POLITECNICO DI TORINO
ScuDo Scuola di Dottorato ~ Doctoral School
WHAT YOU ARE, TAKES YOU FAR

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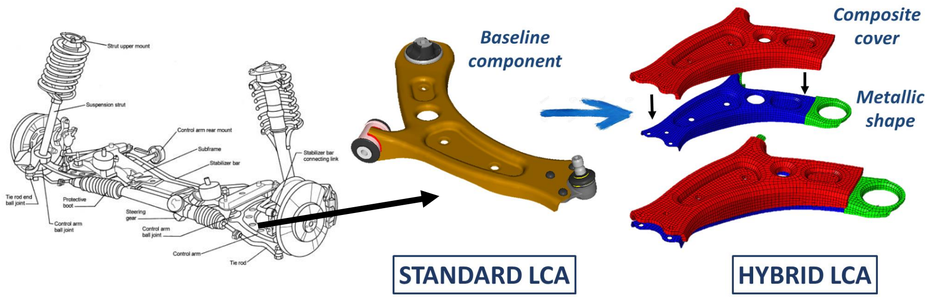
Tutor: **Ing. Massimiliana Carello**

PhD Poster Day - XXXI Cycle

Multi-material Lower Control Arm for a McPherson suspension

Aim of the work

1. Lightweight design of a Lower Control Arm (LCA)
2. Hybrid design: structural composite on metal part
3. Vehicle dynamic analysis and improvement
4. Stiffness and dynamic response evaluation



Vehicle segment reference

- 78% worldwide vehicles use McPherson
- It is mounted on 90% of front driven cars
- The best seller cars from A to C categories are equipped by a front axle McPherson

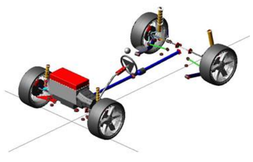
C - Small SUV

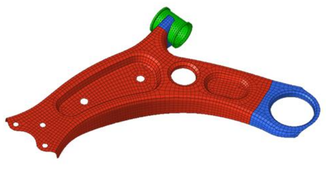

Fiat 500X

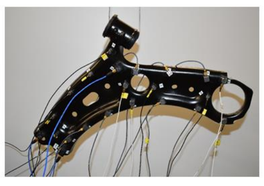

Jeep Renegade

Project Workflow

Vehicle Dynamic Model	Component Design	Component Testing
1.Vehicle reference data	1.FEM model + Load case definition	1.Static and dynamic tests on baseline and hybrid LCA for model validation
2.Vehicle multibody model	2.Baseline mechanical performance	
3.Baseline dynamic performance	3.Static and dynamic target definition for hybrid LCA	
4.Dynamic hybrid LCA targets	4.Hybrid FEM model feasability	







Vehicle Dynamic activities

Vehicle reference data

Suspension System (F/R)	Powertrain	Curb Weight	Wheel base	Track	Tire	Weight ripartition (F/R)
McPherson Strut	4WD	1450 kg	2570 mm	1543 mm	225/55R18	63%-37%
McPherson Strut with virtual center and longitudinal swing arm						

Model hypothesis:

- **Elasto-kinematic:** Ideal joints and rigid bushings
- **COG:** Extracted from mass repartition, and assumed to be 600 mm from ground
- **Unsprung mass:** 40 kg for each wheel
- **Tyre model:** Normal performance city car tyre

SIMULATION SET

Test for component design

- *Constant Cornering Radius*
- *Ramp steer*
- *ISO lane change*
- *Pothole ride*
- *Obstacles (10x100mm,100x100mm)*

→ INPUT FORCES FOR FEA

Test for dynamic improvements

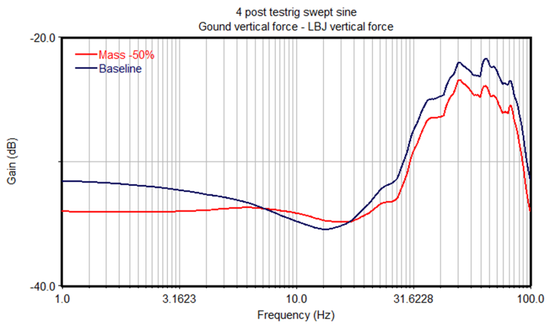
- *Sweep Sine Vertical*
- *Road Excitation (ISO Class B and E)*
- *Sweep sine steering (80km/h, 90deg)*
- *Step Steer (180deg, 80km/h)*
- *Double lane change (ISO 3888)*

→ HANDLING AND COMFORT PERFORMANCE

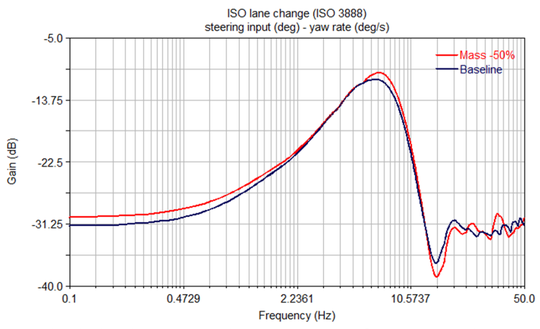
Results and Discussion

Manoeuvre	F_x [N]	F_y [N]	F_{tot} [N]
Costant Cornering Radius (CRC) (40m radius, 0.9g later acc.)	-105	-4440	4441
Ramp Steer (10deg/s, 40s, 80km/h)	-460	-2180	2229
ISO Lane Change (ISO 3888-1)	-342	2790	2810
Hard Braking (160km/h, -1.13g acc.)	9000	-1000	9055
Pothole Ride (100km/h)	214	-1690	1700
Low Obstacle impact (100km/h, 10x100mm)	10	1390	1390
High Obstacle impact (100km/h, 100x100mm)	387	1820	1860

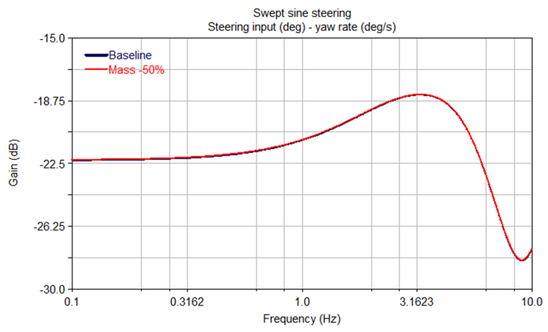
The worst load case is represented by the **CRC** manoeuvre and **hard braking** condition



The hybrid LCA vertical force is reduced because the weight reduction → **Less transmissibility**



The hybrid LCA gives **less moment of inertia** so the un-sprung mass follows faster and better the ground when the body rolls



The hybrid LCA gain is **very similar** to the baseline gain

Experimental tests and correlation on baseline LCA

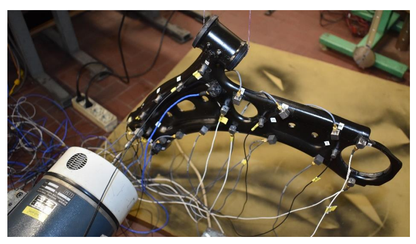
Modal parameter extraction from experimental Frequency Response Analysis (FRA) and correlation with FEM

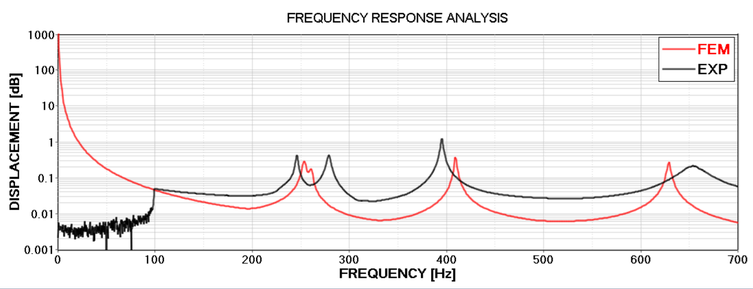
Test set-up:

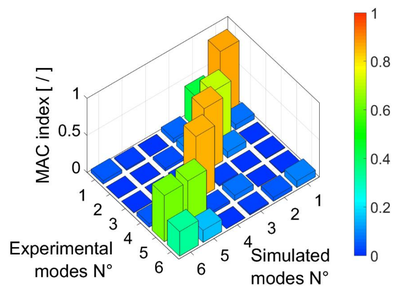
- Free-free boundary condition
- White noise excitation signal (100-1500 Hz)
- 22 channels for data logging + 1 load cell
- Lipez method for modal parameter extraction

Results:

- First six modes extracted
- Good correlation between experimental and FEM FRA
- MAC index from 0,5 to 0,8
- Structural damping extracted for each frequencies







Future Developments

1. Sensitivity study on composite geometric effect on target achieving
2. Final hybrid design and stacking sequence optimization
3. Static and dynamic characterization of bonding material for hybrid interface
4. Further tests on baseline LCA to correlate stiffness and strength with FEM
5. Dynamic tests on hybrid LCA and virtual correlation

FEA Activities

SIMULATION SET

- *Stiffness analysis*
- *Strength analysis*
- *Modal analysis*
- *Load case from vehicle dynamic*

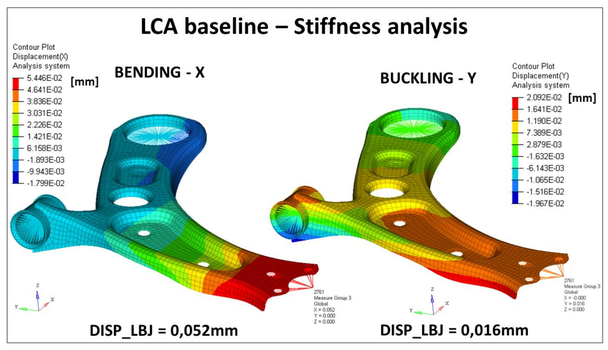
OUTPUT

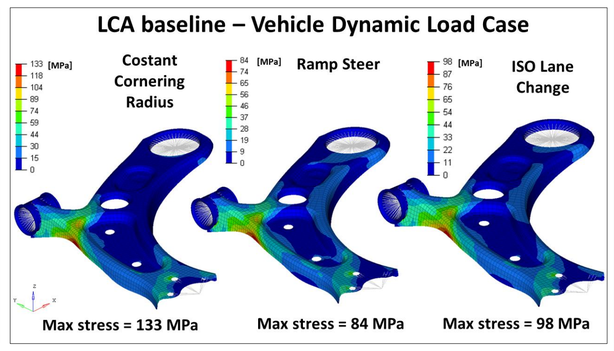
- Stiffness
- Safety factor
- Dynamic response
- Strength curve

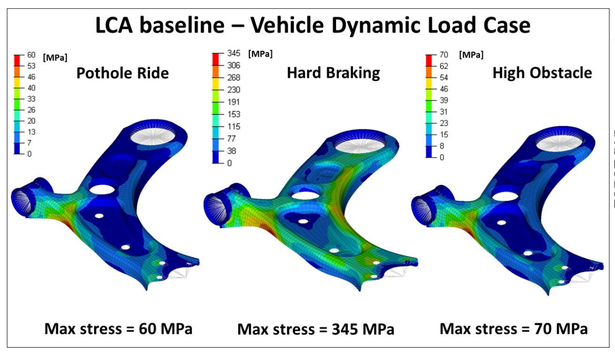
Model hypothesis:

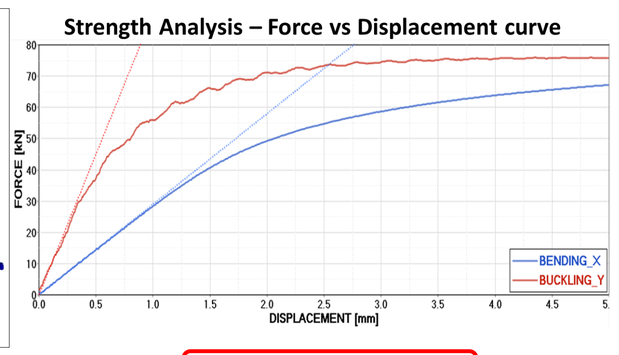
- **No bushing**: rigid link to constraint
- **Elasto-plastic** material model
- **Boundary conditions** depending on load cases

Results and Discussion









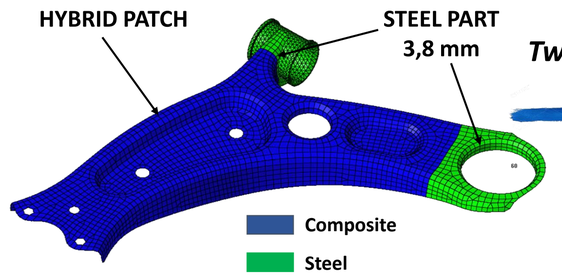
Results Summary

MODEL	Disp X [mm]	Disp Y [mm]	Mass [kg]	Kx [kN/mm]	Ky [kN/mm]	Fx max [kN]	Fy max [kN]
BASELINE	0,052	0,016	2,2	28.8	93.7	67	75

TARGET SETTING

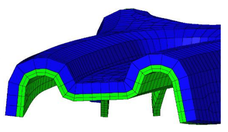
MODEL	Mass [kg]	Safety Factor	Kx [kN/mm]	Ky [kN/mm]	Fx max [kN]	Fy max [kN]
HYBRID	1	≥2	≥35	≥120	≥67	≥75
	-50%		+30%	+30%		

1° Hybrid LCA



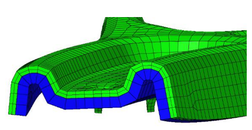
Two solutions:

«TOP» VERSION



Composite wrapping is placed on top of steel shape

«BOTTOM» VERSION



Composite wrapping is placed on bottom of steel shape

1° step: sensitivity study on hybrid thickness

FEM MODEL	Disp X [mm]	Disp Y [mm]	t_metal [mm]	t_comp [mm]	Massa [kg]	Kx [kN/mm]	Ky [kN/mm]	Δ Kx [%]	Δ Ky [%]	Δ kg [%]
BASELINE	0,052	0,016	3,8	-	2,2	28,8	93,7	-	-	-
HYB_TOP_REV 2	0,039	0,01	2	6	1,87	38,4	150	33,3	60	-15
HYB_TOP_REV 6	0,048	0,011	0,8	8	1,46	31,2	136,3	7,6	31,3	-50,7
HYB_BOT_REV 2	0,043	0,01	2	6	1,87	34,8	150	20,9	60	-15
HYB_BOT_REV 6	0,051	0,011	0,8	8	1,46	29,4	136,3	1,9	31,3	-50,7

- Definition of **minimum thickness** of composite and metal on hybrid patch to match the targets
- **First approach**: quasi-isotropic material with equivalent composite performance
- No stacking sequence effect: **equivalent laminate** with one ply of composite and one ply of metal
- Evaluation of the **best configuration** between "top" and "bottom"

The **"top"** solution is better than the "bottom" one. However, **none** configuration **match targets** simultaneously.

→ ***2° step: sensitivity study on geometric shape of hybrid patch***

PhD Activities

Politecnico Courses:

- *Communication (5h)*
- *Lean startup e lean business for l'innovation management (20h)*
- *Modellazione avanzata di problemi strutturali con elementi finiti (30h)*
- *Development of innovative solutions for motor vehicle (20h) (excellence course)*
- *Progettazione affidabilistica di macchine e sistemi meccanici (28h) (attending)*
- *Multiscale structural mechanics (15h)(excellence course)*
- *Hybrid propulsion system (10h)*
- *Modellazione avanzata di problemi strutturali con elementi finiti (30h)*
- *The redefinition of the international System of Units (12h)(excellence course)*
- *Polymers and Polymer Matrix Composites in Harsh Environments (10h)(excellence course)*
- *Progettazione a crash di strutture di veicoli (30h)*
- *Writing scientific papers in English (15h)*
- *Short course on Entrepreneurship (7h)*

External Courses:

- *"Smart Structures for Vibro-Acoustic Control" - CISM and Marie Curie Graduate School (3 days) (20h)*
- *Altair Hyperworks Training on Hypercrash (2days) (16h)*
- *Altair Hyperworks Training on Optistruct Fatigue (1 day) (8h)*
- *Abaqus Standard and Composite (4 days) (32h)*
- *Introduction to LS-Dyna (1 day) (8h)*
- *Simulation of short and continuous fiber composites in LS-Dyna (2 days) (16h)*

Followed students for thesis:

- *2 MSc students, 1 BCs student*

Papers:

- M. CARELLO, A. MESSANA, **"IDRApegasus: a fuel cell prototype for 3000 km/L"**, Computer-Aided Design & Application, 2015, vol. 11 (a), pp. 1-15. - ISSN 1686-4360
- M. CARELLO, A. AIRALE, A. FERRARIS, A. MESSANA, **"Desing and numerical modelization of CFRP innovative transversal leaf spring"**, abstract in atti di convegno, 10th International Conference on Advanced Computational Engineering and Experimenting, ACE-X 2016
- M. CARELLO, A. AIRALE, A. FERRARIS, A. MESSANA, C. DE PASCALIS, **"Correlation between thermo-mechanical properties and chemical compostion of aged thermoplastic and thermosetting FRP material"**, abstract in atti di convegno, 10th International Conference on Advanced Computational Engineering and Experimenting, ACE-X 2016
- M. CARELLO, A. AIRALE, A. FERRARIS, A. MESSANA, L. SISCA **"Static Design and Finite Element Analysis of Innovative CFRP Transverse Leaf Spring,"** Applied Composite Materials, Mar. 2017
- M. CARELLO, A. AIRALE, A. FERRARIS, A. MESSANA, L.SISCA, **"Correlation between thermo-mechanical properties and chemical compostion of aged thermoplastic and thermosetting FRP material"**, Materialwissenschaft und Werkstofftechnik, vol. 48, no. 5, pp. 447–455, May 2017.
- M. CARELLO, A. G. AIRALE, A. FERRARIS, L. SISCA, A. MESSANA, and N. AMIRTH, **"Process analysis for structural optimisation of thermoplastic composite component using the building block approach,"** Composites Part B: Engineering, vol. 126, p. 13, Jun. 2017.

Conference:

- *Oral and poster presentation, 10th International Conference on Advanced Computational Engineering and Experimenting, ACE-X 2016, 3-6 July 2016, Split (Croatia)*

Research Project:

- *Progetto TELEMEC (TELescopic Extractable Mechanized Element in Carbon)*