D4.5 Passive safety systems physical demonstrator

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Executive summary

The SAFE-UP project aims to address the upcoming changes in the automotive industry and future mobility which will involve a mixture of human-driven and automated vehicles.

Previous deliverables of work package 4 (WP4) have already dealt with the specification of the use cases (SAFE-UP project D4.1) as well as definition of the system layouts including new restraint strategies (SAFE-UP project D4.2) which were studied by means of virtual simulations with Human Body Models in several seating positions which are considered to become relevant in automated vehicles (SAFE-UP project D4.4).

The triggering and performance of the restraint system components (i.e., seat belts, airbags) have been adapted according to the information provided by the Occupant Monitoring System (OMS) studies. The changes applied to the restraint systems will be tested in the sled facilities to demonstrate occupants' safety in case of impact.

Therefore, DEMO 1 will demonstrate the performance of adapted restraint systems studied in WP4 for reclined occupant representing novel seating position in autonomous vehicle (SAFE-UP project T5.4.2). It consists of two main parts; the first being an Occupant Monitoring System installed in a Mock-up Vehicle (SAFE-UP project D4.3) and the second being an adaptable sled test set-up for the evaluation of reclined seating positions, with seat back angle between 33º and 48º (SAFE-UP project T4.5).

The generic environment fabricated for the sled test setup and described in this report is based on the virtual generic environment developed in the SAFE-UP project task 4.3.

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List of abbreviations

Abbreviation	Meaning
AV	Autonomous vehicle
WP	Work Package
T	Task
D	Deliverable
OMS	Occupant monitoring system
FFRB	Full-frontal rigid barrier
SCP	Straight crossing path
LTAPOD2	Left turn across path opposite direction 2

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1. Introduction and Objectives

1.1 Introduction

The development of restraint systems for today's vehicles is based on upright seating positions during the task of driving, which are specified by legal or consumer crash testing protocols [7]. The introduction of autonomous vehicles (AV) and the fact that the driver becomes, partially or fully, a passenger in the vehicle amplifies the range of standard upright seating positions by preferable positions such as reclined or rearward shifted [6].

Since current passive safety systems are made for standard upright seating positions according to legislation and consumer ratings, their development is limited by legislation, which nowadays does not consider reclined seating positions. In future AV journeys, most users are expected to spend time performing non-driving activities, which will require interior designs to be optimized, and seating positions will probably change.

An occupant monitoring system (OMS) can detect such positions, as well as occupants' anthropometries and can provide information to the vehicle safety systems to adapt the characteristic parameters of the restraint system, such as airbag pressure and tape lengths, pre-tensioner firing times, and load-limiter forces, based on the individual passenger's anthropometry and posture acquired by OMS.

The team involved in WP4 of the SAFE-UP project studied several restraint system layouts using virtual environments to evaluate the effectiveness of different solutions. System Layout 2 named "Adaptive actuators" was improved by means of simulation considering the input from the OMS data collection activities. Therefore, this case was selected to be transferred to the physical environment as can be seen in the diagram from Figure 1.

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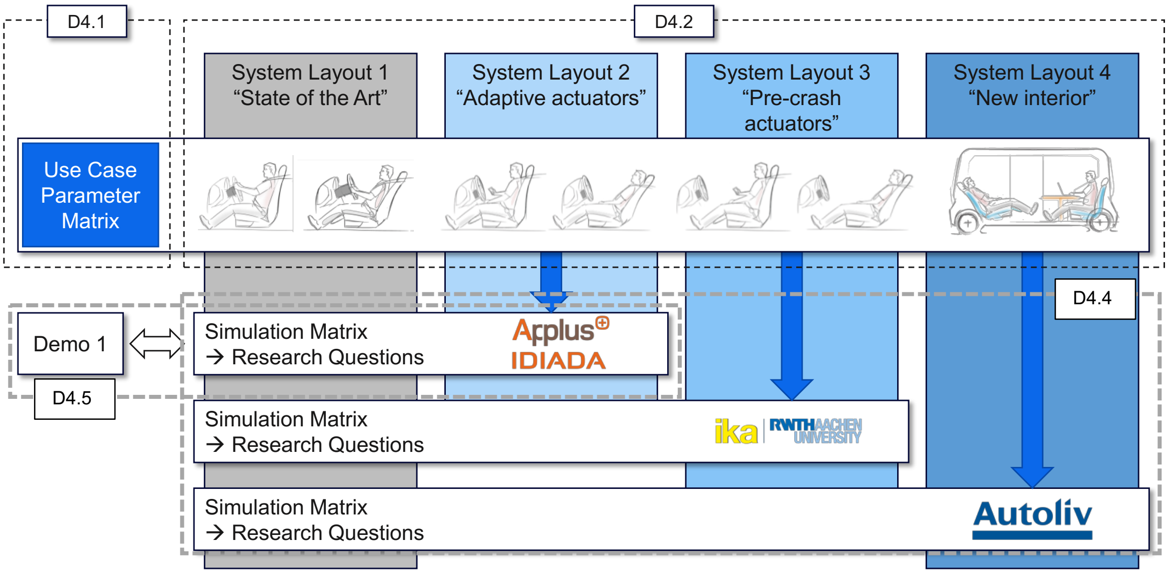

Figure 1: Simulation studies and related system layouts [4]

Looking at the short- and mid-term trend changes in the backrest angle (Figure 2) of the occupant's seat in semi-automated vehicles (tendency to be more reclined as the Autonomous vehicle progresses), the following characterization can be done (as in [6]):

- Upright position: 20-25º
- Reclined position: 33-48º
- Fully reclined or relaxed position: up to 60º

The seat pan angle (shown Figure 2) is set to 15º degrees for all tests performed according to the study reported in Deliverable (D) 4.4.

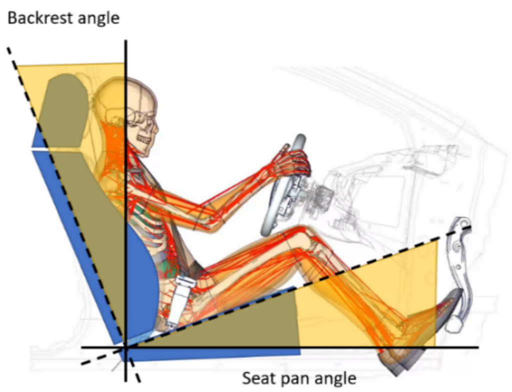

Figure 1: Definition of the angles for seating position (image from OSCCAR D2.3, image background from https://www.toyota.co.jp/thums/contents/video/pre-collision_safety.mp4)

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1.2 Objectives

The objective of the task (T) 4.5 is to build-up an adaptable sled test set-up for the demonstration of one of the layouts defined in the SAFE-UP project D4.2. This demonstrator aims to replicate a System Layout 2 (shown in figure 3 below), L3 vehicle in automated mode with non-driving reclined seating positions.

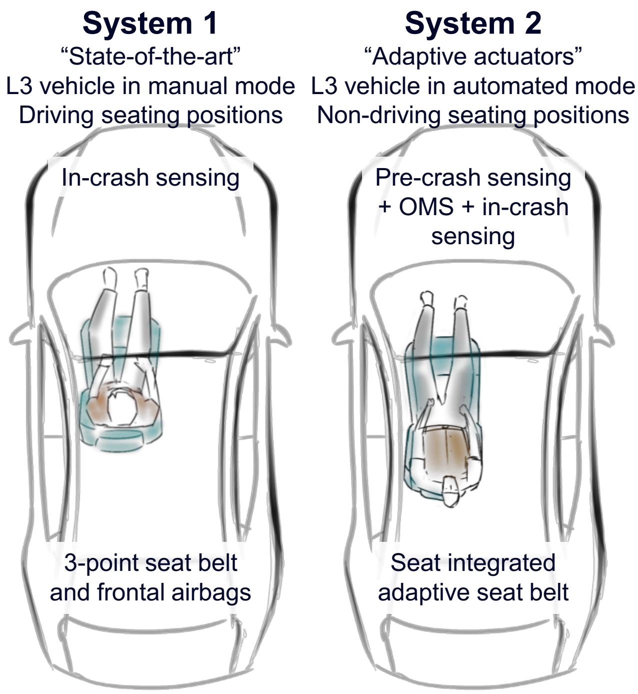

Figure 2: Overview of the two identified system layouts [5]

In the T5.4.2 the sled test set-up will be used to perform several sled tests with THOR-Reclined dummy in order to demonstrate the kinematics of an occupant in reclined positions and to demonstrate the performance of the restraint systems adapted to that specific position.

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2. Sled set-up

The sled set-up is based on the generic virtual model data provided by Autoliv.

The sled set up hardware includes:

- Semi-rigid seat pan
- Seat backrest
- Knee bolster
- Steering column support
- Foot support
- Sled environment
- Airbag

The seat belt is mounted on the seat backrest to demonstrate a “belt-in-seat” configuration (Figure 4).

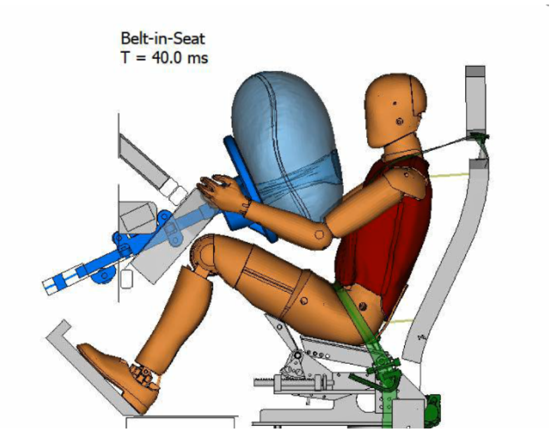

Figure 3: Virtual generic environment provided by Autoliv

2.1 Semi-rigid seat

The semi-rigid seat is an experimental seat designed to better-reproduce the behavior of a real vehicle seat in sled test conditions. This device was developed by Uriot et al. [1] on a previous study with PMHS testing activities.

The semi-rigid seat model was provided by Autoliv and was used both for the performance of the simulation activities and the design of the components to be fabricated for the sled preparation. The seat is modelled with two rotatable rigid plates to reproduce the behavior of a foam seat.

The anterior plate is an anti-submarining system which, due to the lateral springs and the plate in the back, can be adjusted to meet the foam stiffness of the real seat.

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The stiffness of the three springs located under the seat plate are defined by Richardson et al. [2] as front configuration seat: 128 N/mm for the seat pan side springs, 379 N/mm for the seat pan center spring, and 132 N/mm for the anti-submarining springs. The seat model is shown in Figure 4.

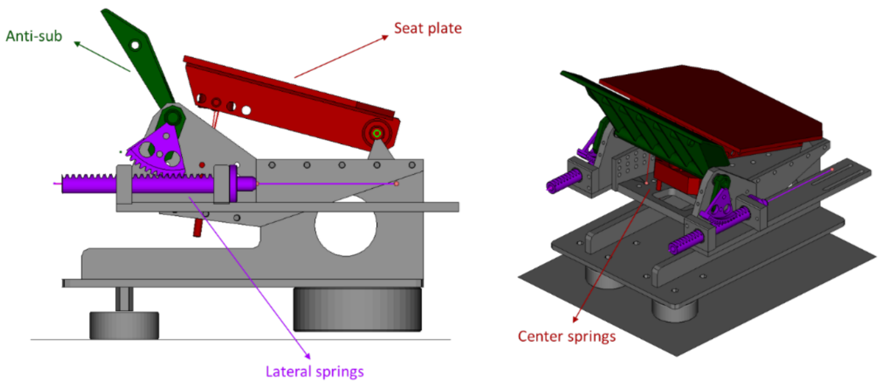

Figure 4: Semi-rigid seat model (frontal configuration)[1]

The delivery of the semi-rigid seat was delayed due to some drawbacks in the project where it was being used. Therefore, the testing activities planned by summer 2022 were cancelled.

Nonetheless, IDIADA took the initiative to fabricate their own seat in order to execute the test series as promised in the Grant Agreement. The device is now in production process and the updated testing plan has been rescheduled to early 2023 and will take place once the semi-rigid seat arrives at IDIADA facilities.

2.2 Seat backrest

Regarding the seat backrest, the original model shown in Figure 3 was simplified for an easier construction as physical part.

The updated model can be seen in **Error! Reference source not found.** and consists of a rigid steel plate that has a foam on top to protect the dummy during the rebound of the crash. This foam is modelled as Ethafoam 220 and has no specific function during the crash phase. The dynamic virtual model of this foam was provided by Autoliv.

The model contains parameters to control the inclination angle of the seat backrest, so it can not only be used for upright positions but also for any reclined angle that needs to be studied.

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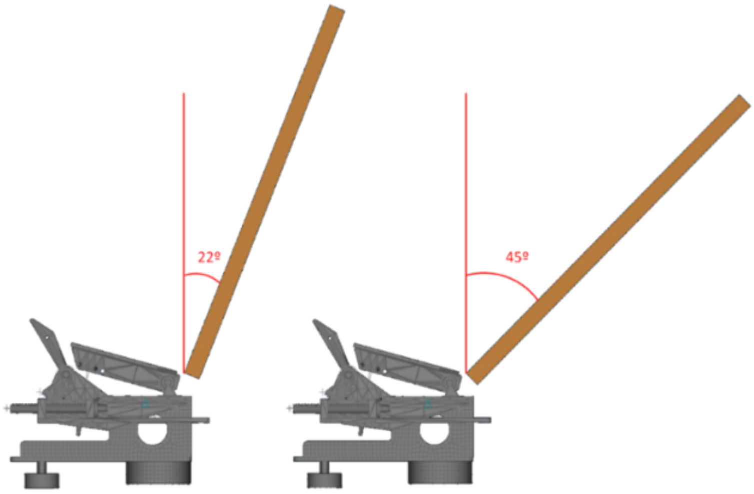

Figure 6: Seat backrest with different angles

2.3 Knee bolster

The knee bolster is attached to the rigid structure that holds the steering column. Ethafoam 220 will be used for the reference sled test/simulation (the same foam used for the seat backrest) which has a density of about 32 g/l.

For the optimized run (with an improved restraint system), a denser Expanded Polypropylenne (EPP) foam of 60 g/l will be used to recreate a stiffer knee bolster (Figure 7) that can withstand higher loads from the occupant's femurs and in that way reduce the pelvis loading.

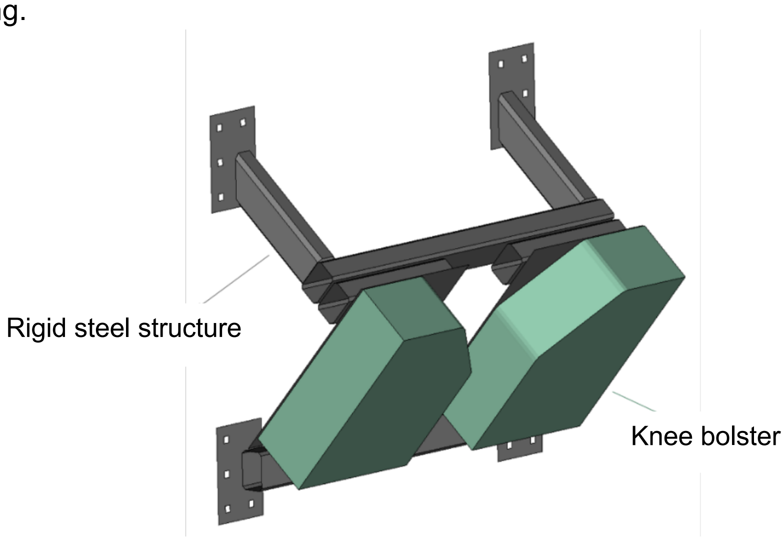

Figure 5: Knee bolster structure

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2.4 Steering column

The steering column can be adapted to maintain a certain force level during the collapsing phase with a maximum collapse distance of 100 mm. This is modelled in LS-Dyna with a spring that uses an experimental force-displacement curve to recreate the behavior of the actual steering column, which simplifies the model and reduces the simulation time.

This curve can be adapted parametrically or changed completely to follow a different characteristic depending on the situation. The steering column is as well coupled with a generic steering wheel, including a generic driver airbag (DAB).

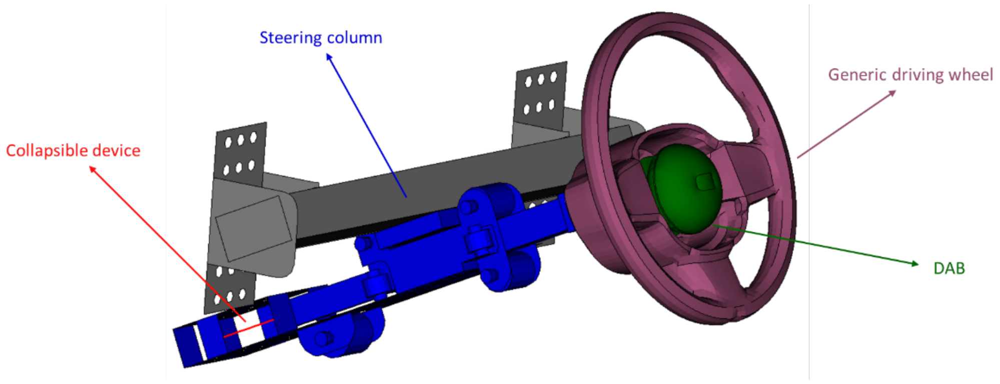

Figure 6: Generic steering column LS-Dyna model with steering wheel and DAB

2.5 Physical generic environment

The physical generic environment can be seen in Figure 7 (Seat is only for demonstration). It consists of the generic steering column, which is equipped with a metal tube (Figure 8) and deformable components that replicate the collapsibility of any steering column.

Figure 7. Physical environment general picture

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This system is able to adapt the collapsibility of the steering column (STC) by changing the thickness of the rear metal plate, which will make the STC to collapse faster or slower (becoming more or less rigid) depending on the thickness of the plate.

The steering wheel and the DAB are provided by Autoliv, being both generic systems. The semi-rigid seat is now being fabricated and will be included to the environment once ready.

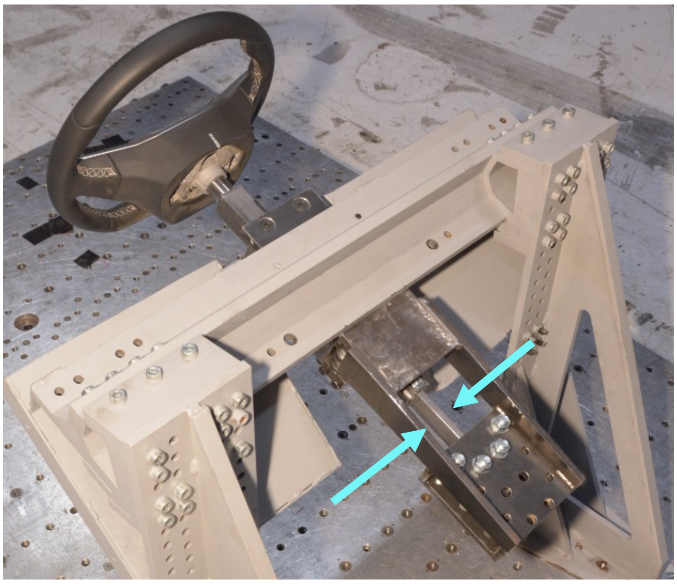

Figure 8. Close up on collapsible tube

Figure 8. Detail on the knee bolster fixing space

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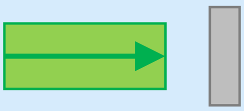
3. Sled Test Matrix

SAFE-UP work package 4 has been investigating several car-to-car (C2C) crash pulses (Table 1) from the European Union (EU) project OSCCAR [3] in a form of computer aided engineering (CAE) simulations, which are the basis for the sled test activities to be performed in DEMO 1. The load cases and pulses were analyzed in WP4 and the results from the occupant monitoring based restraint system simulations can be found in Deliverable (D) 4.4 [4].

Table 1: Car to barrier crash pulse [4]

Scenario*	Name	m_{Host} [kg]	$m_{Opponent}$ [kg]	v_{Host} [km/h]	$v_{Opponent}$ [km/h]	Res. Δv [km/h]
	FFRB 40 km/h	1717	rigid	40	0	47.1

* Host vehicle in green; barrier in grey

The sled tests will be performed on a deceleration platform. The sled will be decelerating by means of deformation of the metal tubes, where the sled will impact.

To achieve the best repeatability of the pulse within a specified range, the full-frontal rigid barrier (FFRB) crash test at 40 km/h has been selected for the demonstrator (Table 1). Maximum acceleration of the FFRB 40 km/h pulse is around 29.4 g.

At least 6 tests will be performed in order to have a reliable result from the sled series. However, up to 10 tests have been defined in the test matrix to ensure that any drawbacks within the test campaign can be overwhelmed. As shown in the tables below, several parameters need to be under control to make a standardized protocol for the crashes.

Variables such as the foot support angle, the material of the knee bolster (default is Ethafoam 220, Opt is Expanded Polypropylenne, the force at the Steering Column, which steering wheel is being used (default means the generic steering wheel from Autoliv), the seat type and the regulable angles of it (Table 2)

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Table 2. Test matrix p1

#	Date	Pulse	ATD	Foot support angle	Knee bolster	Steering column (kN)	Steering wheel	Seat type	Seat pan angle	Anti-submarining angle	Seat back angle
1	tbd	FF 40km/h	THOR-Reclined	45º	Default	4,5	Default	semi-rigid LAB	15º	32,5º	45º
2	tbd	FF 40km/h	THOR-Reclined	45º	Default	4,5	Default	semi-rigid LAB	15º	32,5º	45º
3	tbd	FF 40km/h	THOR-Reclined	45º	Opt	3	Default	semi-rigid LAB	15º	32,5º	45º
4	tbd	FF 40km/h	THOR-Reclined	45º	Opt	3	Default	semi-rigid LAB	15º	32,5º	45º
5	tbd	FF 40km/h	THOR-Reclined	45º	Opt	3	Default	semi-rigid LAB	15º	32,5º	45º
6	tbd	FF 40km/h	THOR-Reclined	45º	Opt	3	Default	semi-rigid LAB	15º	32,5º	45º
7	tbd	FF 40km/h	THOR-Reclined	45º	Opt	3	Default	semi-rigid LAB	15º	32,5º	45º
8	tbd	FF 40km/h	THOR-Reclined	45º	Opt	3	Default	semi-rigid LAB	15º	32,5º	45º
9	tbd	FF 40km/h	THOR-Reclined	45º	Opt	4,5	Default	semi-rigid LAB	15º	32,5º	45º
10	tbd	FF 40km/h	THOR-Reclined	45º	Opt	4,5	Default	semi-rigid LAB	15º	32,5º	45º

Factors regarding characteristics of the seatbelt system and its firing strategy for each test can be found in the test matrix. Furthermore, information of the belt retractor being used and its features and requirements for testing are summarized in Table 3 and Table 4.

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Table 3. Test matrix p2

#	Shoulder belt retractor	Webbing on shoulder belt retractor	Installation	Buckle	End bracket	Ideal Shouder belt RPT	IDIADA RPT proposal	Autoliv's recommendation for activation time [FINAL VALUES]
1	pt, ll=3,5 kN, power=0,8 230.2 LLA 63/32 MGG	370 mm	seat back 90° below	No pt Wire buckle	pt & no ll PLP 1.5	8 ms	8 ms	8 ms
2	pt, ll=3,5 kN, power=0,8 230.2 LLA 63/32 MGG	370 mm	seat back 90° below	No pt Wire buckle	pt & no ll PLP 1.5	8 ms	8 ms	8 ms
3	pt, ll=2,5 kN, power=1 230.2 LLA 63/32 MGG	370 mm	seat back 90° below	pt & no ll Pyro Buckle pretensioner	pt & no ll PLP 1.5 or retractor	0 ms	8 ms	11 ms
4	pt, ll=2,5 kN, power=1 230.2 LLA 63/32 MGG	370 mm	seat back 90° below	pt & no ll Pyro Buckle pretensioner	pt & no ll PLP 1.5 or retractor	0 ms	8 ms	11 ms
5	pt, ll=2,5 kN, power=1 230.2 LLA 63/32 MGG	370 mm	seat back 90° below	pt & no ll Pyro Buckle pretensioner	pt & no ll PLP 1.5 or retractor	0 ms	8 ms	11 ms
6	pt, ll=2,5 kN, power=1 230.2 LLA 63/32 MGG	370 mm	seat back 90° below	pt & no ll Pyro Buckle pretensioner	pt & no ll PLP 1.5 or retractor	0 ms	8 ms	11 ms
7	pt, ll=2,5 kN, power=1 230.2 LLA 63/32 MGG	370 mm	seat back 90° below	pt & no ll Pyro Buckle pretensioner	pt & no ll PLP 1.5 or retractor	0 ms	8 ms	11 ms
8	pt, ll=2,5 kN, power=1 230.2 LLA 63/32 MGG	370 mm	seat back 90° below	pt & no ll Pyro Buckle pretensioner	pt & no ll PLP 1.5 or retractor	0 ms	8 ms	11 ms
9	pt, ll=3,5 kN, power=0,8 230.2 LLA 63/32 MGG	370 mm	seat back 90° below	No pt Wire buckle	pt & no ll PLP 1.5	8 ms	8 ms	8 ms
10	pt, ll=3,5 kN, power=0,8 230.2 LLA 63/32 MGG	370 mm	seat back 90° below	No pt Wire buckle	pt & no ll PLP 1.5	8 ms	8 ms	8 ms

The airbag and its many parameters, such as its physical dimensions (Table 5) or the timings for the firing of its both stages can be found also in the test matrix. The venthole diameters were modified according to the optimization study performed in WP4.

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Table 4. Test matrix p3

#	Ideal Shouder belt RPT	IDIADA RPT proposal	Autoliv's recommendation for activation time [FINAL VALUES]	Ideal Buckle PT	IDIADA BPT proposal	Autoliv's recommendation for activation time [FINAL VALUES]	Ideal End braket PT	IDIADA EBPT proposal	Autoliv's recommendation for activation time [FINAL VALUES]
1	8 ms	8 ms	8 ms	N/A	N/A	N/A	13 ms	13 ms	15 ms
2	8 ms	8 ms	8 ms	N/A	N/A	N/A	13 ms	13 ms	15 ms
3	0 ms	8 ms	11 ms	0 ms	3 ms	3 ms	6 ms	13 ms	18 ms
4	0 ms	8 ms	11 ms	0 ms	3 ms	3 ms	6 ms	10 ms	18 ms
5	0 ms	8 ms	11 ms	0 ms	3 ms	3 ms	6 ms	10 ms	18 ms
6	0 ms	8 ms	11 ms	0 ms	3 ms	3 ms	6 ms	10 ms	18 ms
7	0 ms	8 ms	11 ms	0 ms	3 ms	3 ms	6 ms	10 ms	18 ms
8	0 ms	8 ms	11 ms	0 ms	3 ms	3 ms	6 ms	10 ms	18 ms
9	8 ms	8 ms	8 ms	N/A	N/A	N/A	13 ms	13 ms	15 ms
10	8 ms	8 ms	8 ms	N/A	N/A	N/A	13 ms	13 ms	15 ms

As can be seen, the airbag firing times and the tether length are the same within the whole sled series in order to see reduce the number of variables affecting the restraint system performance. Finally, in Table 5, the objectives of each test can be found in the same table.

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Table 5. Test matrix p4

#	Diameter	vent	Tethers	Trig 1 (stage 1)	Trig 2 (stage 2)	#	Objectives
1	710 mm	2xØ35 mm	230 mm	10 ms	15 ms	1	Demonstrate the limitations of the state-of-the-art restraint system for reclined positions
2	710 mm	2xØ35 mm	230 mm	10 ms	15 ms	2	Repetition of the 1st test
3	710 mm	2xØ35 mm	230 mm	10 ms	15 ms	3	Demonstrate the improvement of injury values with adapted restraint systems
4	710 mm	2xØ40 mm	230 mm	10 ms	15 ms	4	Demonstrate the improvement of injury values with adapted restraint systems + Sensitivity on venthole
5	710 mm	2xØ45 mm	230 mm	10 ms	15 ms	5	Demonstrate the improvement of injury values with adapted restraint systems + Sensitivity on venthole [Optional]
6	710 mm		230 mm	10 ms	15 ms	6	Repetition of the best test between 3, 4,(5)
7	710 mm		230 mm	10 ms	15 ms	7	Back-up
8	710 mm		230 mm	10 ms	15 ms	8	Back-up
9	710 mm	2xØ35 mm	230 mm	10 ms	15 ms	9	SET-UP
10	710 mm	2xØ35 mm	232 mm	10 ms	15 ms	10	SET-UP

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The full-frontal 40kph pulse used for the sled testing activities was defined in the OSCCAR project [3]. It was also used to run few simulations within the work done in SAFE-UP T4.4 to understand the performance of the optimized restraint systems under such conditions. The accelerations and velocities in XYZ directions of the pulse can be seen in Figure 10.

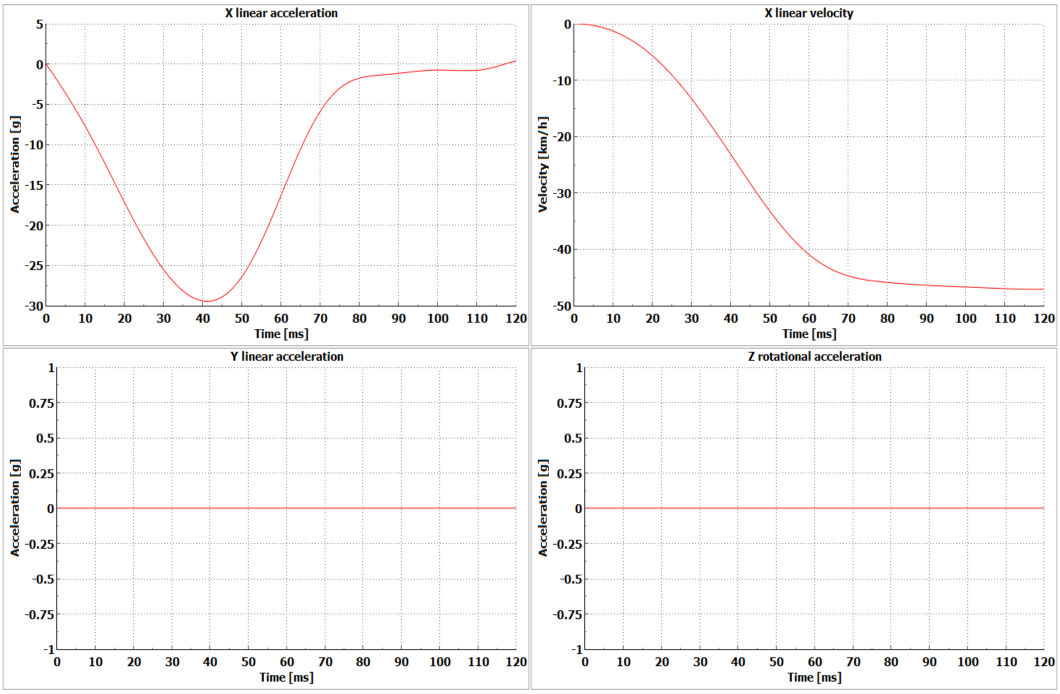

Figure 9: FFRB 40 km/h crash pulse [4]

Given that the ideal pulse is not fully reproduceable in the reality, preliminary runs have been performed in the sled test facility to define some corridors to assess repeatability of the tests executed. Upper and lower limits of the corridor were defined for the maximum peak of the acceleration of the given pulse. The corridor represents the tolerance of the sled that ensures the test can be performed accurately. The resulting range of the corridors can be seen in Figure 11.

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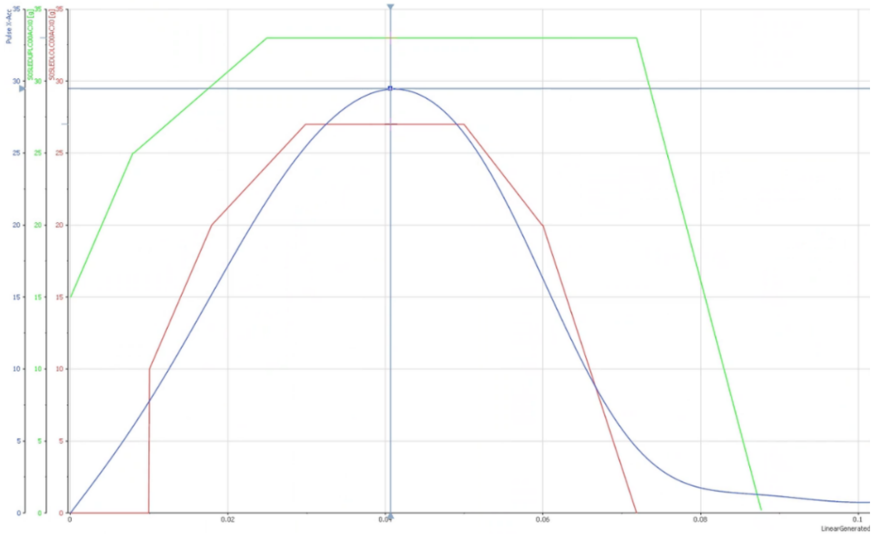

Figure 10: Simulation pulse 40 kph (blue) and upper (green) and lower (red) corridor for the potential sled tests

Restraint system configuration

The belt system is a three-point belt provided by Autoliv that can be mounted on the B-pillar or the seat depending on the posture and reclination of the occupant. This seatbelt has pretensioners on the three points (retractor, buckle and anchor/end bracket) and has a two-level force limiting device in the retractor and a one-level force limiting device in the anchor and the buckle.

This implies that the three points can perform a pretension (PT) and a load limit (LL). The firing of the restraint system is time-based, and the same system is used for all the tests. The DAB model that will be used for physical tests is provided by Autoliv and is a 270 mm diameter airbag with a tether of 230 mm.

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4. Summary

This document describes the components developed for DEMO1, which will be tested in a sled environment for restraint system configurations studied in WP4. These developments include the preparation of the generic environment with the design and construction of the generic steering column and its support, as well as the fabrication of the knee bolster support. The semi-rigid seat device has been updated and will be added to the generic physical environment once it is ready.

The first assembly of the fabricated parts have been done and will be tested separately on the sled to ensure its integrity before the complete sled test campaign. The pulse corridors have been also defined for the full-frontal crash test at 40 km/h according to the characteristics of the sled test facilities.

The complete system will be tested for demonstration purposes in the IDIADA sled test facilities using a THOR-Reclined dummy with the selected pulse in different seat and restraint system configurations. The results of these tests will be reported in D5.4.

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References

[1] Uriot J, Potier P, Baudrit P, Trosseille X, Petit P, Richard O, Compigne S, Masuda M, Douard R., *"Reference PMHS Sled Tests to Assess Submarining"* Stapp Car Crash Journal, Vol. 59, pp. 203-223, 2015.

[2] Richardson R, Jayathirtha M, Chastain K, et al., "Thoracolumbar spine kinematics and injuries in frontal impacts with reclined occupants.," *Traffic Injury Prevention,* vol. 21(sup1), pp. S66-S71, 2020.

[3] Dobberstein J. et al. (2021) *"Final results on detailed crash configurations from collisions expected to remain for automated vehicles"*; Deliverable D1.3; OSCCAR Project; Grant Agreement No. 768947; 2021.

[4] Becker J., Östling M., Lozano P., Klein C., Weihmayr D., Wimmer P. (2022) *Occupant monitoring based restraint strategies for future seating configurations.* Deliverable 4.4, EU Project SAFE-UP, Grand Agreement No. 861570, 2022.

[5] Östling M., D'Addetta G.A., da Silva J.L., Zimmer A., Lubbe N. (2021) *Architecture of Passive Safety Systems.* Deliverable 4.2, EU Project SAFE-UP, Grand Agreement No. 861570, 2021.

[6] Östling M., et al. "*Potential future seating positions and the impact on injury risks in a Learning Intelligent Vehicle (LIV)*" conference paper, (2017)

[7] Euro NCAP, "*ASSESSMENT PROTOCOL – ADULT OCCUPANT PROTECTION",* EUROPEAN NEW CAR ASSESSMENT PROGRAMME, Version 9.1.2, June 2020

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