



Faculty of Engineering
University of Kragujevac



Ministry of Science, Technological
Development and Innovation

**11th International Congress
Motor Vehicles & Motors 2026
ECOLOGY -
VEHICLE AND ROAD SAFETY
- EFFICIENCY
Proceedings**



University of Kragujevac



Department for Motor Vehicles
and Motors



International Journal for Vehicle
Mechanics, Engines and
Transportation Systems

October 8th - 9th, 2026
Kragujevac, Serbia

**11th International Congress
Motor Vehicles & Motors 2026**

**ECOLOGY -
VEHICLE AND ROAD SAFETY
- EFFICIENCY**

BOOK OF PROCEEDINGS

October 8th - 9th, 2026
Kragujevac, Serbia

Publisher: The Faculty of Engineering of the University of Kragujevac
Serbia, 34000 Kragujevac, Sestre Janjić 6

For Publisher: Prof. Slobodan Savić, Ph.D.
Dean of the Faculty of Engineering

Editors: Prof. Danijela Miloradović, Ph.D.
Assist. prof. Nadica Stojanović, Ph.D.
The Faculty of Engineering of the University of Kragujevac

Technical preparation: Asisst. Prof. Nadica Stojanović, Ph.D.

Cover: Nemanja Lazarević

USB edition: Faculty of Engineering, University of Kragujevac, Kragujevac

ISBN: 978-86-6335-132-5

Year of publication: 2026.

Published on USB by: InterPrint
Aleksinačka St. nn, 34000 Kragujevac, Serbia

Number of copies: 100

CIP - Каталогизacija y yбликацији Народна библиотека Србије, Београд

629.3(082)(0.034.2)
621.43(082)(0.034.2)

INTERNATIONAL Congress Motor Vehicles & Motors (11 ; 2026 ; Kragujevac)

Ecology - Vehicle and Road Safety - Efficiency [Elektronski izvor] : proceedings
/ 11th international congress Motor vehicles & motors 2026, October 8th - 9th,
2026 Kragujevac, Serbia ; [editors Danijela Miloradović, Nadica Stojanović]. -
Kragujevac : University, Faculty of Engineering, 2026 (Kragujevac : InterPrint). -
1 USB fleš memorija ; 1 x 2 x 6 cm

Sistemske zahtevi: Nisu navedeni. - Nasl. sa nasl. strane dokumenta. - Tiraž 100.
- Bibliografija uz svaki rad.

ISBN 978-86-6335-132-5

a) Моторна возила – Зборници b) Моторни са унутрашњим сагоревањем -
- Зборници

COBISS.SR-ID 201905929

*Publishing of this USB Book of proceedings was supported by
Ministry of Science, Technological Development and Innovation of the Republic of Serbia*

Copyright © 2026 Faculty of Engineering, University of Kragujevac



This book is published online with Open Access and distributed under the terms
of the Creative Commons Attribution License 4.0 (CC BY 4.0).

SCIENTIFIC BOARD

President

Prof. Danijela Miloradović, Ph.D., UniKg, FE, Serbia

Secretaries

Assist. Prof., Slavica Mačužić Saveljić, Ph.D., UniKg, FE, Serbia

Assist. Prof., Saša Milojević, Ph.D., UniKg, FE, Serbia

Members

Prof. Oday Ibraheem Abdulah, ANUni, CoE, Baghdad, Iraq

Assist. Prof. Ali Belhocine, UniMSM, FST, Mascara, Algeria

Emeritus Prof. Giovanni Belingardi, Ph.D., PoliTo, Turin, Italy

Prof. Murat Ciniviz, Ph.D., SelUni, FT, Konya, Turkey

Prof. Adrian Clenci Ph.D., UniPolBU, Bucharest, Romania

Prof. Bruno Dalla Chiara, Ph.D., PoliTo, Turin, Italy

Assoc. Prof. Aleksandar Davinić, Ph.D., UniKG, FE, Kragujevac, Serbia

Prof. Miroslav Demić, Ph.D., UniKG, FE, Kragujevac, Serbia

Prof. Jovan Dorić Ph.D., UniNS, FTS, Novi Sad, Serbia

Prof. Mohamed Ali Emam, Ph.D., HUni, FE, Cairo, Egypt

Prof. Jasna Glišović, Ph.D., UniKG, FE, Kragujevac, Serbia

Prof. Valentina Golubović Bugarski, Ph.D., UniBL, FME, Banja Luka, RS, Bosnia and Herzegovina

Assoc. Prof. Ivan Grujć, Ph.D., UniKG, FE, Kragujevac, Serbia

Prof. Rosen Hristov, Ph.D., TU Varna, Varna, Bulgaria

Prof. Aleksandra Janković, Ph.D., UniKG, FE, Kragujevac, Serbia

Assoc. Prof. Aleksandar Jovanović, Ph.D., UniKG, FE, Kragujevac, Serbia

Prof. Emrullah Hakan Kaleli, Ph.D., YTU, Istanbul, Turkey

Prof. Janez Kopač, Ph.D., UniLJ, FME, Ljubljana, Slovenia

Prof. Jovanka Lukić, Ph.D., UniKG, FE, Kragujevac, Serbia

Assist. Prof. Slavica Mačužić Saveljić, Ph.D., UniKG, FE, Kragujevac, Serbia

Assist. Prof. Saša Milojević, Ph.D., UniKG, FE, Kragujevac, Serbia

Assist. Prof. Slobodan Mišanović, Ph.D., CPTC Belgrade, Belgrade, Serbia

Prof. Alexander Novikov, Ph.D., OSUni, Orel, Russian Federation

Prof. Sreten Perić, Ph.D., UniD, MA, Belgrade, Serbia

Prof. Radivoje Pešić, Ph.D., UniKG, FE, Kragujevac Serbia

Prof. Snezana Petković, Ph.D., UniBL, FME, Banja Luka, RS, Bosnia and Herzegovina

Prof. Ralph Puetz, Ph.D., LUniAS, Landshut, Germany

Prof. Dragan Ružić, Ph.D., UniNS, FTS, Novi Sad, Serbia

Prof. Mikhail Shatrov, Ph.D., MADI, Moscow, Russian Federation

Assoc. Prof. Aleksandar Stevanović, Ph.D., UniPitt, Pittsburgh, USA

Assist. Prof. Nadica Stojanović, Ph.D., UniKG, FE, Kragujevac, Serbia

Assoc. Prof. Boris Stojić, Ph.D., UniNS, FTS, Novi Sad, Serbia

Prof. Radoje Vujadinović, Ph.D., UniMN, FME, Podgorica, Montenegro

Assoc. Prof. Predrag Živanović, Ph.D., UniBG, FTTE, Belgrade, Serbia

ORGANIZATIONAL BOARD

President

Asst. Prof., Nadica Stojanović, Ph.D., UniKg, FE, Serbia

Secretaries

Assist. Prof., Slavica Mačužić Saveljić, Ph.D., UniKg, FE, Serbia

Assist. Prof., Saša Milojević, Ph.D., UniKg, FE, Serbia

Members:

Prof. dr Jovanka Lukić, UniKg, FE, Kragujevac, Serbia

Prof. dr Jasna Glišović, UniKg, FE, Kragujevac, Serbia

Assoc. Prof. dr Aleksandar Davinić, UniKg, FE, Kragujevac, Serbia

Assoc. prof. dr Aleksandar Jovanović, UniKg, FE, Kragujevac, Serbia

Assoc. prof. dr Ivan Grujić, UniKg, FE, Kragujevac, Serbia

MVM2026 CONGRESS ORGANIZERS

Faculty of Engineering of the University of Kragujevac
Department for Motor Vehicles and Motors, FE Kragujevac
International Journal "Mobility & Vehicle Mechanics"

MVM2026 CONGRESS PATRONS

Ministry of Science, Technological Development and Innovation of the Republic of Serbia
Faculty of Engineering of the University of Kragujevac

MVM2026 CONGRESS REVIEWERS

Prof. dr Oday Ibraheem Abdulah, UniBAG, CoE, Baghdad, Iraq
Assist. Prof. dr Ali Belhocine, UniMSM, FST, Mascara, Algeria
Emeritus Prof. dr Giovanni Belingardi, PoliTo, Turin, Italy
Assoc. Prof. dr Aleksandar Davinić, UniKG, FE, Kragujevac, Serbia
Prof. dr Miroslav Demić, UniKG, FE, Kragujevac, Serbia
Prof. dr Jovan Dorić, UniNS, FTS, Novi Sad, Serbia
Prof. dr Jasna Glišović, UniKG, FE, Kragujevac, Serbia
Prof. dr Valentina Golubović Bugarski, UniBL, FME, Banja Luka, RS, Bosnia & Herzegovina
Assoc. Prof. dr Ivan Grujić, UniKG, FE, Kragujevac, Serbia
Prof. dr Rosen Hristov, TU Varna, Varna, Bulgaria
Assoc. Prof. dr Aleksandar Jovanović, UniKG, FE, Kragujevac, Serbia
Prof. dr Janez Kopač, UniLJ, FME, Ljubljana, Slovenia
Prof. dr Jovanka Lukić, UniKG, FE, Kragujevac, Serbia
Assist. Prof. dr Slavica Mačužić Saveljić, UniKG, FE, Kragujevac, Serbia
Assist. Prof. dr Saša Milojević, UniKG, FE, Kragujevac, Serbia
Prof. dr Danijela Miloradović, UniKG, FE, Kragujevac, Serbia
Assist. Prof. dr Slobodan Mišanović, CPTC Belgrade, Belgrade, Serbia
Prof. dr Radivoje Pešić, UniKG, FE, Kragujevac, Serbia
Prof. dr Snezana Petković, UniBL, FME, Banja Luka, RS, Bosnia & Herzegovina
Prof. dr Dragan Ružić, UniNS, FTS, Novi Sad, Serbia
Assoc. Prof. dr Aleksandar Stevanović, UniPitt, Pittsburgh, USA
Assist. Prof. dr Nadica Stojanović, UniKG, FE, Kragujevac, Serbia
Assoc. Prof. dr Boris Stojić, UniNS, FTS, Novi Sad, Serbia

FOREWORD

For 47 years, a traditional international gathering - originally known as a Symposium and, since 2006, as the "Motor Vehicles and Motors" Congress - has been held biennially at the Faculty of Engineering (formerly the Faculty of Mechanical Engineering) of the University of Kragujevac. This year, the 11th International Congress "Motor Vehicles and Motors" took place in Kragujevac on October 8th–9th, 2026, under the traditional motto: "Ecology – Vehicle and Road Safety – Efficiency".

A large number of authors from both the country and abroad responded to the organizers' invitation, resulting in numerous high-quality submissions across the event's core areas: "Power Train Technology," "Vehicle Design and Manufacturing," "Vehicle Dynamics and Intelligent Control Systems," "Driver/Vehicle Interface, Information Systems, and Assistance Systems," and "Transport Challenges in Emerging Economies." Additionally, two topics were officially introduced for the first time: "Artificial Intelligence in Automotive Technology" and "Autonomous Vehicles".

A total of 63 papers were accepted for presentation following a rigorous peer-review process. The presentations were organized into sessions, including a newly introduced poster session dedicated to students and young researchers.

The Congress organizers extend their special gratitude to the distinguished scientists in the fields of motor vehicles and transportation who agreed to deliver three inspiring introductory lectures addressing the heart of contemporary issues in the sector: prof. dr Ralph Putz (Landshut University of Applied Sciences, Germany), prof. dr Aleksandar Stevanović (University of Pittsburgh, USA), and prof. dr. Isak Karabegović (Academy of Sciences and Arts of Bosnia and Herzegovina, Bosnia and Herzegovina).

We extend our sincere gratitude to the esteemed members of the Congress Scientific Committee—who also served as reviewers for the papers submitted for presentation—for their significant contribution to the overall quality of the accepted papers.

The organization of the Congress was once again supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, the Faculty of Engineering of the University of Kragujevac, and the International journal "Mobility & Vehicle Mechanics" and we sincerely thank them for their support.

Scientific Board and Organizational Board of MVM2026 Congress

PREDGOVOR

Već 47 godina, svake druge godine, na Fakultetu inženjerskih nauka (nekada Mašinskom fakultetu) Univerziteta u Kragujevcu održava se tradicionalan međunarodni skup, nekada nazivan Simpozijum, a od 2006. godine - Kongres „Motorna vozila i motori“. Ovogodišnji, 11. Međunarodni kongres „Motorna vozila i motori“ održan je u Kragujevcu od 8. do 9. oktobra 2026. godine, uz tradicionalni moto „Ekologija – Vozilo i bezbednost na putu – Efikasnost“.

Na poziv organizatora odazvao se veliki broj autora iz zemlje i inostranstva, što je donelo veliki broj prijavljenih kvalitetnih radova iz glavnih oblasti skupa: „Tehnologija pogonskog sistema“, „Dizajn i proizvodnja vozila“, „Dinamika vozila i inteligentni upravljački sistemi“, „Interfejs vozač/vozilo, informacioni sistemi i sistemi za pomoć“, „Transportni izazovi ekonomija u usponu“, uz prvi put zvanično promovisane teme – „Veštačka inteligencija u automobilskoj tehnologiji“ i „Autonomna vozila“.

Ukupan broj od 63 radova je prihvaćen za prezentaciju posle rigoroznog procesa recenziranja. Rad je organizovan po sekcijama, uz prvi put promovisanu poster sekciju namenjenu za studente i mlade istraživače.

Organizatori Kongresa su posebno zahvalni istaknutim naučnicima iz oblasti motornih vozila i saobraćaja koji su pristali da održe tri inspirativna uvodna predavanja koja zadiru u srž savremenih pitanja vezana za vozila i saobraćaj, a to su: prof. dr Ralph Putz (Landshut University of Applied Sciences, Nemačka), prof. dr Aleksandar Stevanović (University of Pittsburgh, SAD) i prof. dr Isak Karabegović (Akademija nauka i umjetnosti Bosne i Hercegovine, Bosna i Hercegovina).

Veliku zahvalnost dugujemo našim dragim članovima Naučnog odbora Kongresa, ujedno i recenzentima radova prijavljenih za prezentaciju na Kongresu, koji su mnogo doprineli ukupnom kvalitetu konačno prihvaćenih radova.

Organizaciju Kongresa i ovog puta su podržali: Ministarstvo nauke, tehnološkog razvoja i inovacija Republike Srbije, Fakultet inženjerskih nauka Univeziteta u Kragujevcu i Međunarodni časopis „Mobility & Vehicle Mechanics“, na čemu im se iskreno zahvaljujemo.

Naučni odbor i Organizacioni odbor Kongresa MVM2026

CONTENT

INTRODUCTORY LECTURES

MVM2026-IL1	Ralph Pütz	OPERATING COSTS OF PUBLIC TRANSPORT BUSES WITH DIFFERENT PROPULSION SYSTEMS AND VARIOUS TYPES OF RENEWABLE ENERGY OVER TIME – WHERE IS THE JOURNEY HEADING?	3
MVM2026-IL3	Isak Karabegović	COLLABORATIVE ROBOTICS AND ARTIFICIAL INTELLIGENCE IN THE AUTOMOTIVE INDUSTRY: SMART ASSEMBLY AND AUTOMATED QUALITY CONTROL	13

SECTION A Power Train Technology

MVM2026-003	Ivan Grujic Aleksandar Davinic Zeljko Djuric Jovan Doric Milan Eremija Attila Kiss Sunny Narayan	THE INVESTIGATION OF THE COMBUSTION PROCESS OF THE BLEND OF THE CONVENTIONAL DIESEL FUEL AND BIODIESEL MADE FROM THE WASTE GRAPE SEEDS	35
MVM2026-008	Željko Đurić Ivan Grujić Nadica Stojanović Snežana Petković Jelena Adžić Milan Eremija	EXPERIMENTAL INVESTIGATION OF THE COMBUSTION PROCESS AND EFFICIENCY OF A DIESEL ENGINE IN THE CASE OF BIODIESEL FUEL APPLICATION	41
MVM2026-011	Milan Eremija Ivan Grujić Danijela Miloradović Željko Đurić Svetko Milutinović Nadica Stojanović	EXPERIMENTAL ANALYSIS OF EXHAUST GAS TEMPERATURE DURING THE USE OF BIODIESEL FUEL	53
MVM2026-013	Krasimir Markov Hristo Stanchev	INVESTIGATION OF THE FUEL CONSUMPTION AND EMISSIONS OF A DIESEL ENGINE RUNNING ON DIESEL WITH AN ADDITIVE	61
MVM2026-015	Milan Eremija Zoran Ristikić Svetko Milutinović Mesud Ajanović	EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF TIRE PRESSURE ON THE ROLLING RESISTANCE COEFFICIENT OF COMMERCIAL VEHICLES	67
MVM2026-025	Marko Lučić Mirjana Grdinić-Rakonjac Radoje Vujadinović Vladimir Pajković Ivan Grujić	ENERGY USE IN MONTENEGRO'S ROAD TRANSPORT SECTOR: TRENDS, FUEL STRUCTURE AND DEPENDENCE ON PETROLEUM-BASED FUELS	77

MVM2026-030	Vladimir Kočović Živana Jovanović Pešić Miloš Pešić Jelena Đusić Dragan Džunić	TRIBOLOGICAL PERFORMANCE OF BRASS SURFACES LUBRICATED WITH NEW AND USED ENGINE OILS	85
MVM2026-034	Mihailo Đuković Saša Milojević Slobodan Savić Blaža Stojanović Horia Abaitancei	APPLICATION OF A RADIAL HYDRAULIC MOTOR IN ALTERNATIVE VEHICLE DRIVE SYSTEMS	91
MVM2026-036	Marko Kitanović Slobodan Popović Nenad Miljić Predrag Mrđa	EFFECTIVE MIXTURE COMPOSITION IN THE ANGULAR DOMAIN IN SUPERCHARGED DISI ENGINE WITH MULTIPLE INJECTIONS	111
MVM2026-037	Petar Markov Radivoje Pušara Dragan Peruničić	A SINGLE-RANGE POLYNOMIAL MODEL FOR TEMPERATURE-DEPENDENT MIXTURE PROPERTIES IN COMBUSTION ENGINES WITH VARIABLE EGR RATES	125
MVM2026-038	Dragan Peruničić Petar Markov Radivoje Pušara	MODELING OF SPECIFIC HEAT RATIO FOR DISI ENGINES WITH COMPLEX MIXTURE FORMATION AND HIGH EGR RATES	139
MVM2026-041	Predrag Mrđa Slobodan Popović Nenad Miljić Marko Kitanović	EXPERIMENTAL AND CFD-BASED INVESTIGATION OF VAPOUR POCKET FORMATION IN AN INTERNAL COMBUSTION ENGINE COOLING SYSTEM	155
MVM2026-042	Nenad Miljić Predrag Mrđa Slobodan J. Popović	QUANTIFYING IMEP EVALUATION ERROR INDUCED BY PIEZOELECTRIC PRESSURE SENSOR AGEING IN INTERNAL COMBUSTION ENGINE INDICATION	165
MVM2026-051	Saša Milojević Marija Rafailović Michal Loman Branislav Šarkan Ján Vrábel Slobodan Savić	SAFETY AND OPERATIONAL CONSIDERATIONS FOR COMPOSITE HYDROGEN AND CNG STORAGE CYLINDERS IN VEHICLES	175
MVM2026-068	Mitar Mišić Stjepan Galamboš Boris Stojić Jovan Dorić Luka Sekicki	DEVELOPMENT OF AN ELECTRONIC MEASUREMENT SYSTEM FOR TURBOCHARGER WASTEGATE ACTUATOR RESPONSE-TIME TESTING	185
MVM2026-071	Mitar Mišić Stjepan Galamboš Jovan Dorić Boris Stojić Luka Sekicki	DESIGN AND IMPLEMENTATION OF A TEST BENCH FOR EVALUATING THE DYNAMICS OF PNEUMATIC WASTEGATE ACTUATORS	193

SECTION B

Vehicle Design and Manufacturing

MVM2026-006	Gordana Bogdanović Aleksandar Radaković Dragan Čukanović Petar Knežević Aleksandar Nešović	VARIATIONAL SHEAR CONTROL IN ESL–HSDT LAMINATES FOR AUTOMOTIVE STRUCTURES	203
-------------	--	---	-----

MVM2026-007	Gordana Bogdanović Aleksandar Radaković Petar Knežević Dragan Čukanović Marko Milošević	FATIGUE ANALYSIS OF MATERIALS AND METHODS FOR CYCLE COUNTING UNDER ARBITRARY LOAD HISTORIES	211
MVM2026-009	Julija Boskovic Ivan Grujic Stefan Djuric Nadica Stojanovic Bogdan Zivkovic Milan Ivkovic Suzana Petrovic Savic	DEVELOPMENT OF AN EXPERIMENTAL FIVE-AXIS CNC SYSTEM USING STEPPER MOTORS	219
MVM2026-012	Saša Vasiljević Jasna Glišović Slobodan Vasiljević	ANALYSIS OF EXPERIMENTAL METHODOLOGIES FOR TESTING INNOVATIVE BRAKE SOLUTIONS	235
MVM2026-016	Ljubica Spasojević Zorica Djordjević Sonja Kostić Saša Jovanović	MODAL ANALYSIS OF A COMPOSITE CRANKSHAFT FOR AN INTERNAL COMBUSTION ENGINE (ICE)	245
MVM2026-017	Zvonko Petrović Suzana Petrović Savić Milica Tufegdžić Nikola Kostić Milena Petrović	MATHEMATICAL MODELING OF HYDRAULIC DRIVE FOR THE MITSUBISHI RV-2FRL INDUSTRIAL ROBOT: INFLUENCE OF MOMENT OF INERTIA ON SERVO VALVE RESPONSE TIME	253
MVM2026-022	Marko Delić Vesna Mandić Nada Ratković Nikola Komatina Dušan Arsić Nikola Kastratović	ANALYSIS OF THE INFLUENCE OF IMPORTANT FORMING PARAMETERS IN SHEET METAL STAMPING IN AUTOMOTIVE INDUSTRY USING FEA	267
MVM2026-024	Milan Simonović Dragan Adamović Đorđe Ivković Marko Simonović	ANALYSIS OF THE POSSIBILITY OF PREDICTING THE TENSILE STRENGTH OF ADVANCED STRUCTURAL STEELS USED IN THE AUTOMOTIVE INDUSTRY USING ARTIFICIAL NEURAL NETWORKS WITH DIFFERENT NUMBERS OF NEURONS IN THE HIDDEN LAYER	275
MVM2026-026	Nenad Petrović Živana Jovanović Pešić Dragan Džunić Vladimir Kočović Strahinja Milenković	CREATING CURVED MESHES BY HEAT-FORMING 3D-PRINTED PARTS	287
MVM2026-050	Danijela Tadić Jasna Glišović Nikola Komatina	COMPARATIVE ANALYSIS OF OBJECTIVE CRITERIA WEIGHTING METHODS FOR ELECTRIC VEHICLE EVALUATION	293
MVM2026-052	Dragan Čukanović Gordana Bogdanović Aleksandar Radaković Petar Knežević	APPLICATION, MODELLING AND BENDING ANALYSIS OF COMPOSITE LAMINATES IN MODERN VEHICLES	303
MVM2026-053	Mihajlo Jevtić Aleksandra Obradović Bogdan Todorović Nebojša Hristov Damir Jerković	FINITE ELEMENT ANALYSIS OF STRUCTURAL SUPPORT REACTIONS IN WHEELED MOBILE PLATFORM UNDER HIGH-INTENSITY IMPULSIVE LOADING	311

MVM2026-059	Dušan Milojević Nikola Kotorčević Đorđe Damljanović Nikola Živčević Dušan Arsić Fatima Živić	EFFECTS OF UNIT CELL GEOMETRY AND STRUT THICKNESS ON THE COMPRESSIVE BEHAVIOR OF 3D-PRINTED MECHANICAL METAMATERIALS	321
MVM2026-060	Nebojša Arsić Nenad Kostić Nenad Petrović Nenad Marjanović	APPLICATION OF 3D SCANNING AND CAD DEVIATION ANALYSIS AS A BASIS FOR PRESS TOOL OPTIMISATION IN THE AUTOMOTIVE INDUSTRY	325
MVM2026-061	Sandra Gajević Slavica Miladinović Nikola Mitrović Zorica Djordjević Saša Milojević Blaža Stojanović	APPLICATION OF LAMINATED COMPOSITES IN THE AUTOMOTIVE, AVIATION AND MARINE INDUSTRY	333
MVM2026-067	Luka Milić Ilija Vidović Matija Simanić Momir Drakulić Aleksandar Đurić	ADDITIVE MANUFACTURING AS A FABRICATION METHOD FOR A LIGHTWEIGHT TRACKED ROBOT PLATFORM	345
MVM2026-070	Dobrivoje Čatić Vladimir Čatić	A COMBINED FTA-FMEA PROCEDURE FOR PRODUCT DEVELOPMENT	355
MVM2026-073	Milan Blagojević Milan Bojović Živče Šarkočević	REVERSE ENGINEERING OF A COMPLETE VEHICLE FOR THE DEVELOPMENT OF A MODULAR VEHICLE PLATFORM	363
MVM2026-076	Nenad Miloradović Rodoljub Vujanac Mirjana Piskulić	WAREHOUSE SYSTEMS IN THE AUTOMOTIVE INDUSTRY: A COMPARATIVE STUDY OF STORAGE SYSTEMS, HANDLING EQUIPMENT AND SAFETY CLEARANCE	369

SECTION C

Vehicle Dynamics and Intelligent Control Systems

MVM2026-001	Miroslav Demić Mikhail P. Malinovsky Andrija Vujičić	THEORETICAL-EXPERIMENTAL APPROACH TO THE DEVELOPMENT OF A METHOD FOR IDENTIFYING THE HEAT DISSIPATION RATE OF MOTOR VEHICLE SHOCK ABSORBERS	379
MVM2026-002	Aleksandar Jovanović Katarina Kukić Ana Uzelac Dušan Teodorović	DEEP Q-LEARNING ALGORITHM FOR TRAFFIC CONTROL AT A DISPLACED LEFT-TURN INTERSECTION	393
MVM2026-014	Boris Stojić Nebojša Nikolić Luka Sekicki	A FLEXIBLE COMPUTATIONAL MODEL FOR FUEL CONSUMPTION ESTIMATION IN ARBITRARY VEHICLE DRIVING CYCLES	403
MVM2026-018	Dušan Opsenica Ivan Blagojević Saša Mitić	THE INFLUENCE OF ELECTRIC VEHICLE CONFIGURATION ON VEHICLE DYNAMIC CHARACTERISTICS	413
MVM2026-023	Snežana Petković Valentina Golubović Bugarski Jelena Adžić Milan Eremija	ANALYSIS OF PARAMETERS INFLUENCING ROAD TANKER ROLLOVER	425

MVM2026-028	Momir Drakulić Aleksandar Đurić Sreten Perić	SENSITIVITY ANALYSIS OF A TERRAMECHANICS MODEL OF TRACK- TERRAIN INTERACTION WITH RESPECT TO VEHICLE DESIGN PARAMETERS	435
MVM2026-031	Marko Simonović Dragan Adamović Đorđe Ivković Milan Simonović	SELECTION OF MATERIALS FOR FRICTION COMPONENTS OF THE BRAKE MECHANISM	447
MVM2026-032	Zoran Papić Nenad Saulić Milja Simeunović	PREDICTION OF EES VALUES IN VEHICLE IMPACTS USING AI	461
MVM2026-035	Marijana Jeremić Lazar Krstić Miloš Ivanović Mihailo Lazarević Milan Matijević	DIGITAL TWIN DESIGN FOR TORSIONAL STIFFNESS ESTIMATION IN MOTOR-LOAD OSCILLATORY SYSTEMS USING PHYSICS- INFORMED NEURAL NETWORKS	471
MVM2026-040	Nebojša Jovičić Angelina Cvetanović Goran Bošković	EVALUATING THE EFFICIENCY OF OPTIMIZED WASTE COLLECTION ROUTES USING DATA ENVELOPMENT ANALYSIS	485
MVM2026-046	Aikaterini Zafeiri Clio Vossou Dimitrios Koulocheris	FLUID-STRUCTURE INTERACTION IN A TANK VEHICLE TRANSPORTING LIQUID FUEL	497
MVM2026-048	Ognjen Jovanović Milan Matijević	APPLICATION OF THE TIA PORTAL ENVIRONMENT FOR SOFTWARE-IN-THE-LOOP SIMULATION OF PLC CONTROL OF A FIRST- ORDER DYNAMIC SYSTEM	507
MVM2026-058	Nikola Gunić Hana Stefanović Milan Matijević	A NEW GENERATION OF WHEEL POSITION AND SPEED INTELLIGENT SENSORS FOR MOTOR VEHICLES	523
MVM2026-065	Danijela Miloradović Jasna Glišović Jovanka Lukić Nadica Stojanović	CONDITIONAL SPECTRAL ANALYSIS OF VEHICLE VIBRATION DATA	529
MVM2026-066	Matija Simanić Ilija Vidović Luka Milić Momir Drakulić Aleksandar Đurić	SIMULATION-BASED MOTION ANALYSIS OF A LIGHTWEIGHT TRACKED ROBOT USING WEBOTS	541
MVM2026-075	Branko Miličić Nikola Frlić Sekulić Miloš Mitrović Ivan Blagojević	IDENTIFICATION OF EFFECTIVE THERMO- PNEUMATIC TIRE PARAMETERS FROM REAL- WORLD ROAD TEST DATA	553

SECTION D

Driver/Vehicle Interface, Information and Assistance Systems

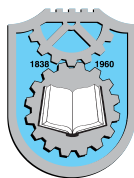
MVM2026-005	Slobodan Mišanović	THE INFLUENCE OF ENERGY DEMAND FOR PASSENGER COMPARTMENT CLIMATE CONTROL OF THE ENERGY EFFICIENCY OF ELECTRIC BUS	567
MVM2026-019	Dragan Ružić Miloš Vujković	DETERMINING THE FUEL CONSUMPTION REQUIRED FOR AIR-CONDITIONING OF A PASSENGER CAR UNDER REAL-WORLD CONDITIONS	579

MVM2026-020	Dragan Stojadinović Aleksandar Đurić Snežana Jovanović Miroslav Jovanović	THE INFLUENCE OF SEAT DESIGN AND SURFACE TYPE ON THE LEVEL OF VIBRATIONS EXPERIENCED BY A TRUCK DRIVER	589
MVM2026-063	Slavica Mačužić Saveljić Ognjen Matić Igor Saveljić	MACHINE LEARNING-BASED PREDICTION AND EXPLAINABILITY OF DRIVER DISCOMFORT AND FATIGUE: A DATA-DRIVEN EXTENSION OF A RAMSIS-BASED DIGITAL HUMAN MODEL STUDY	599
MVM2026-072	Jovanka Lukić Jasna Glišović Danijela Miloradović	COMPONENT COHERENCE-BASED ASSESSMENT OF MASKING EFFECTS IN TWO- DIRECTIONAL WHOLE-BODY VIBRATION	609
MVM2026-074	Milan Blagojević Saša Milojević Živče Šarkoćević Ivica Čamagić Dragan Lazarević	FIAT 500L REAR IMPACT PERFORMANCE IN EURO NCAP AND IIHS ASSESSMENTS	623

SECTION E

Transport Challenges in Emerging Economies

MVM2026-033	Janez Kopač Franci Pušavec	HIGHWAY ROAD TRAPS AS HIDDEN SOURCES OF CRASH RISK	633
MVM2026-044	Nadica Stojanović Ali Belhocine Ivan Grujić Željko Đurić Suzana Petrović Savić Oday I. Abdullah	THE IMPACT OF “DRUNK BUSTERS” ON THE ADEQUATE PERFORMANCE OF TASKS	645
MVM2026-055	Vladimir Vukašinović Dušan Gordić Vanja Šuštersiћ Mladen Josijević	SUSTAINABLE BIOFUELS FOR THE DECARBONISATION OF THE TRANSPORT SECTOR IN CITIES	659
MVM2026-062	Goran Bošković Nebojša Jovičić Angelina Cvetanović Saša Milojević	ASSESSMENT OF THE NUMBER OF END-OF- LIFE VEHICLES IN THE REPUBLIC OF SERBIA	669
MVM2026-064	Bojana Bošković Nadica Stojanović Saša Babić Milena Petrović Anđela Egerić	PREDICTION AND TIME-SERIES ANALYSIS OF ROAD DEATHS PER MILLION INHABITANTS IN THE REPUBLIC OF SERBIA AND THE EUROPEAN UNION FOR THE PERIOD 2012 TO 2030	677
MVM2026-069	Saša Jovanović Zorica Đorđević Danijela Nikolić Lozica Ivanović Saša Milojević	A SAW-BASED DECISION SUPPORT MODEL FOR THE SELECTION OF NEW AND USED PASSENGER CARS	691



The 11th International Congress
Motor Vehicles & Motors 2026
Kragujevac, Serbia
October 8th - 9th, 2026



MVM2026-074

<https://doi.org/10.24874/CMVM2026.074>
Original scientific paper

Milan Blagojević¹

Saša Milojević²

Živče Šarkoćević³

Ivica Čamagić⁴

Dragan Lazarević⁵

FIAT 500L REAR IMPACT PERFORMANCE IN EURO NCAP AND IIHS ASSESSMENTS

ABSTRACT: This paper examines Fiat 500L rear-impact performance by combining published Euro NCAP and IIHS assessments with video-based kinematic reanalysis of official Euro NCAP footage. Euro NCAP reported 2.3 points and marginal whiplash protection for the 2012 European variant, whereas IIHS rated the seat and head restraint of the United States model range as good. The ratings are not directly interchangeable because the programmes used different pulses, seat specifications, measured quantities and scoring rules. To supplement the published results, WhiplashApp was used as the motion-analysis tool. Two user-defined head-region points were tracked by Lucas-Kanade optical flow, and the smoothed trajectories were used to calculate angle of head, angular velocity and angular acceleration. The resulting curves identify motion reversal, extension-rebound and intervals of rapid head rotation. These observations complement the IIHS values for favourable restraint geometry and 56 ms head contact and help explain how a good IIHS rating can coexist with the marginal Euro NCAP result. The study demonstrates the value of traceable video kinematics for interpreting published automotive test results. WhiplashApp provides an effective tool for this workflow and a suitable basis for further whiplash and video-based biomechanical analyses with additional synchronised measurement channels.

KEYWORDS: whiplash, rear impact, motion analysis, seat, head restraint, Fiat 500L

¹ Milan Blagojević, University of Pristina, Faculty of Technical Sciences, Knjaza Miloša 7, Kosovska Mitrovica, milan.blagojevic@pr.ac.rs,  <https://orcid.org/0000-0003-0710-5297>

² Saša Milojević, University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, Kragujevac, sasa.milojevic@kg.ac.rs,  <https://orcid.org/0000-0003-0569-047X>

³ Živče Šarkoćević, University of Pristina, Faculty of Technical Sciences, Knjaza Miloša 7, Kosovska Mitrovica, zivce.sarkocevic@pr.ac.rs,  <https://orcid.org/0000-0001-5110-6620>

⁴ Ivica Čamagić, University of Pristina, Faculty of Technical Sciences, Knjaza Miloša 7, Kosovska Mitrovica, ivica.camagic@pr.ac.rs,  <https://orcid.org/0000-0003-4706-6333>

⁵ Dragan Lazarević, University of Pristina, Faculty of Technical Sciences, Knjaza Miloša 7, Kosovska Mitrovica, dragan.lazarevic@pr.ac.rs,  <https://orcid.org/0000-0001-5106-554X>

FIAT 500L U EURO NCAP I IIHS PROCENAMA UDARA OTPOZADI

REZIME: U ovom radu analiziraju se performanse automobila Fiat 500L pri udaru otpozadi povezivanjem objavljenih rezultata Euro NCAP i IIHS ispitivanja sa naknadnom video-kinematičkom analizom zvaničnog snimka Euro NCAP testa. Euro NCAP je za evropsku varijantu vozila iz 2012. godine dodelio 2,3 poena i ocenio zaštitu od trzajne povrede vrata kao marginalnu, dok je IIHS sedište i naslon za glavu američke verzije modela ocenio kao dobre. Ove ocene nisu neposredno uporedive jer su u programima primenjeni različiti impulsi udara, specifikacije sedišta, merene veličine i pravila ocenjivanja. Kao dopuna objavljenim rezultatima, WhiplashApp je korišćen kao alat za analizu kretanja. Dve korisnički definisane tačke u oblasti glave praćene su primenom Lucas–Kanade metode optičkog toka, a izgladene putanje korišćene su za izračunavanje ugla glave, ugaone brzine i ugaonog ubrzanja. Dobijene krive omogućavaju identifikovanje promene smera kretanja, faze ekstenzije i povratnog kretanja, kao i vremenskih intervala brze rotacije glave. Ova zapažanja dopunjuju rezultate IIHS ispitivanja, koji ukazuju na povoljnu geometriju sistema za oslanjanje glave i ostvarivanje kontakta glave sa naslonom nakon 56 ms, i pomažu u objašnjenju kako dobra IIHS ocena može postojati istovremeno sa marginalnim rezultatom Euro NCAP ispitivanja. Istraživanje pokazuje značaj sledjive video-kinematičke analize za tumačenje objavljenih rezultata ispitivanja bezbednosti automobila. WhiplashApp predstavlja efikasan alat za ovakav postupak i odgovarajuću osnovu za dalji razvoj analiza trzajnih povreda vrata i drugih biomehaničkih ispitivanja zasnovanih na video-snimcima, uz mogućnost uključivanja dodatnih sinhronizovanih mernih kanala.

KLJUČNE REČI: trzajna povreda vrata, udar otpozadi, analiza kretanja, sedište, naslon za glavu, Fiat 500L

INTRODUCTION

Whiplash-associated disorders are commonly linked to low- and moderate-severity rear impacts. During the initial phase of such an event, the seat accelerates the torso while the head tends to remain behind because of inertia. The resulting relative motion depends on head-restraint geometry, seatback stiffness, energy absorption and the timing of head contact. Consumer assessment programmes therefore evaluate the seat and head restraint as a system rather than considering only the nominal presence of a restraint (IIHS, 2023).

The Fiat 500L provides an informative case because it was manufactured at the Kragujevac plant (Government of Serbia, 2012) and was assessed on both sides of the Atlantic. Euro NCAP awarded the vehicle five stars in 2012 and 94% for adult occupant protection but described its rear-impact whiplash protection as marginal. IIHS later assigned a good rating to the head restraints and seats of the United States model range. Reading these labels without the corresponding protocols could suggest a contradiction that is not supported by the available evidence. The objective of this study is to establish which parts of the two assessments are comparable, quantify the published Fiat 500L results and identify the information required for a defensible experimental reanalysis. The study is a documentary case analysis; no unpublished manufacturer data or new sled tests are presented.

MATERIALS AND METHOD

The Euro NCAP record concerns a left-hand-drive Fiat 500L 1.4 petrol Easy 4x2, publication year 2012 and test mass 1245 kg. The published adult-occupant score was 34 points (94%), including 2.3 points for rear impact whiplash protection. Euro NCAP explicitly characterised the protection provided by the seat and head restraint as marginal (Euro NCAP, 2012a). The IIHS record identifies a manual cloth seat and states that the rating applies to 2014-2020 models. IIHS reports a good overall evaluation, good dynamic rating and good seat/head-restraint geometry (IIHS, n.d.-a).

The comparison was made at three levels: test object and occupant surrogate; excitation and positioning; and reported outputs. A value was treated as directly comparable only when its definition and unit were common to both sources. Programme-specific categories were compared qualitatively and were not converted to an artificial common numerical scale.

The Euro NCAP procedure current around the assessment period was based on three sled tests intended to represent the range of pulse shapes and velocity changes observed in rear crashes. The 2008 protocol specified low and medium pulses near 16 km/h and a high pulse near 24 km/h. Although the low and medium velocity changes were similar, their durations and acceleration-time histories differed. Thus, pulse severity cannot be described by

velocity change or peak acceleration alone. The seat was installed in a vehicle-representative geometry and loaded by a belted BioRID dummy (Euro NCAP, 2008).

Table 1 Crosswalk of the historical rear-impact assessment procedures

Characteristic	Euro NCAP procedure	IIHS procedure
Test object	Forward-facing front seat and head restraint mounted on a sled	Front seat and head restraint mounted on a sled
Occupant surrogate	BioRID rear-impact dummy, standardised seating and three-point belt	BioRID dummy with realistic articulated spine
Dynamic excitation	Three pulses: low, medium and high severity	One pulse with Δv about 16 km/h (10 mph)
Euro NCAP low	Δv 16.10 $\pm$ 0.80 km/h; 105.8 $\pm$ 3.0 ms; mean 42.35 $\pm$ 4.50 m/s ²	Not applicable
Euro NCAP medium	Δv 15.65 $\pm$ 0.80 km/h; 91.0 $\pm$ 3.0 ms; mean 47.85 $\pm$ 4.00 m/s ²	Closest in Δv , but not necessarily identical in shape
Euro NCAP high	Δv 24.45 $\pm$ 1.20 km/h; 107.7 $\pm$ 3.0 ms; mean 63.15 $\pm$ 4.85 m/s ²	No corresponding pulse in the historical rating
Geometry	Included in protocol and assessment rules	Separate static height and backset assessment
Output	Points contributing to adult-occupant/star rating	Good, Acceptable, Marginal or Poor category

The historical IIHS evaluation used a two-stage logic. Static measurements first described the height and backset of the restraint relative to a 50th-percentile male reference. A dynamic sled test with BioRID then evaluated how the system managed occupant motion and crash energy. The dynamic pulse represented a velocity change of 10 mph, equivalent to a stationary vehicle being struck at 20 mph by a vehicle of equal mass (IIHS, 2023). This is close to the Euro NCAP medium pulse in velocity change, but equivalence of the complete acceleration histories and scoring thresholds should not be assumed.

BIOMECHANICAL AND KINEMATIC PARAMETERS

Euro NCAP assessment quantities

The Euro NCAP whiplash assessment combines complementary quantities because no single measurement fully describes the loading mechanism. The Neck Injury Criterion (NIC) represents the effect of relative horizontal acceleration and velocity between the head and the first thoracic vertebra. Nkm combines upper neck shear force and sagittal bending moment using normalising intercepts and therefore describes coupled force-moment loading. Head rebound velocity characterises forward head motion after seat and head-restraint interaction. These quantities are supplemented by upper-neck shear force, upper-neck tension, T1 acceleration and the time of head-restraint contact.

In the contemporaneous Euro NCAP adult-occupant assessment, each pulse could contribute up to three points. NIC, Nkm, rebound velocity, neck shear and neck tension each contributed up to 0.5 points, while a further 0.5 points was based on the better result from T1 acceleration or head-restraint contact time. Exceeding a capping limit in a principal criterion could reduce the complete pulse score to zero. The high-severity pulse also included a seatback-opening check, with a penalty for rotation of 32 degrees or more. Static geometry and worst-case geometry were then combined with the dynamic scores and scaled to the four-point whiplash contribution (Euro NCAP, 2013).

IIHS assessment quantities

The historical IIHS procedure divided the dynamic information into seat-design and dummy-response parameters. Time to head-restraint contact tested whether initially favourable geometry remained effective during deformation, while T1 acceleration reflected the ability of the seat to absorb crash energy and limit torso acceleration. Neck shear and neck tension were used to verify that early contact or energy absorption did not introduce unfavourable direct loading. A good dynamic rating required at least one seat design parameter to pass together with low neck forces (IIHS, 2020).

This difference in aggregation is important for the Fiat 500L. The IIHS values of 56 ms for head contact and 11.8 g for T1 acceleration describe two alternative seat-design paths in the IIHS rating logic. They cannot be inserted directly into the Euro NCAP score without confirming the pulse, reference time, filtering, dummy version and processing

window. Likewise, the reported IIHS shear and tension maxima do not reconstruct NIC, Nkm or rebound velocity, which require additional synchronised channels.

Whiplash software - Calculation of video-based kinematic quantities

For the video reanalysis, in-house WhiplashApp was used as a desktop motion-analysis application. The user manually selects points of interest in a video frame, after which the application tracks them through time by the Lucas-Kanade optical-flow method implemented through OpenCvSharp. The resulting trajectories are processed to calculate displacement, travelled distance, velocity, acceleration, distances between points, segment angles, angular velocity and angular acceleration, with smoothing applied to reduce tracking noise. Results are displayed as live plots on the WPF canvas and can be exported in CSV format.

In addition to video post-processing, the application integrates measurement hardware, including industrial cameras, the HBM Spider measurement system and Arduino triggers. This modular architecture supports synchronised experimental work and makes WhiplashApp applicable both to whiplash analysis and to related biomechanical and engineering test scenarios.

The official Euro NCAP recording of the 2012 Fiat 500L test was analysed in Whiplash software. Two points in the head region were tracked to obtain their image-coordinate histories and the orientation of the connecting segment, denoted as head angle A1. The same trajectories provided the input for the calculated translational and rotational quantities.

After spatial calibration, the tracked image coordinates x and y are expressed in physical units at equally spaced instants t_i , with the sampling interval Δt equal to the reciprocal of the verified frame rate. For an interior sample, translational velocity and acceleration can be estimated by central finite differences:

$$v_{x,i} = (x_{i+1} - x_{i-1})/(2\Delta t), \quad v_{y,i} = (y_{i+1} - y_{i-1})/(2\Delta t) \quad (1)$$

$$a_{x,i} = (x_{i+1} - 2x_i + x_{i-1})/\Delta t^2, \quad a_{y,i} = (y_{i+1} - 2y_i + y_{i-1})/\Delta t^2 \quad (2)$$

The corresponding velocity and acceleration magnitudes are obtained from their orthogonal components:

$$v_i = \sqrt{(v_{x,i})^2 + (v_{y,i})^2}, \quad a_i = \sqrt{(a_{x,i})^2 + (a_{y,i})^2} \quad (3)$$

The software calculates the unoriented angle between tracked vectors u and v from their scalar product. Angular velocity and angular acceleration then follow from the central-difference operator.

$$\theta_i = \text{acos}[(u_i \cdot v_i)/(|u_i||v_i|)] \quad (4)$$

$$\omega_i = (\theta_{i+1} - \theta_{i-1})/(2\Delta t) \quad (5)$$

$$\alpha_i = (\theta_{i+1} - 2\theta_i + \theta_{i-1})/\Delta t^2 \quad (6)$$

Before differentiation, the tracked x and y coordinates were smoothed by a centred moving-average filter with equal weights and a radius of six frames. The filtered position at sample i was calculated as.

$$\bar{p}_i = (1/N_i) \sum p_{i+k}, \quad k = -r, \dots, r \quad (7)$$

Translational speed was calculated from the filtered positions by a central difference over three frames.

$$v_i = ||\bar{p}_{i+3} - \bar{p}_{i-3}||/(6\Delta t) \quad (8)$$

Evaluation started at the fourth sample and ended three samples before the final sample; a value was recorded when both symmetric neighbours were valid. The speed series was then smoothed by a one-dimensional moving average with a radius of five samples.

Equation (4) yields an unoriented angle from 0 to 180 degrees, from which angular velocity and angular acceleration were calculated.

Table 2 Relationship between assessment parameters and video-derived quantities

Parameter	Euro NCAP	Historical IIHS	Video contribution
Head-restraint geometry	Static score	Static rating	Initial height and backset if scale and view permit
Head contact time	Alternative to T1 score	Seat-design parameter	Directly observable after time synchronisation
T1 acceleration	Alternative to contact-time score	Seat-design parameter	Can be estimated; instrumentation remains reference
Neck shear and tension	Separate criteria with caps	Dummy-response parameters	Not obtainable from video alone
NIC	Scored and capped	Not a rating parameter	Needs head and T1 kinematics with controlled differentiation
Nkm	Scored and capped	Not a rating parameter	Needs upper-neck force and moment channels
Head rebound velocity	Scored and capped	Not published for 500L	Derivable from calibrated head trajectory
Seatback opening	High-pulse modifier	Not part of published 500L values	Derivable from two or more seatback targets

RESULTS

The published vehicle-specific rear-impact results are summarised in Table 2, which places the Euro NCAP score beside the available IIHS rating and measured quantities. As Table 2 shows, the IIHS geometry is favourable: the restraint is relatively close to the back of the reference head and extends close to its top. The reported head-contact time of 56 ms indicates early engagement of the restraint within the dynamic event. IIHS also published a maximum T1 acceleration of 11.8 g, maximum neck shear of 52 N and maximum neck tension of 503 N. Equivalent channel maxima for the Euro NCAP Fiat 500L tests are not included in the public vehicle datasheet; therefore, a channel-by-channel numerical comparison is not possible from the identified sources.

Table 3 Published rear-impact results for the Fiat 500L

Quantity	Euro NCAP 2012	IIHS 2014-2020 applicability
Seat identification	500L 1.4 petrol Easy, LHD	Manual cloth seat
Overall rear-impact result	2.3 points; Marginal	Good
Dynamic rating	Included in programme score	Good
Geometry rating	No Fiat-specific values published in datasheet	Good
Backset	Not published	55 mm
Distance below top of head	Not published	26 mm
Maximum T1 acceleration	Not published	11.8 g
Head contact time	Not published	56 ms
Maximum neck shear force	Not published	52 N
Maximum neck tension	Not published	503 N

Figure 1 shows the two tracked head-region trajectories and the resulting head angle in Whiplash software. The analysed sequence is taken from the official Euro NCAP recording of the 2012 Fiat 500L test (Euro NCAP, 2012b).

Head angle A1 describes head-segment orientation. Its minimum, reached approximately 0.07 s after the start of the analysed interval, identifies motion reversal; the subsequent increase describes the extension-rebound phase. This event occurs in the same time range as the IIHS head-contact result of 56 ms, although the different time origins and test configurations prevent numerical equivalence. The comparison nevertheless demonstrates that Whiplash can locate candidate contact and rebound events directly from video and provide an independent check of timing parameters used in seat and head-restraint assessment.

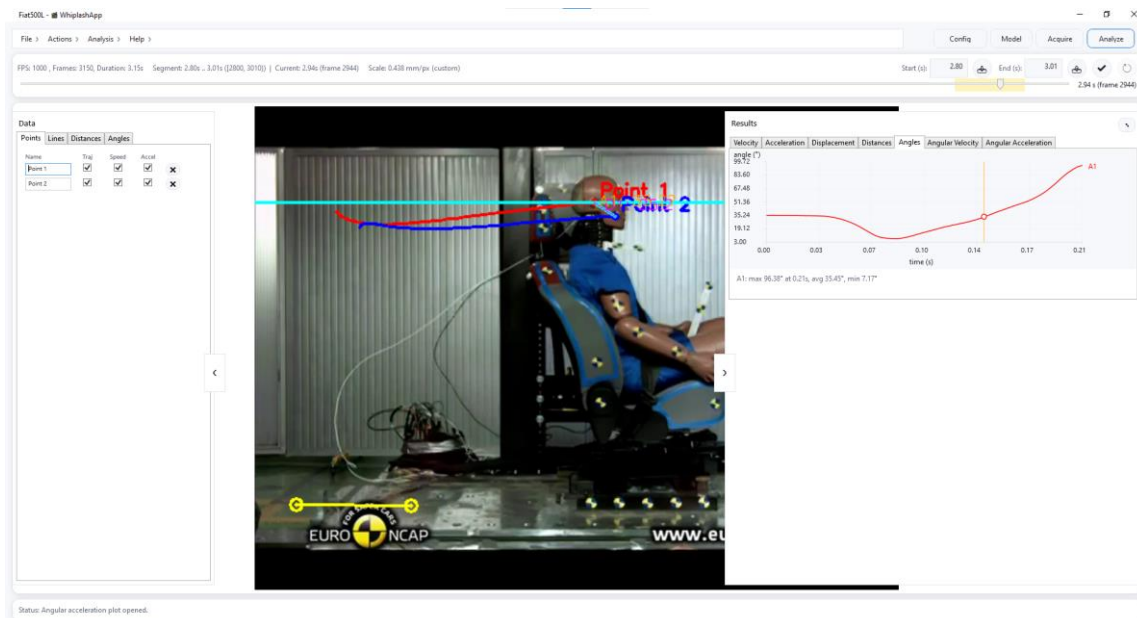


Figure 1 Fiat 500L head-point tracking and head angle in Whiplash software

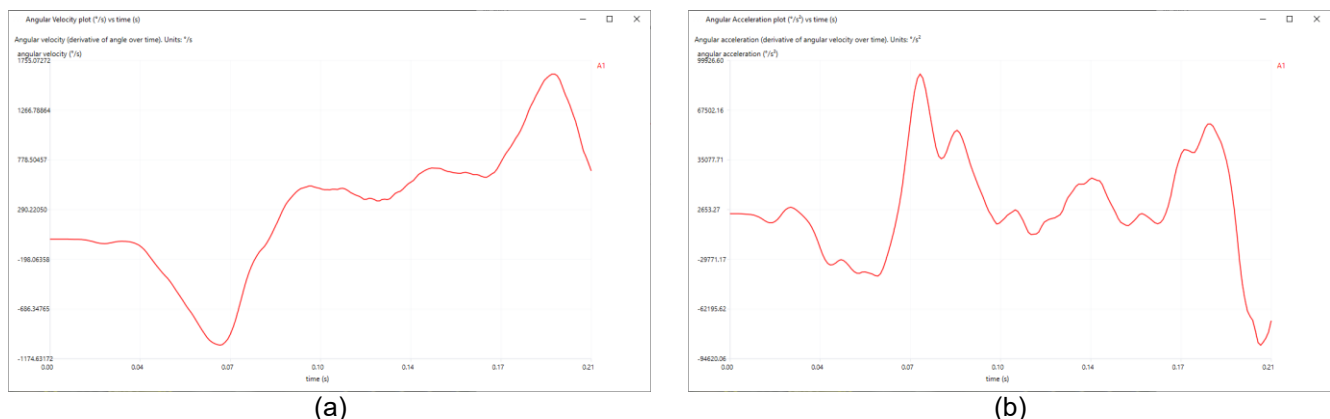


Figure 2 Derived rotational kinematics of head angle: (a) angular velocity and (b) angular acceleration

As shown in Figure 2, the negative angular-velocity extremum near 0.07 s and the larger positive extremum near 0.19 s separate the initial reversal from the later rebound, while angular-acceleration peaks identify the most rapid changes in rotational response. These features complement the IIHS evidence of favourable geometry and early contact by showing how the head continues to move after engagement. They are also relevant to the Euro NCAP assessment, which additionally considers rebound and neck-loading criteria over three pulses. The pronounced rotational response cannot by itself explain the marginal Euro NCAP score, but it shows why the good IIHS result and the Euro NCAP result are not contradictory. Whiplash thus supplies a traceable kinematic layer between the test video and the protocol metrics; synchronised T1 and neck-load channels would extend the same analysis to NIC and Nkm.

DISCUSSION

The difference between the published ratings is consistent with four combined factors: pulse selection, aggregation of criteria, seat specification and prescribed adjustment. Euro NCAP used three pulses, including a 24.45 km/h high-severity test, whereas IIHS combined static geometry with one approximately 16 km/h pulse. A seat can therefore achieve early contact and low forces in the IIHS configuration while showing greater rebound, seatback rotation or relative head-torso motion under another pulse. In addition, the European Easy seat and the United States manual cloth seat may differ in foam, frame, head restraint or production revision. The Whiplash curves clarify the sequence and intensity of head rotation, but the published data do not isolate which of these factors produced the different final categories.

The analysis also defines a clear route for extending the Whiplash workflow. Direct protocol comparison requires tracking the head centre, T1, head restraint, pelvis, seatback and fixed sled references. Together with synchronised sled acceleration, upper-neck forces and bending moment, these channels would enable calculation of backset, contact time, rebound, seatback opening, NIC, Nkm and the IIHS dummy-response quantities.

Planned extensions include protocol-based time-zero alignment, signed angles, automatic contact and rebound detection, video-sensor synchronisation, uncertainty evaluation, threshold comparison and automated reporting, strengthening Whiplash as a complete and auditable environment for comparative sled-test analysis. The interpretation is subject to the limitations of the available sources. Public Euro NCAP and IIHS records do not provide complete, equivalent time histories and refer to different markets and model years. The present curves therefore support event-level interpretation, not a numerical reconstruction of either rating or inference beyond this vehicle case.

CONCLUSIONS

The Euro NCAP and historical IIHS rear-impact assessments share the same fundamental test concept: a vehicle seat is mounted on a sled and loaded by a BioRID occupant surrogate to evaluate the combined action of the seat and head restraint. Their final ratings are nevertheless not directly interchangeable. Euro NCAP used three pulses and integrated the whiplash score into adult-occupant protection, while IIHS combined static geometry with one approximately 16 km/h dynamic pulse and reported a categorical seat rating.

For the Fiat 500L, Whiplash identifies motion reversal, extension-rebound and the intervals of greatest angular velocity and acceleration in the official Euro NCAP video. These results complement the IIHS values for geometry and early head contact and help explain why a good IIHS result can coexist with the marginal Euro NCAP score of 2.3 points. These capabilities demonstrate that Whiplash is developing in a technically sound direction and provide a strong basis for further improvement. Its traceable, extensible video-processing workflow is a promising platform not only for whiplash assessment but also for other biomechanical investigations based on automotive test recordings. Additional tracked landmarks and synchronised dummy channels would enable protocol-level calculations and direct comparison with Euro NCAP and IIHS limits.

ACKNOWLEDGMENTS

The part of this research is funded by Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract No. 451-03-65/2024-03/200155.

REFERENCES

- Euro NCAP. (2008). Euro NCAP whiplash test protocol, Version 2.8. European New Car Assessment Programme. https://www.vdrsyt.com/ancap_datasheets/xprotocol_archive/EuroNCAP/Euro-NCAP-Whiplash-test-protocol-V2.8.pdf
- Euro NCAP. (2012a). Fiat 500L safety assessment datasheet. European New Car Assessment Programme. https://asset.moto.it/pricelist/auto/8a707164bd2a8632dace6f8c9f4762f5/it-euroncap-com_it_results_fiat_500l_487.pdf
- Euro NCAP. (2012b). Fiat 500L - Crash Test 2012 [Video and still images]. © Euro NCAP. Reproduced with permission. Source: <https://youtu.be/Jhs4QHBN2Ug?si=sjGhDOA5kj98spaK&t=112>
- Euro NCAP. (2013). Assessment protocol - Adult occupant protection, Version 5.5. European New Car Assessment Programme. https://cdn.euroncap.com/cars/assets/euro_ncap_assessment_protocol_aop_v55_08882358ea.pdf
- Government of Serbia. (2012). Mass production of Fiat 500L in Kragujevac starts in April. <https://www.srbija.gov.rs/vest/en/84138/mass-production-of-fiat-500-l-in-kragujevac-starts-in-april.php>
- Insurance Institute for Highway Safety. (n.d.-a). 2018 Fiat 500L: Head restraints and seats. Retrieved September 11, 2026, from <https://www.iihs.org/ratings/vehicle/fiat/500l-4-door-hatchback/2018>
- Insurance Institute for Highway Safety. (n.d.-b). Head restraints: Discontinued test. Retrieved September 11, 2026, from <https://www.iihs.org/ratings/about-our-tests/head-restraints>
- Insurance Institute for Highway Safety. (2023). Virtual testing will help us chart a new course in neck injury prevention. <https://www.iihs.org/news/detail/virtual-testing-will-help-us-chart-a-new-course-in-neck-injury-prevention>
- Insurance Institute for Highway Safety. (2020). Vehicle seat/head restraint evaluation protocol, dynamic criteria, Version VI. https://www.iihs.org/media/30da9417-bb37-4247-807e-aeb5e78ba8b0/5rL9NQ/Ratings/Protocols/current/head_restraint_protocol_dynamic_vi.pdf

