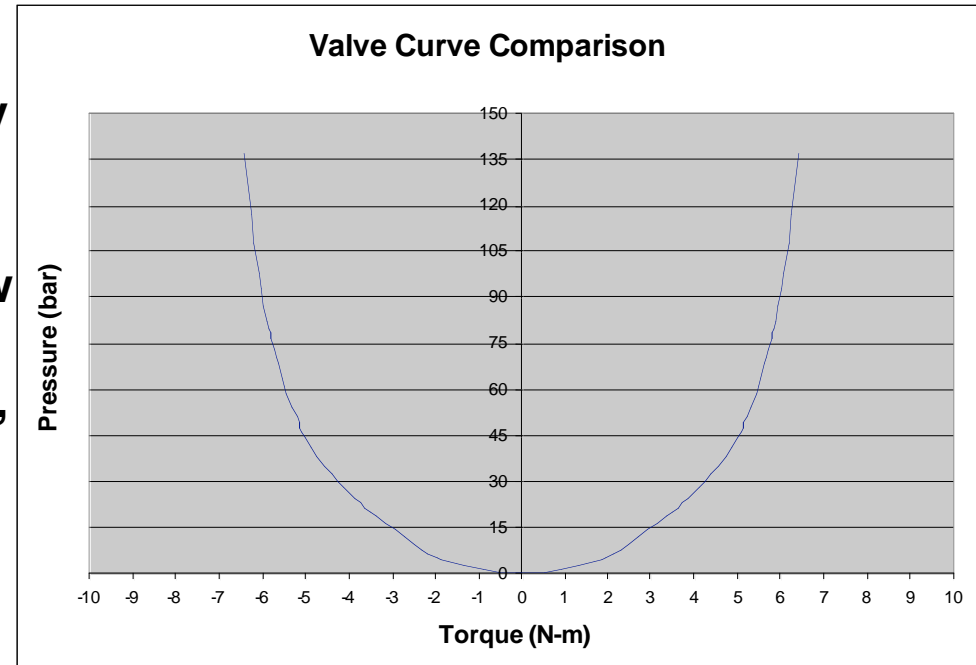
# Conventional Steering Feel

## The “Bath-tub Curve”

- Rotary open center valve displaced by input torque on torsion bar.
- Relationship between input torque and assist natural consequence of flow through orifice.
- Torsion bar between input and output, assist urges output to follow input.
- Nonlinear position follower servo-mechanism.
- Low frequency nonlinear torque amplifier.

## Fundamental compromise of steering systems:

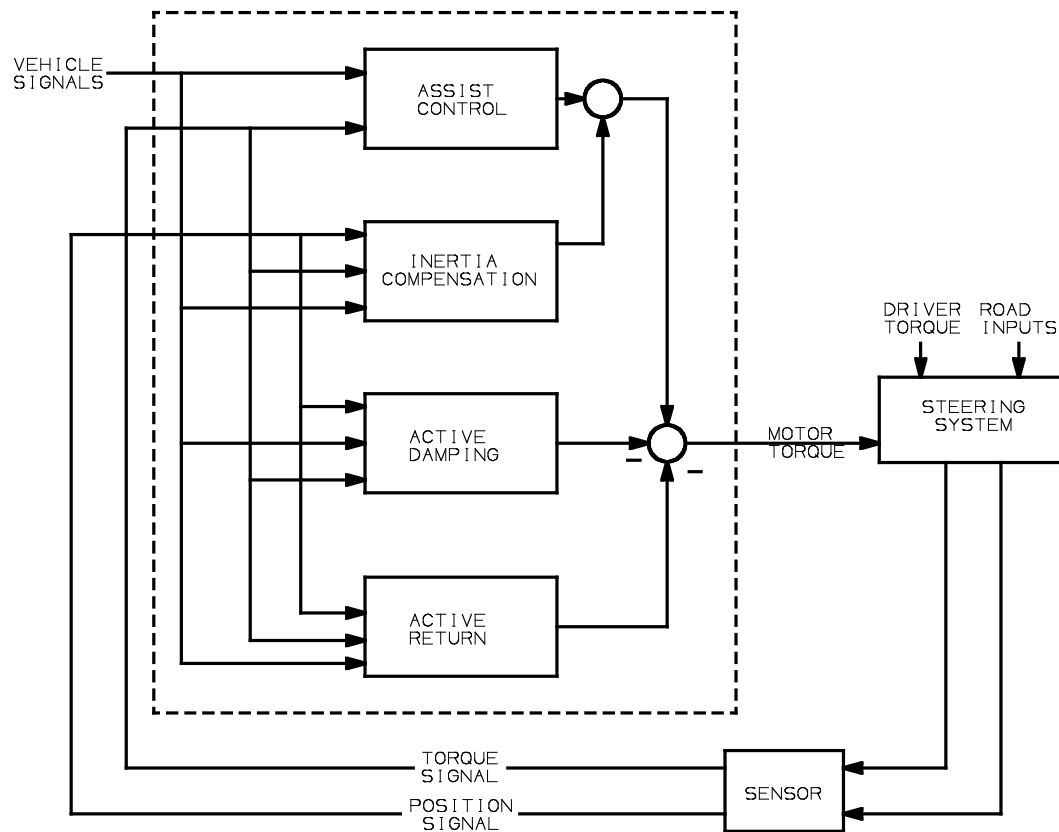
- Good controllability (torque feedback on-center)
- Low efforts (actuation away from center)



## For decades the bath-tub curve has been an excellent solution

- Sized for actuation.
- Tweaked for driver feedback.
- Actuation and feedback coupled.

# Passenger Car EPS Control



Ref: Badawy et al (1999) and Brocker (2006)

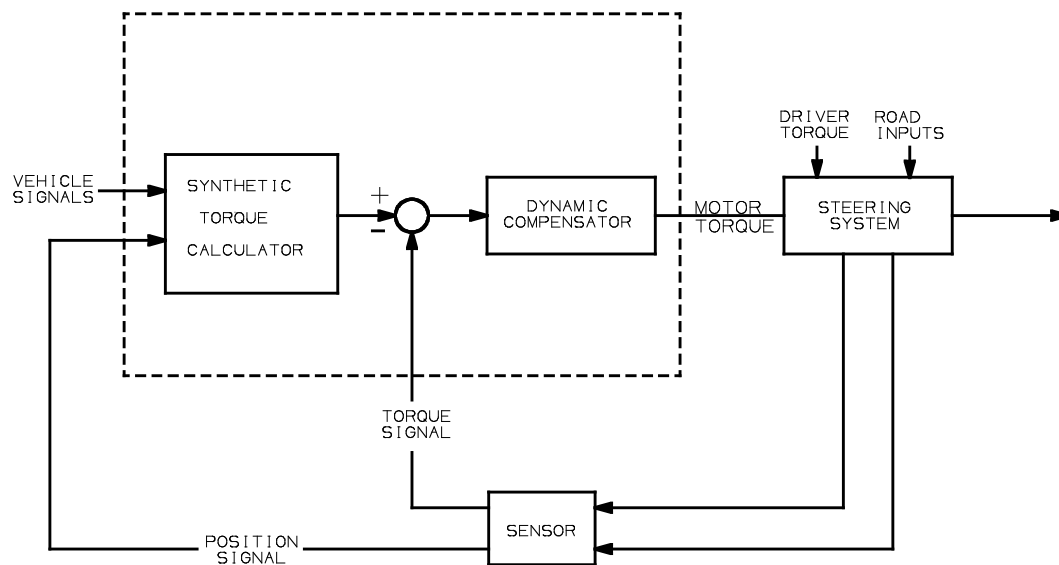
**Assist control based on bath-tub curve.**

**Other complex, nonlinear speed dependant functions allow many tuning degrees of freedom to modify assist.**

**Torque feedback**

- No reference signal (0 by default).
- Low gain on center.
- Effectively open-loop.

# ColumnDrive Control



**Dynamic compensator provides classic high-fidelity closed torque loop such that reference signal is achieved.**

**Reference signal calculated from steering and vehicle measurements.**

**Full authority on-center.**

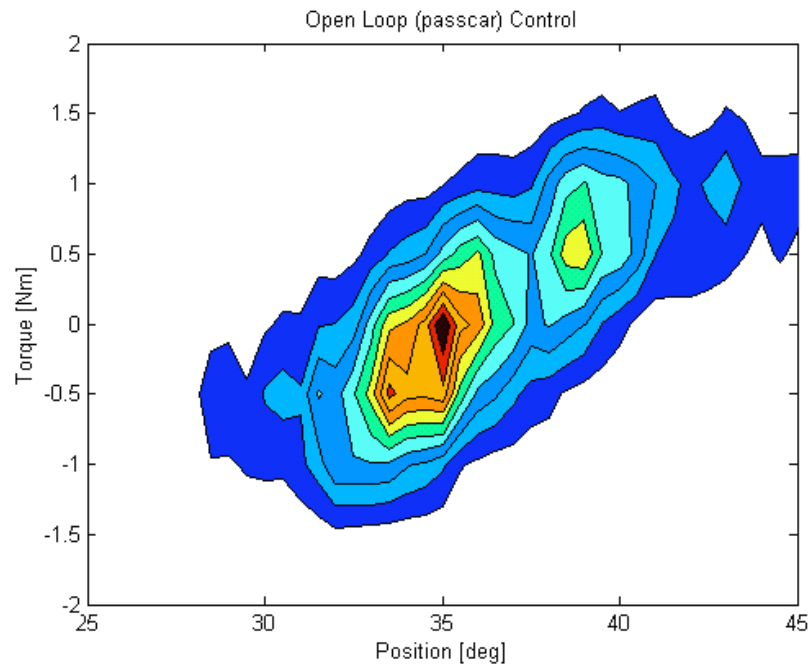
**Torque feedback completely decoupled from actuation.**

# Hysteresis of Various Control

**Dry park: Steering fully loaded axle of motionless vehicle from stop to stop.**

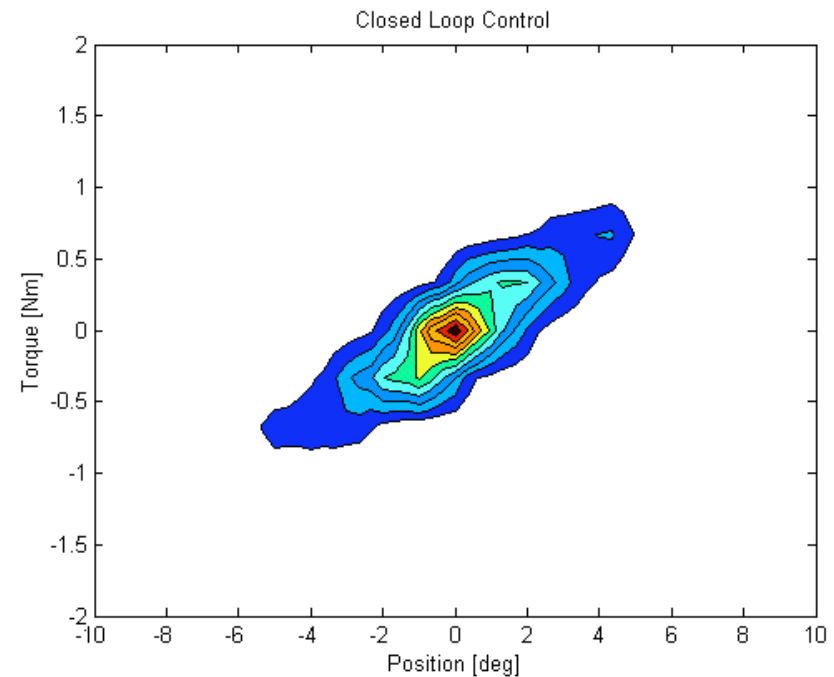
- **Most demanding maneuver sizes conventional system components.**
- **Open loop EPS demonstrates same qualitative performance as conventional system with lower torque values.**
- **Demonstrates low frequency disturbance rejection properties of dynamic compenstor.**

# On-Center Comparison



## Higher stiffness is better

- Conventionally compromised by low efforts.
- Also limited by steady state torque associated with steering input displacement bias

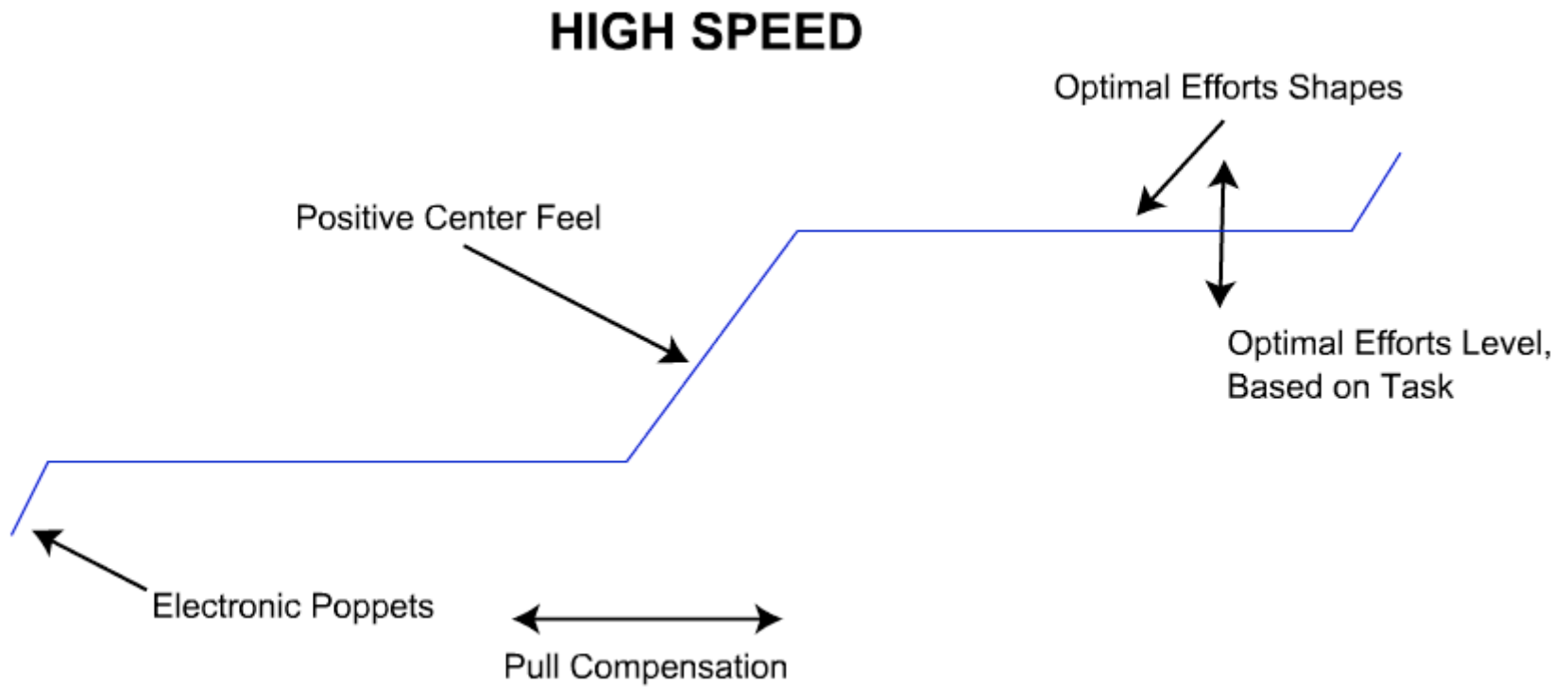


## Less uncertainty is better

- Vertical range is “friction”
- Horizontal range is “lash”
- Unique repeatable relationship provides controllability and driver confidence.

# Synthetic Torque Command

# ColumnDrive Control



# Programmable Damping

**Damping ratio tuned  
consistent with other  
vehicle dynamics.**

**Damping rate varies with  
stiffness and speed.**

# Bias Rejection

**Tunable adaptation window.**

**Valued feature for large, heavy commercial vehicles.**

**Allows higher on-center stiffness w/o increasing steady state efforts.**

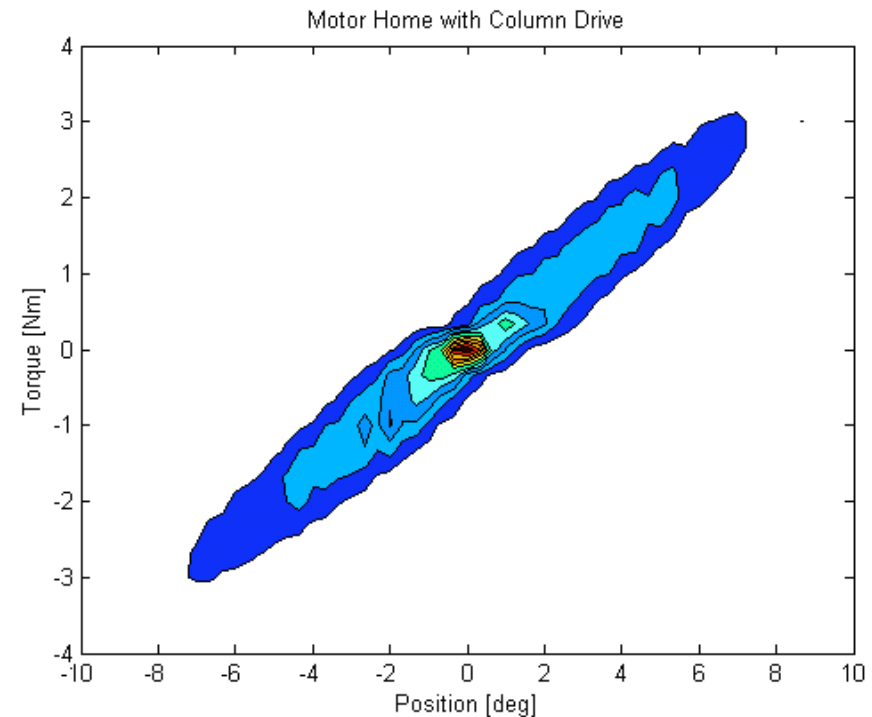
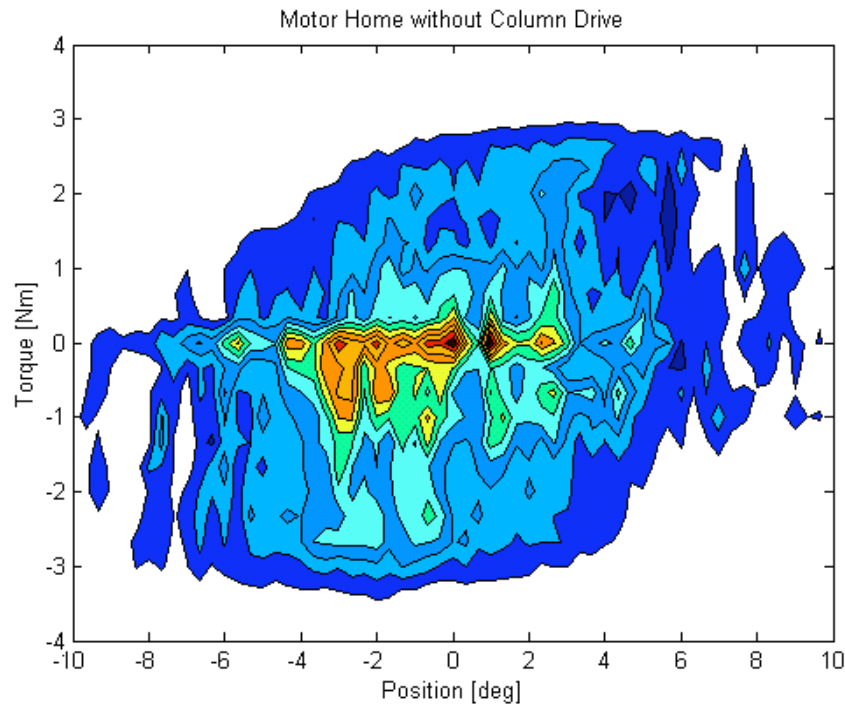
# Commercial Vehicle Application



# Motorhome



# On-Center Vehicle Performance



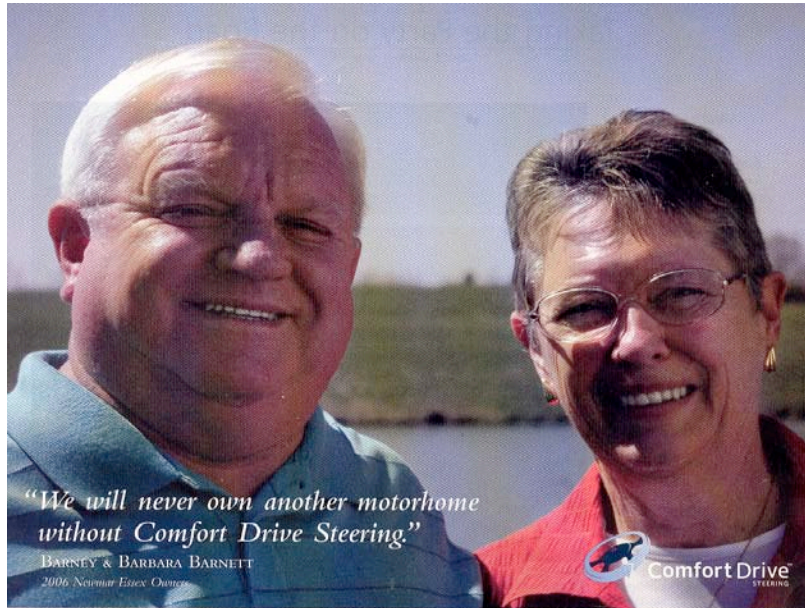
**Motor home duty cycle typical of over the road commercial vehicles.**

**Motor homes are particularly softly sprung, many with IFS.**

**Steering input drive line nonlinearities degrade conventional handling.**

**High on-center stiffness and bias rejection create value.**

# Field Experience



*"We will never own another motorhome without Comfort Drive Steering."*  
BARNEY & BARBARA BARNETT  
2006 Newmar Essex Owner

Comfort Drive STEERING


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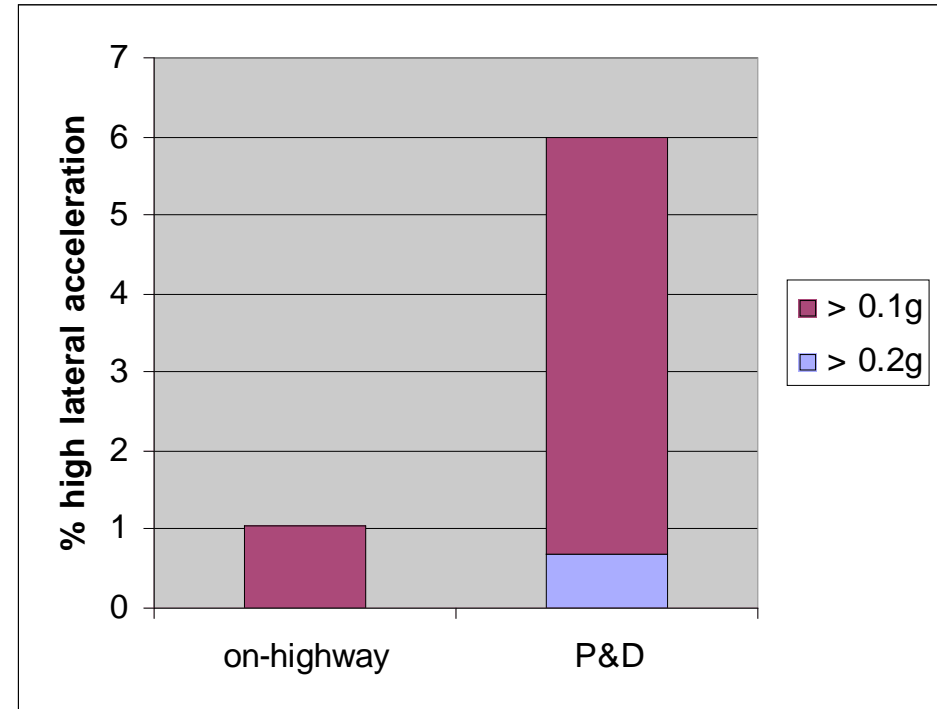
### Anecdotal End User Comments:

- Fatigue in arms used to limit motorhome travel to 400 mi/day. With column drive, traveled 1500 mi in three days and was not fatigued.
- With column drive wife can share motorhome driving duties. Husband gets a break from driving, and wife enjoys the break in monotony.
- Column drive eliminated the need for transit bus driver to take medication at night to sleep.

# Torque vs. Angle Overlay

## Angle Overlay (active steer)

- Planetary gearset provides auxiliary steering displacement input.
- Can change ratio
- Can modify vehicle dynamics
- Most appropriate for off-center portions of duty cycle (0.2-0.6g)
- Good passenger car solution



## Torque Overlay (closed loop control of ColumnDrive)

- Electric motor provides auxiliary steering torque input.
- Can mask input driveline nonlinearities
- Most appropriate for on-center portions of duty cycle (<0.2g)
- Good commercial vehicle solution

*Angle Overlay and Torque Overlay are completely complementary.*

# Conclusion

# Conclusions

- **Commercial vehicle duty cycles are dominated by high speed lane maintenance and low speed maneuvering modes, both of which can be characterised by low lateral accelerations.**
- **ColumnDrive creates value in the high speed lane maintenance mode by increasing on-center stiffness, reducing uncertainty and eliminating torque bias**
- **ColumnDrive creates value in the low speed maneuvering mode by decreasing driver efforts and workload.**
- **High lateral acceleration applications of ColumnDrive more typical of passenger cars have not been developed or evaluated.**