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THE WEIGHT INFLUENCE OF IN-WHEEL MOTOR ON MACPHERSON SUSPENSION HARD POINTS

BY

VALENTIN POPOVICI*, IOANA RAMONA GRIGORAȘ, ALEXANDRU-GABRIEL POPA and EDWARD RAKOȘI

"Gheorghe Asachi" Technical University of Iași,
Faculty of Mechanical Engineering, Iași, Romania

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Abstract. The integration of In-Wheel Motors (IWMs) in electric vehicles offers benefits in packaging, modularity, and control. However, the added unsprung mass may adversely affect suspension performance and ride quality. This study investigates the influence of IWMs on a MacPherson suspension, focusing on the behaviour of suspension hard points (HPs)–the fixed locations that define geometry and affect kinematics. Two Altair MotionView models were used: one for a standard MacPherson system, and another with added IWM mass but identical HPs. A full Kinematics and Compliance (K&C) test suite, including ride, roll, lateral, braking, and steering scenarios, was performed. Results indicate that while HPs remain geometrically unchanged, the IWM-equipped system shows increased camber and toe variations, lateral displacement, and reduced alignment stability. These degrade ride comfort and handling. Thus, although existing HP layouts can house IWMs spatially, performance losses demand suspension re-optimization to preserve dynamic behaviour.

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*Corresponding author; *e-mail*: valentin.popovici@student.tuiasi.ro

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1. Introduction

The evolution of electric vehicles (EVs) has been accelerated by innovations in electric motor design, targeting improvements in efficiency, packaging, and control. Among these, in-wheel motor (IWM) systems have gained traction for enabling the elimination of driveline components and allowing precise torque vectoring at each wheel (Chan, 2007; Kritika Deepak, 2023; Protean Electric, 2022). Their compact and modular nature also enhances design flexibility, particularly in space-constrained architectures (Abebe *et al*. 2016).

However, IWMs introduce considerable unsprung mass, which directly affects ride comfort, steering response, and handling stability (Wong, 2008; Gillespie, 1992). These effects are magnified in vehicles employing MacPherson suspension, where control over tire - road interaction depends heavily on managing wheel-end inertia.

A key element in this context is the configuration of suspension hard points - geometric nodes that define the suspension's kinematic behavior, influencing parameters like camber gain, roll center migration, and toe variation (Dixon, 2009). Previous research by (Constantinescu, 2019) optimized a MacPherson suspension to minimize steering-related errors using multibody simulation, reinforcing the value of kinematic modelling in system refinement. Similarly, other studies within the *Romanian Journal of Automotive Engineering* have utilized simplified quarter-car models in MATLAB to analyze active suspension performance, demonstrating the broad application of simulation in evaluating vehicle dynamics (Marcu, 2020).

Many IWM integration efforts preserve existing suspension geometry to avoid structural redesign, but doing so without adapting for added mass can degrade system dynamics (Li *et al*., 2020; Burke, 2023; Shun Cai *et al*., December 2022).

This study examines the consequences of adding IWM mass to a MacPherson suspension without altering its hard point layout. Two simulation models were developed using Altair MotionView: one representing a baseline internal combustion engine (ICE) vehicle, and another incorporating the mass and inertia of a commercial axial flux IWM (Winterborne, 2020). The models were subjected to standardized dynamic events - ride, roll, lateral force response, braking, and steering - to evaluate changes in key performance metrics including toe angle, camber gain, wheel center displacement, and alignment behavior.

By isolating the inertial impact of IWM integration, this analysis highlights the extent to which added unsprung mass alone can compromise suspension function. The results provide guidance for future suspension re-optimization efforts in EVs employing IWM systems.

2. Methodology

To evaluate the impact of in-wheel motor (IWM) integration on suspension dynamics, a comparative modeling study was performed using Altair MotionView (Altair Engineering Inc., 2024). The focus was to isolate the effects of increased unsprung mass while keeping suspension geometry constant across all scenarios.

A baseline MacPherson suspension model was developed based on a production internal combustion engine (ICE) vehicle. The architecture included a lower control arm, coil-over-strut, and knuckle, with all hard point coordinates based on manufacturer data (Dixon, 2009; Genta, 1997).

An IWM-enhanced variant was created by adding the mass and inertia of a commercial axial flux motor - specifically the YASA motor (Yasa, n.d.; Yasa Technology, n.d.; Husian, 2011) - to the unsprung assembly, without altering suspension geometry. This allowed for controlled analysis of mass effects under real packaging constraints. The modified configuration is illustrated in Fig. 1, which shows the IWM positioned at the wheel hub.

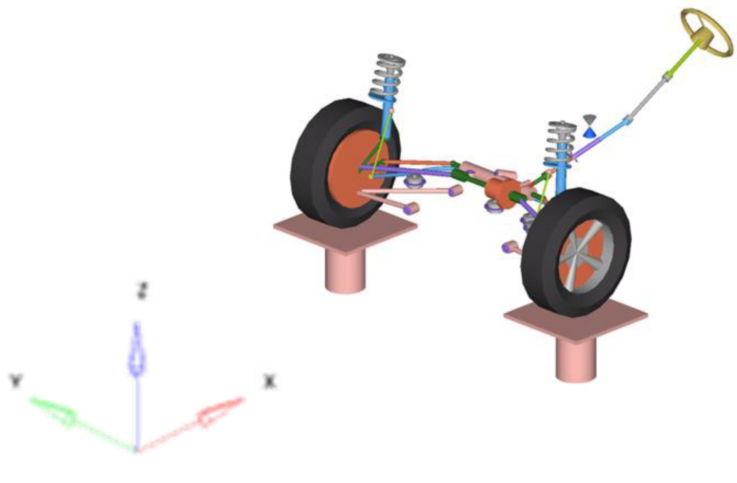

Fig. 1 – IWM MacPherson Suspension model with additional unsprung mass representing the integrated electric motor.

Four dynamic test events were simulated:

- **Ride**: Vertical Jounce and rebound travel.
- **Roll**: Opposing vertical displacements between left and right wheels.

- **Contact Patch Force**: Lateral and aligning loads at the tire-ground interface.
- **Steering**: Controlled angle inputs.

All tests used time-controlled protocols under identical boundary conditions. Outputs included toe, camber, caster, and wheel center (WC) displacements.

To ensure readability, results are presented for the right wheel only, as left - right symmetry was confirmed.

3. Results and Discussion

The influence of added unsprung mass from in-wheel motor (IWM) integration was assessed through four dynamic test categories: ride, roll, contact patch force, and steering. Simulations were performed under identical boundary conditions for both the baseline and IWM - equipped MacPherson models. Results focus on the right wheel, given the symmetrical response.

Ride Event. In the ride simulation, vertical wheel travel highlighted clear differences in toe and camber behaviour. As shown in Fig. 2, the IWM - equipped suspension exhibited a toe - out increase of 83% during jounce and rebound, indicating reduced straight - line stability due to mass - induced compliance.

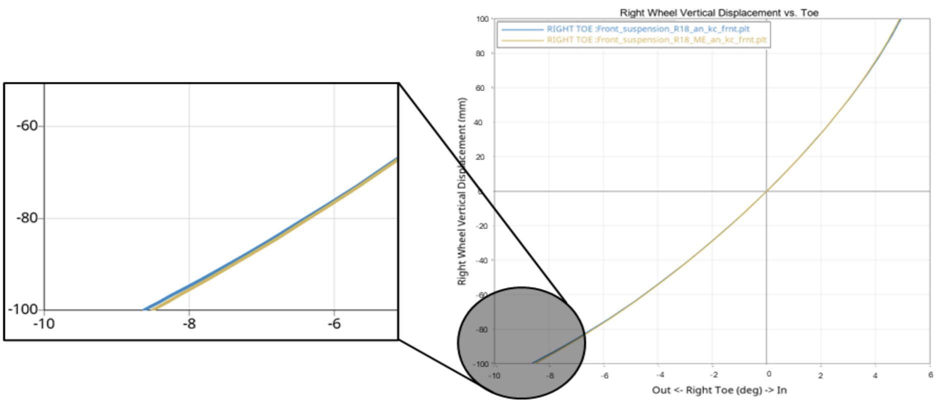

Fig. 2 – Ride Test: Toe Angle vs. Wheel Travel (right wheel only).

Camber gain, illustrated in Fig. 3, was significantly lower in the IWM case, decreasing by 42%, which may reduce lateral grip and increase tire wear during suspension articulation.

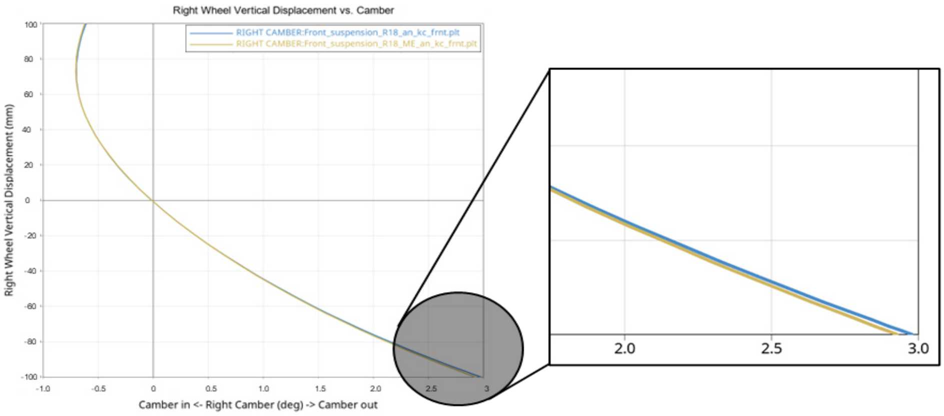

Fig. 3 – Ride Test: Camber Angle vs. Wheel Travel (right wheel only).

Roll Event. During the roll test, where left and right wheels experienced opposing vertical displacement, the IWM configuration displayed increased toe sensitivity. Fig. 4 shows a ~87% rise in toe variation, which could result in oversteer or unpredictable vehicle behaviour during aggressive cornering.

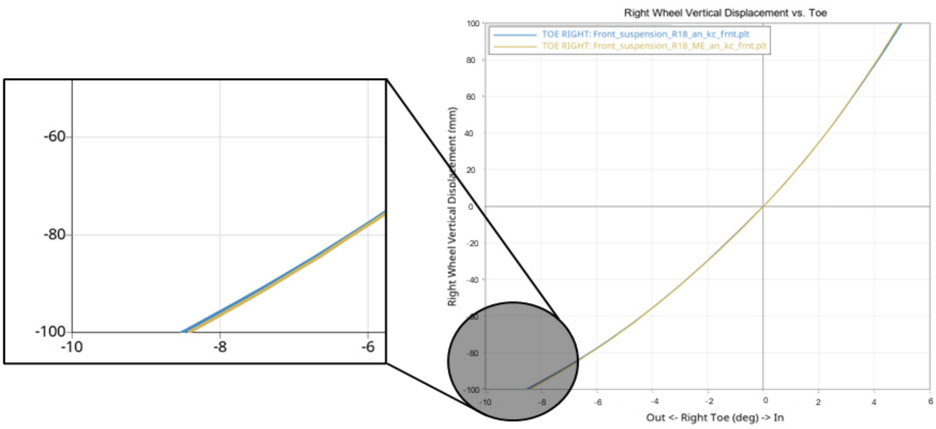

Fig. 4 – Roll Test: Toe Angle vs. Roll Angle (right wheel only).

Camber loss under roll, presented in Fig. 5, increased by 50% with IWM integration, suggesting compromised contact patch effectiveness and reduced cornering force generation.

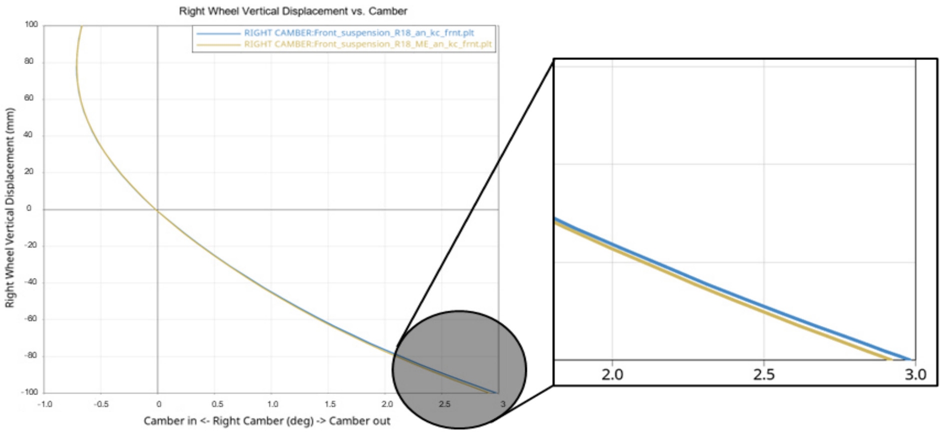

Fig. 5 – Roll Test: Camber Angle vs. Roll Angle (right wheel only).

Contact Patch Force Analysis. The system's lateral stiffness was evaluated under parallel lateral force loading. As shown in Fig. 6, the IWM - equipped suspension showed a 72% increase in lateral wheel centre displacement, indicating reduced side - load resistance and greater alignment compliance.

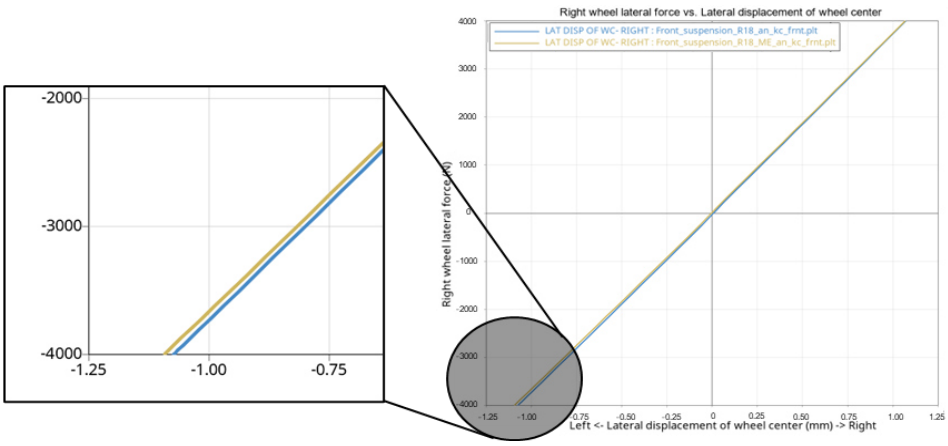

Fig. 6 – Contact Patch Event: Lateral Displacement under Parallel Lateral Force (right wheel only).

Additional contact patch events (aligning torque and opposing lateral loads) followed similar trends and were excluded here for brevity.

Braking Response. Toe behaviour under longitudinal braking forces is shown in Fig. 7. The IWM - equipped model experienced a toe - out increase of 200%, highlighting a critical degradation in directional stability during deceleration. Such behaviour may compromise braking predictability and increase stopping distances.

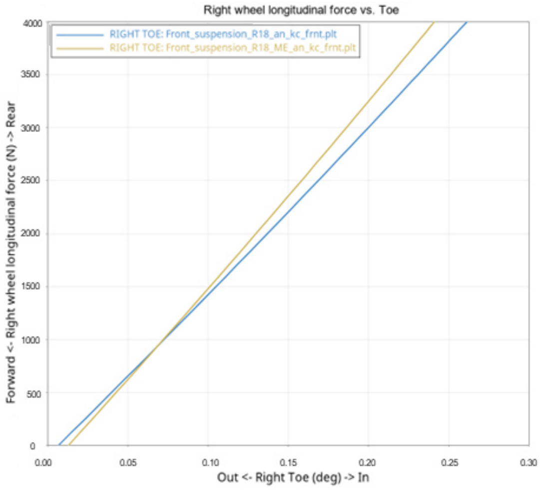

Fig. 7 – Braking Event: Toe Angle vs. Longitudinal Braking Force (right wheel only).

Steering Input. Under steering input, toe sensitivity rose by 89% in the IWM model, as shown in Fig. 8. This suggests reduced steering precision and increased responsiveness to small input changes, potentially degrading control at higher speeds or in emergency manoeuvres.

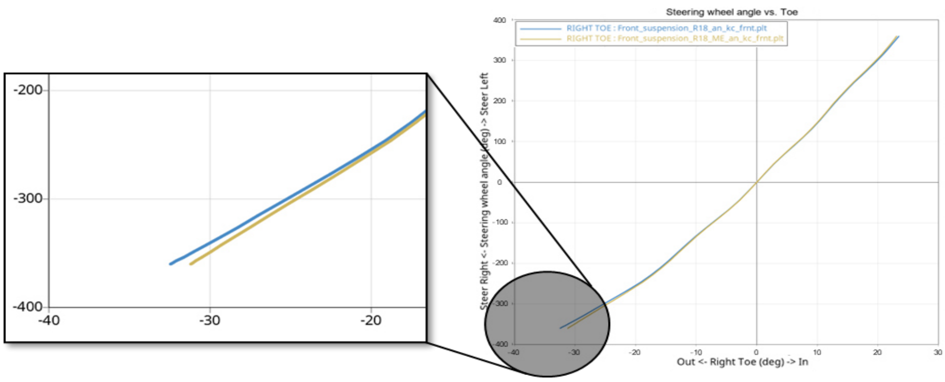

Fig. 8 – Steering Event: Toe Angle vs. Steering Angle (right wheel only).

Summary of Observations. The results confirm that IWM integration - while spatially feasible - leads to measurable deterioration in suspension behaviour. Table 1 consolidates key performance metrics. In nearly every category, the IWM-equipped system exhibits elevated toe angles, reduced camber recovery, and greater wheel center motion, all of which impact ride comfort, safety, and alignment durability.

- Toe changes: +83% (ride), +87% (roll), +200% (braking)
- Camber loss: –42% (ride), –50% (roll)
- WC displacement: +72–90% depending on axis

These findings underscore the need for suspension re-optimization when integrating IWMs, even when hard point geometry remains unchanged. Future system designs must account for mass - induced compliance and dynamic instability to ensure reliable vehicle handling.

Table 1

Quantitative comparison of key kinematic and compliance parameters between classic and IWM-equipped MacPherson suspensions

Parameter	Test Condition	Baseline	IWM	Difference	Observed Impact
Toe Angle Change	Ride Travel	~0.6°	~1.1°	+83%	Increased toe-out → ↓ straight-line stability
Camber Angle Change	Ride Travel	~1.2°	~0.7°	–42%	Reduced camber gain → ↓ tire contact patch
Lateral WC Displacement	Ride Travel	~2.5 mm	~4.3 mm	+72%	Higher compliance → ↓ alignment stability
Longitudinal WC Displacement	Ride Travel	~1.8 mm	~3.2 mm	+78%	Increased fore-aft shift → ↓ braking/traction feel
Toe Angle Change	Roll	~0.8°	~1.5°	+87%	More toe shift in roll → ↓ cornering stability
Camber Angle Change	Roll	~2.4°	~3.6°	+50%	More camber loss → ↓ lateral grip
Lateral WC Displacement	Roll	~3.0 mm	~5.4 mm	+80%	Lower structural stiffness → ↓ handling precision
Longitudinal WC Displacement	Roll	~2.0 mm	~3.8 mm	+90%	Increased shift → potential instability
Toe under Braking	Braking Force	~0.3°	~0.9°	+200%	Severe toe-out → ↓ braking safety
Toe under	Accelerati	~0.4°	~1.0°	+150%	Higher deviation

Acceleration	on Force				→ ↓ directional control
Toe under Steering Input	Steering	~0.9°	~1.7°	+89%	Increased sensitivity → ↓ steering predictability

4. Conclusion and Future Work

This study evaluated the dynamic impact of integrating an axial flux in-wheel motor (IWM) into a MacPherson suspension system, focusing on the effect of increased unsprung mass without altering the suspension's hard point geometry. Using Altair MotionView, two models–baseline and IWM-enhanced–were simulated under standardized dynamic conditions including ride, roll, contact patch force, braking, and steering.

The IWM-equipped model consistently exhibited degraded performance across all scenarios:

- **Toe angle deviations** increased by up to **200%** during braking and **89%** during steering, impacting straight-line stability and predictability.
- **Camber gain** decreased by **42–50%**, reducing lateral grip under both vertical and lateral load conditions.
- **Wheel center displacements** rose by more than **70%** in all directions, indicating lower structural stiffness and alignment integrity.

These results confirm that while IWMs can be physically integrated into existing suspension geometries, the added mass significantly alters suspension behavior. Maintaining original hard point configurations without compensation leads to reduced ride comfort, diminished handling precision, and compromised safety.

Future Work

To address these challenges, future research will focus on:

- **Topological Optimization of IWM Structures**: Reducing unsprung mass through optimized motor housing designs while maintaining strength.
- **Integrated Thermal Analysis**: Simulating heat transfer within compact wheel spaces to ensure safe thermal performance of IWM and brake components.
- **Suspension System Re-Calibration**: Re-tuning spring rates, damping, and bushing stiffness to compensate for inertial changes.

- **Next-Generation IWM Architecture**: Designing compact, lightweight units that integrate motor, inverter, and thermal management into a unified package.

These efforts aim to support the development of future EV platforms that utilize IWM technologies without compromising dynamic performance or safety.

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INFLUENȚA GREUTĂȚII MOTORULUI INTEGRAT ÎN ROATĂ ASUPRA PUNCTELOR FIXE ALE SUSPENSIEI MACPHERSON

(Rezumat)

Dispunerea motoarului integrat în roată (MIR) în vehiculele electrice oferă avantaje semnificative în ceea ce privește înglobarea eficientă a componentelor, modularitatea sistemului și flexibilitatea controlului vehiculului. Totuși, masa nesuspendată suplimentară introdusă de MIR poate afecta negativ performanța suspensiei și confortul la rulare. Acest studiu investighează influența MIR asupra unei suspensii de tip MacPherson, cu accent pe comportamentul punctelor fixe (PF) ale suspensiei – adică acele locații fixe care definesc geometria sistemului și influențează răspunsul cinematic. Două modele au fost dezvoltate în Altair MotionView: unul reprezentând o suspensie MacPherson standard și celălalt cu o masă suplimentară aferentă unui MIR, păstrând însă aceleași PF. A fost efectuat un set complet de teste de Cinematică și Conformitate (C&C), care a inclus scenarii de rulare, ruliu, deplasare laterală, frânare și direcție. Rezultatele arată că, deși poziția geometrică a PF rămâne neschimbată, sistemul echipat cu MIR prezintă variații mai mari de unghi de cădere și unghi de convergență, deplasări laterale mai pronunțate și o stabilitate redusă a aliniamentului roților. Aceste efecte afectează negativ confortul și manevrabilitatea. Prin urmare, chiar dacă PF-urile existente permit integrarea MIR-urilor din punct de vedere al spațiului, pierderile de performanță evidențiate impun o reoptimizare a suspensiei pentru a conserva comportamentul dinamic al vehiculului.