AutoCFD5 – Test Case 2a/b: DrivAer

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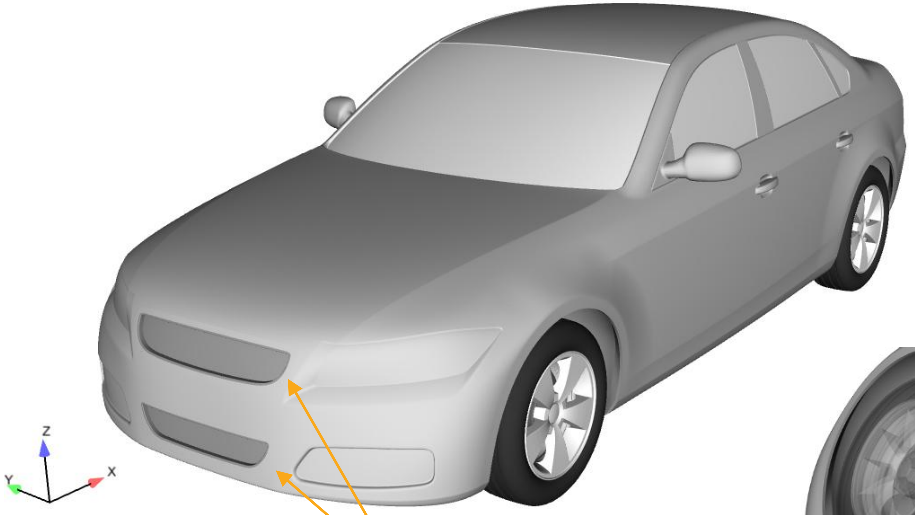
Table of Content

Introduction

- **AutoCFD4 Test Case 2: Open Cooling DrivAer – Notchback**
  - **Motivation:**
    - » **Realistic test case relevant to automotive industry**
    - » **Accepted standard for automotive aerodynamic CFD correlation**
    - » **Availability of detailed surface pressure and flow field measurements**
    - » **Ability to further extent test case by considering different bodystyles, including wheel rotation, including cooling airflow and …**
  - **Configuration details:**
    - » **Detailed underbody (→ slightly different to detailed underbody of original closed cooling DrivAer)**
    - » **Closed Cooling (→ limit complexity by disabling cooling airflow)**
    - » **Static floor & wheels (→ limit complexity by excluding wheel rotation and deformation)**

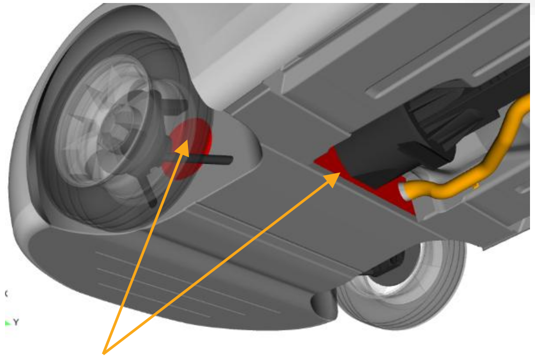
Testcase 2: DrivAer Geometry

- **Configuration details**

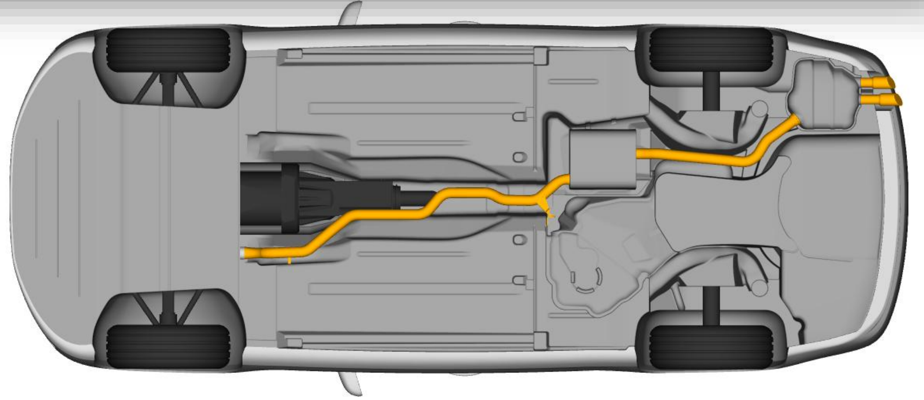


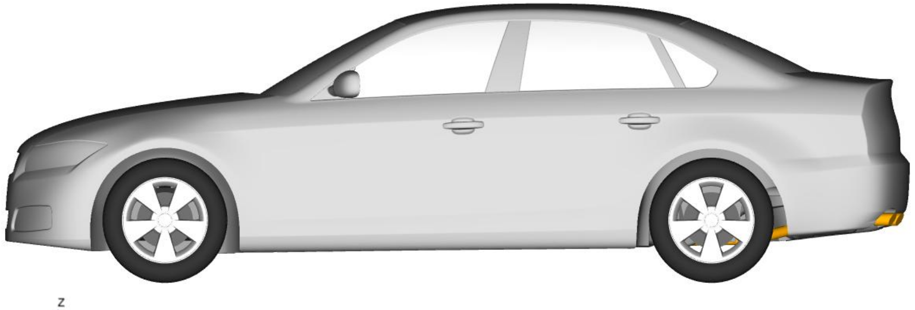
1:1 scale Ford Open Cooling DrivAer

Closed Cooling[1]



Closed Engine Bay[1]





[1] To limit the complexity of the test case not only the grill opening are close but also the opening from the engine bay to the wheelhouse and the exhaust tunnel. With that the engine bay is excluded from the flow domain.

Heft, A., Indinger, T., and Adams, N., "Introduction of a New Realistic Generic Car Model for Aerodynamic Investigations," SAE Technical Paper 2012-01-0168, 2012, doi:10.4271/2012-01-0168.

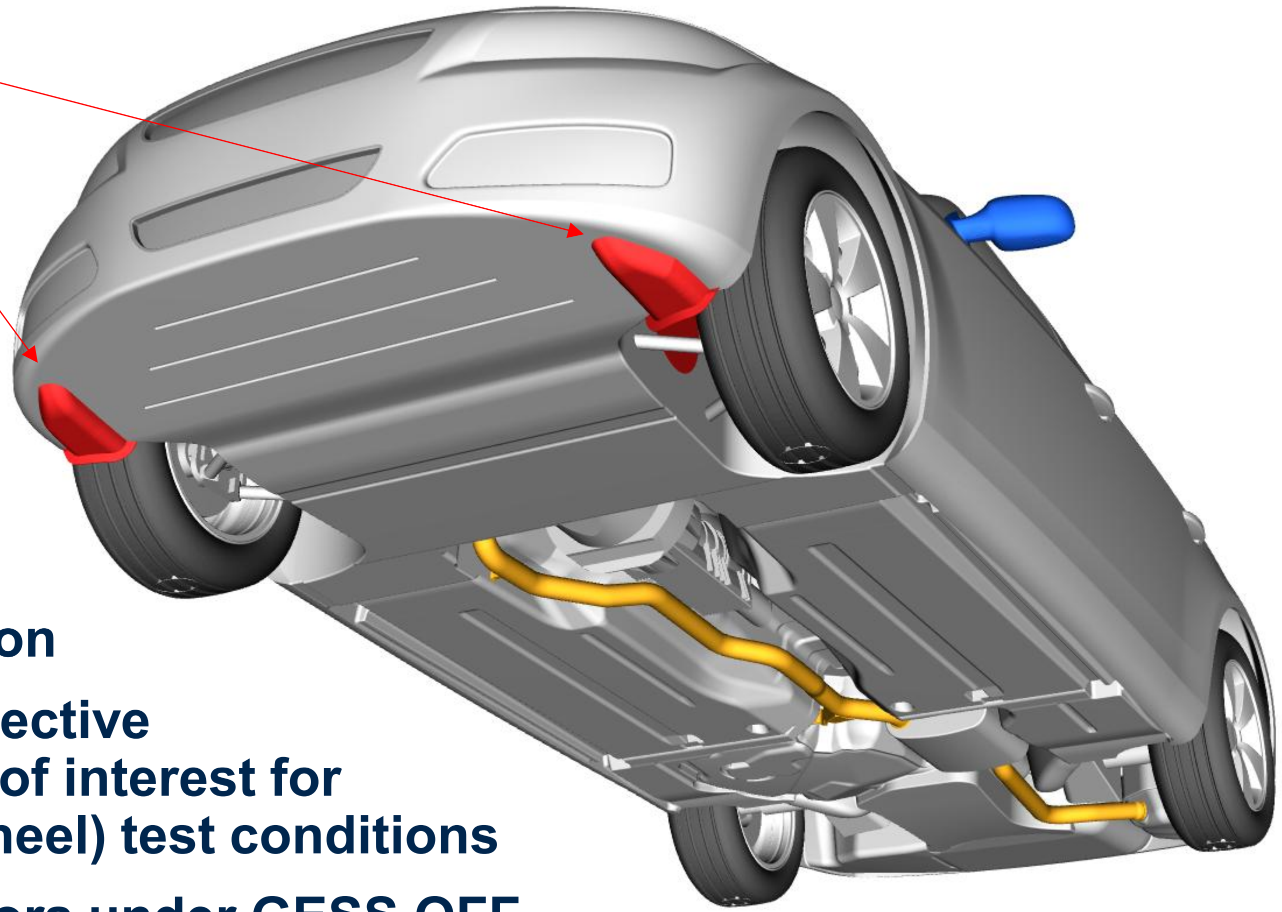
AutoCFD4 Testcase 2

- Testcase 2a: The Ford DrivAer, remains to be one of the test cases for AutoCFD5
  - Stick to the strategy to establish standards for future CFD method development & validation
  - Enable participants to demonstrate improvements in their prediction capability
  - Enable participants to run numerical studies

- Testcase 2b: A proven A – B predictions capability is important to the automotive industry.
  - To assess the A – B prediction capability a variant of the AutoCFD2 testcase 2 which features a front wheel air deflector (FWD) has been added for AutoCFD3
  - On- and Off-body test data will be available to evaluate A – B prediction capability (subset of the data available for the baseline test case)

Testcase 2b: DrivAer w/ Front Wheel Air Deflector

- **Front Wheel Air Deflectors:**
  - can significantly improve the overall vehicle drag
  - significantly change the airflow around the front wheels:
    - » Aerodynamic forces
    - » Wheel-wake size and shape
    - » Vehicle base pressure
    - » Wheel-house pressure distribution
- **From an automotive application perspective front wheel deflectors are specifically of interest for GESS ON (moving ground, rotating wheel) test conditions**
- **AutoCFD5: Use front wheel air deflectors under GESS OFF conditions (avoid complexity resulting from GESS ON test condition)**



Unchanged vs. AutoCFD4

Testcase 2a/b: DrivAer Configuration & Test Condition

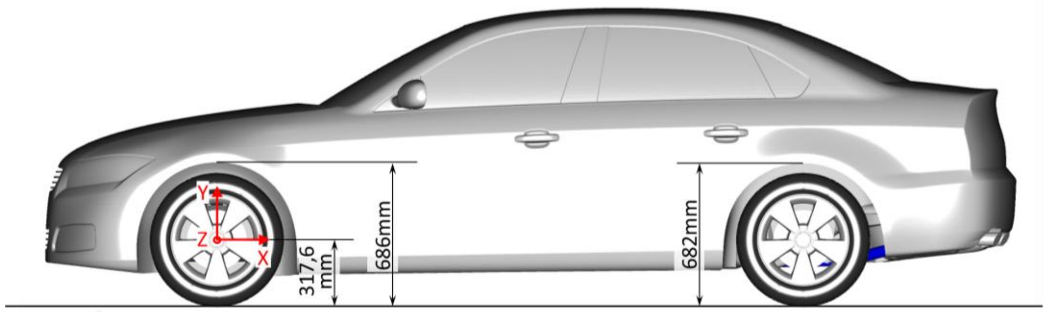
DrivAer Configuration

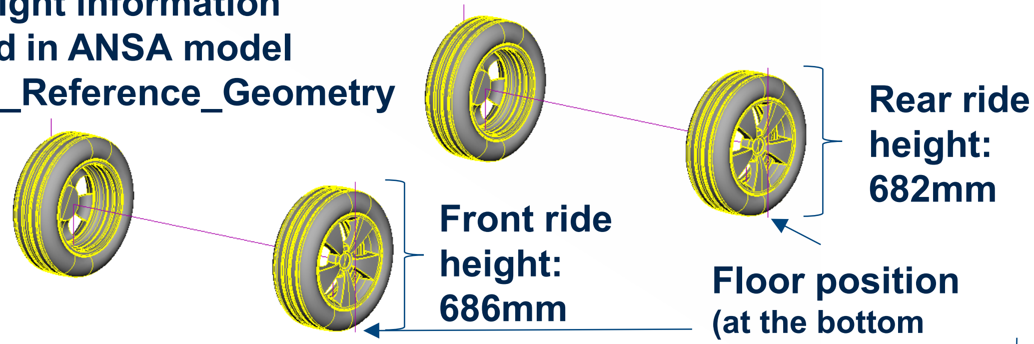
- **Body style:** Notchback
- **Wheels:** DrivAer wheels
- **Grills:** Closed
- **Ride Heights:** Front: 686mm/Rear: 682mm

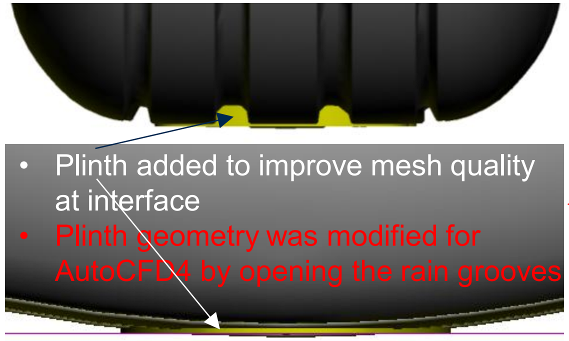
Wind tunnel setup (Pininfarina)

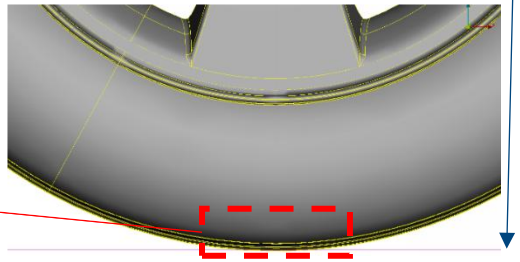
- **Vehicle Speed:** 140kph
- **Yaw angle:** 0°
- **Ground Effect Simulation System: OFF**
  (Static floor & wheels)
- **Turbulence Intensity:** 0,26%
- **Turbulent Length scale:** 5m
- **Ambient Air Pressure*:** 101325Pa
  (s. slide 10 for pressure reference point definition)
- **Ambient Air Density:** 1,204kg/m^3
- **Dynamic viscosity:** 1.8138E-5Pa*s

(Ambient Air Temperature: 20,08°C)









Testcase 2a/b: Wind Tunnel Boundary Layer

- All wind tunnel test data used for CFD correlation in the context of AutoCFD2 has been collected in the Pininfarina Wind Tunnel.
- The boundary layer (BL) profile measured at the center of the turn table using a hot wire anemometer for T-Belt OFF and scoop & tangential blowing ON conditions is shown in Figure 1.
- Based on the measurement the BL thickness has been defined as: δ_{TTC} = 55mm
- Based on the following equation defining the BL thickness of a fully turbulent BL: $$\delta(\mathbf{x}) = \frac{0{,}37\mathbf{x}^{4/5} \cdot \nu^{1/5}}{\mathbf{U}_0^{1/5}}$$ the starting point of the BL upstream of the center of the turn table can be calculated as: x'_{BL} = 3,710m which correspond to a BL starting point at x_{BL} = -2,339m with reference to the DrivAer coordinate system (s. Figure 2). (The starting point of the "no-slip" floor is reflected in the provided volume mesh.)

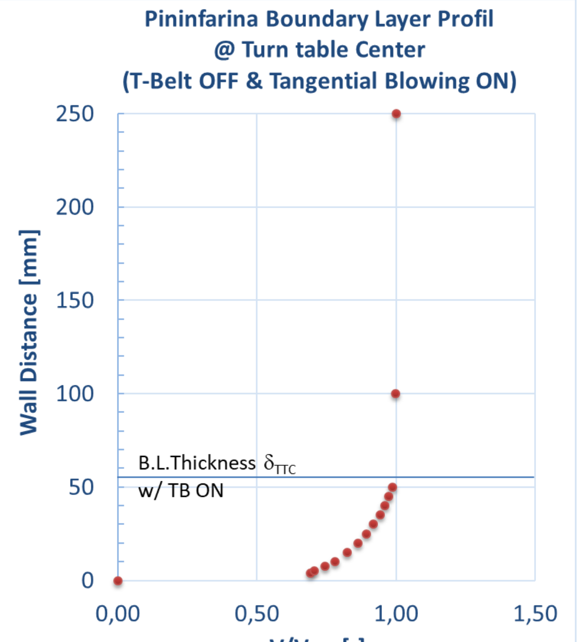


Figure 1

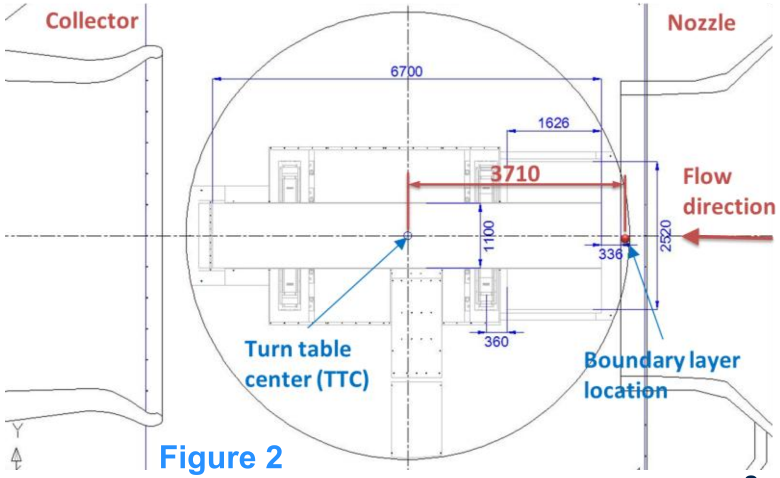
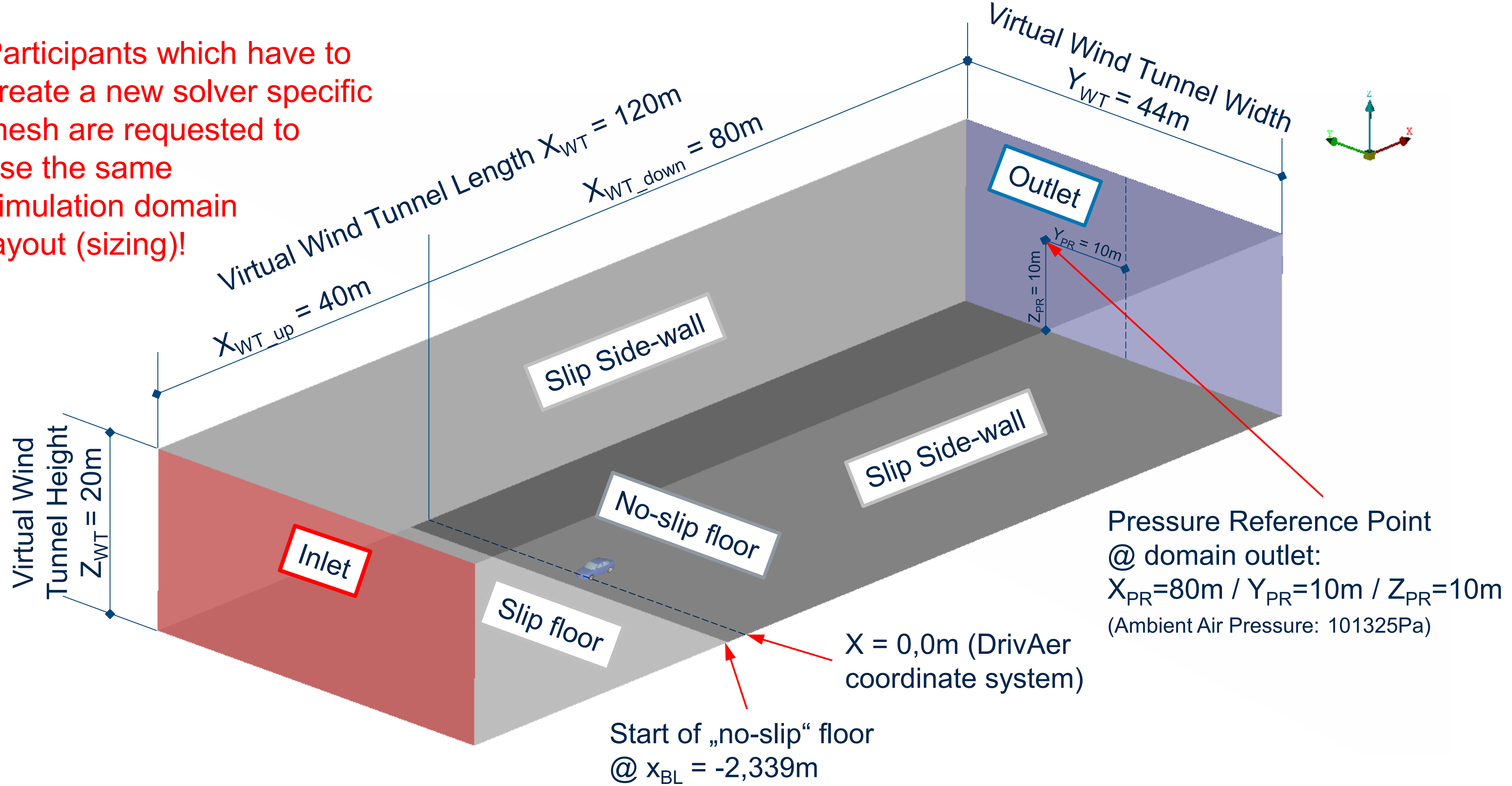


Figure 2

Unchanged vs. AutoCFD4

Testcase 2a/b: ANSA Volume Mesh – Virtual Wind Tunnel

Participants which have to create a new solver specific mesh are requested to use the same simulation domain layout (sizing)!



Testcase 2a/b: ANSA Mesh Update – Overview (1/5)

Revised for AutoCFD5

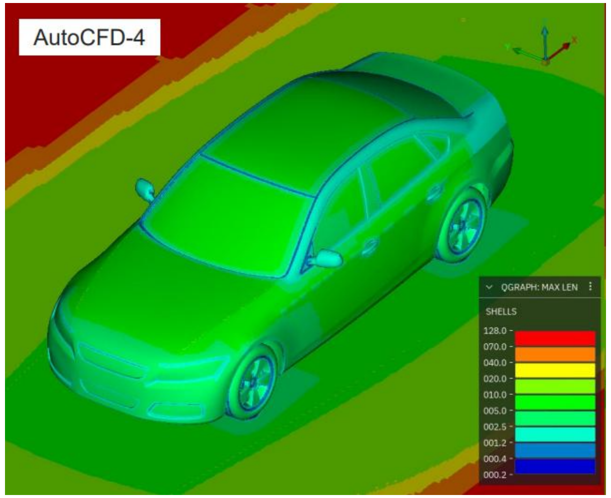
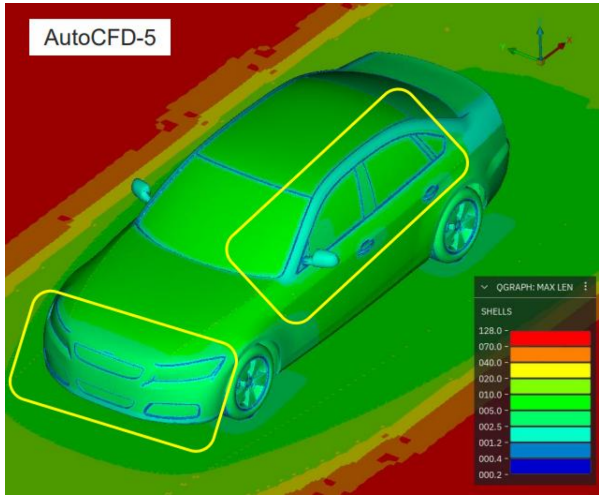
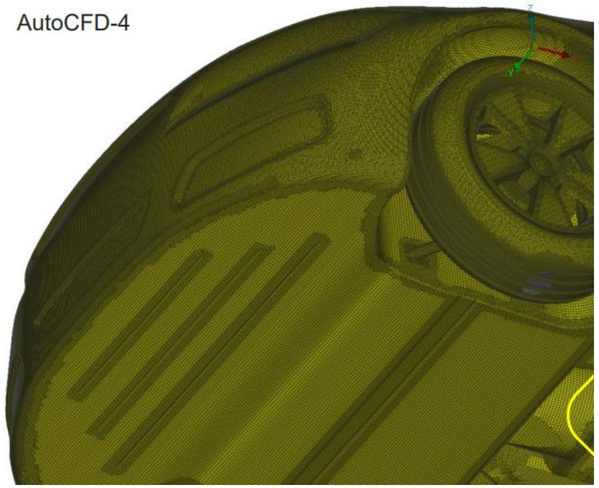
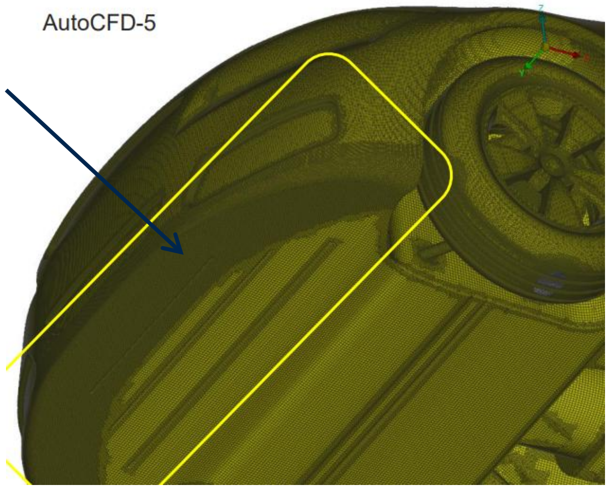
- **For AutoCFD5 a new volume mesh has been created for testcase 2a & 2b to:**
  - **Improve the mesh quality for improved simulation robustness**
  - **Reduce cell count for faster turn-around**

- **Overview of mesh modifications**
  - **Redistribution of refinement zones aimed at:**
    - » Further refinement of surface curvatures
    - » Further refinement of important flow regions
    - » Coarsening of unnecessarily refined areas
    - » Use of fewer Size Boxes and rely more on Surface Offset and Sweep rules
  - **Reduction of total # of layers from 7 to 5**
  - **Overall ~20% reduction in cell count**
  - **Better quality criteria for more CFD solvers**

	AutoCFD4		AutoCFD5	
	2a	2b	2a	2b
# of shell elements [mio]	11.2	11.3	10.4	10.5
# of volume elements [mio]	157	158	124	127
1st layer height [mm]	0.75		0.75	
# of viscous layers	7		5	
Growth rate	1.2 – 1.4 variable		1.2 – 1.4 variable	

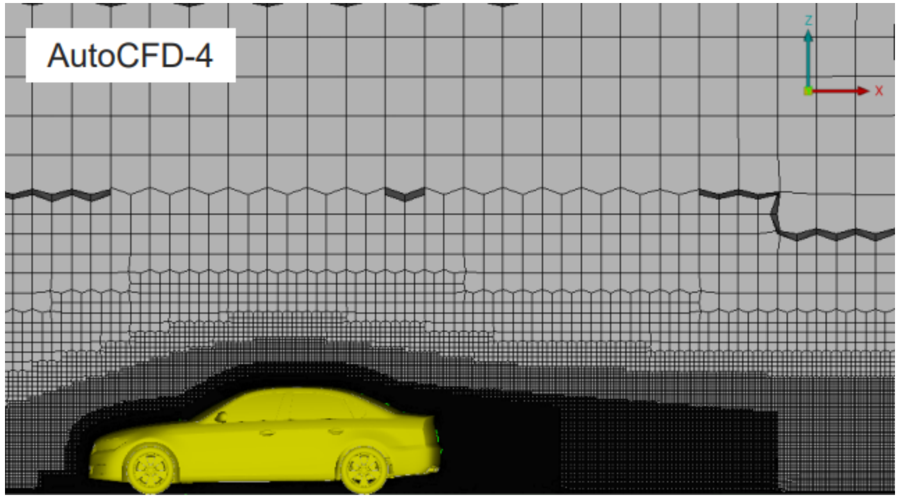
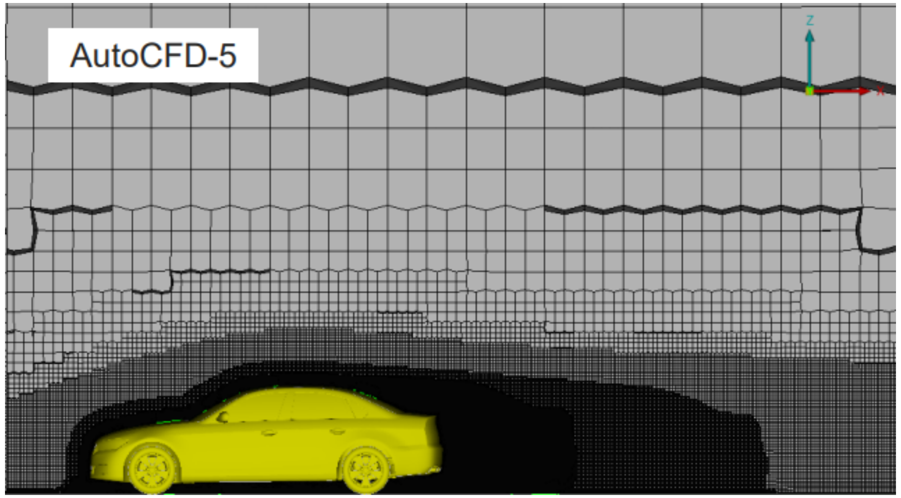
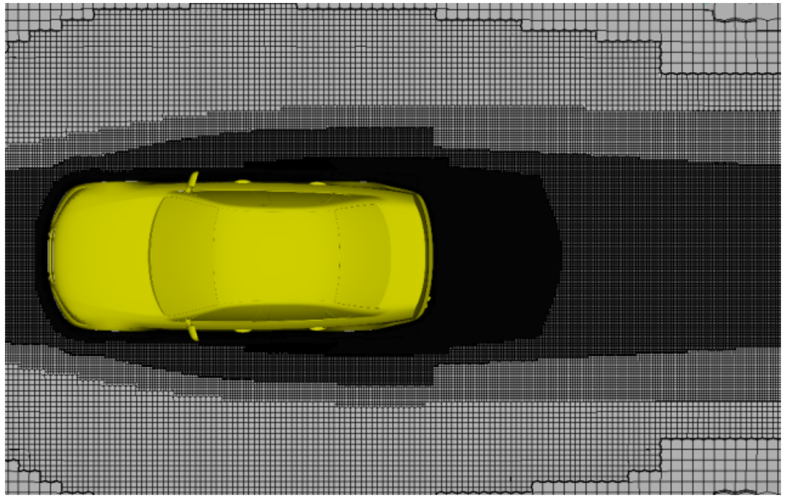
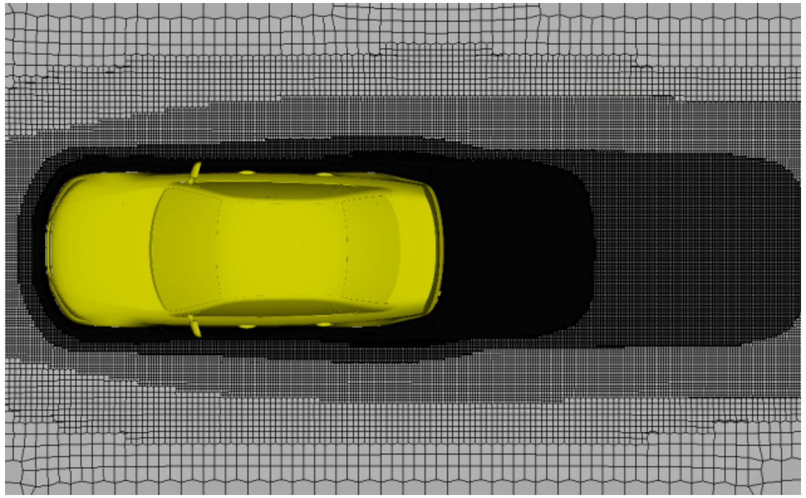
Testcase 2a/b: ANSA Mesh Update – Overview (2/5)

Revised for AutoCFD4

	AutoCFD4	AutoCFD5
Surface Mesh Refinement		
		**New PID!** 

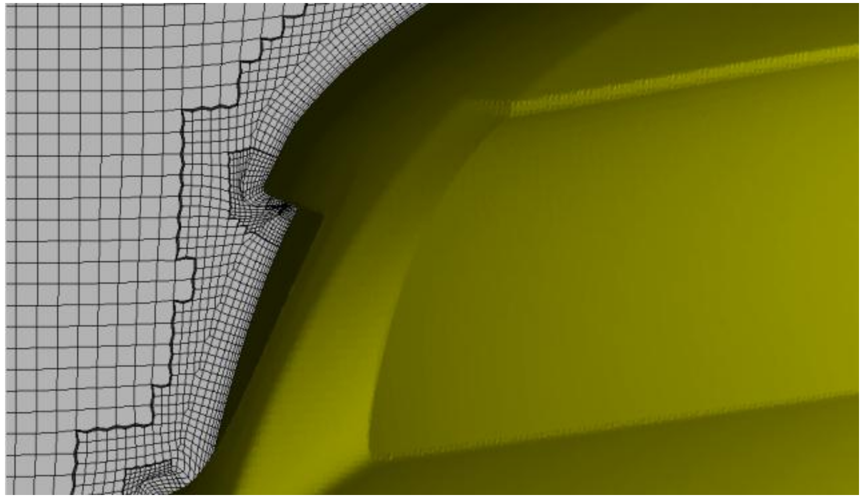
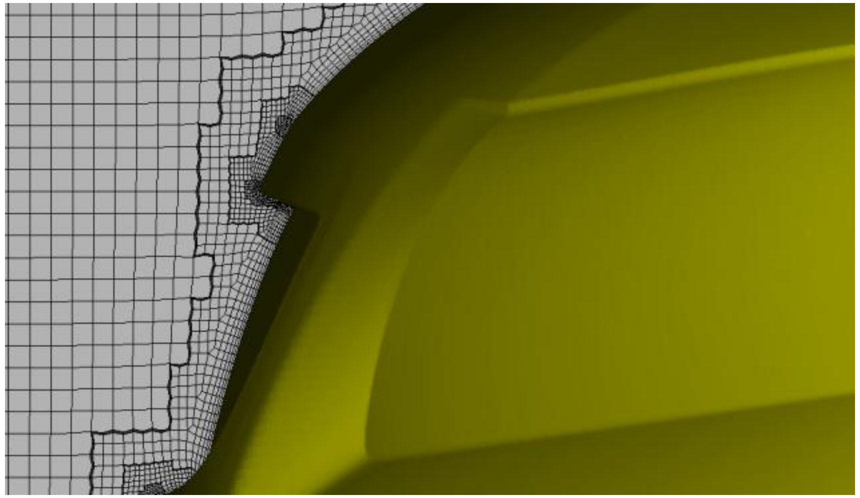
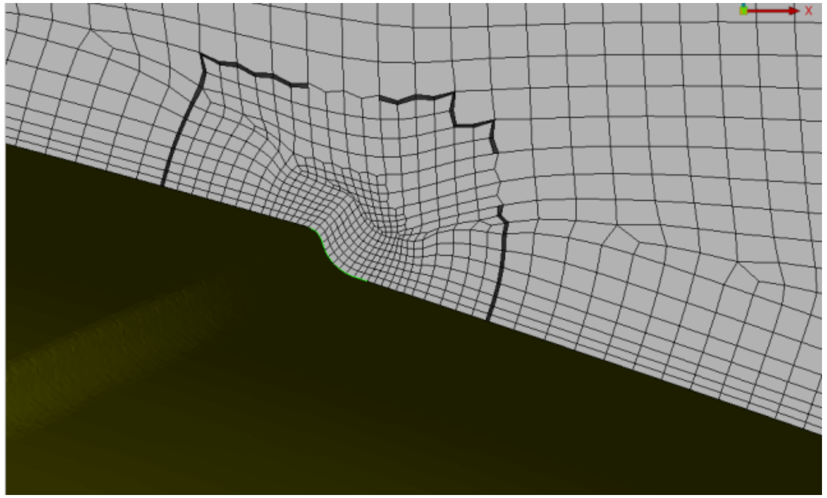
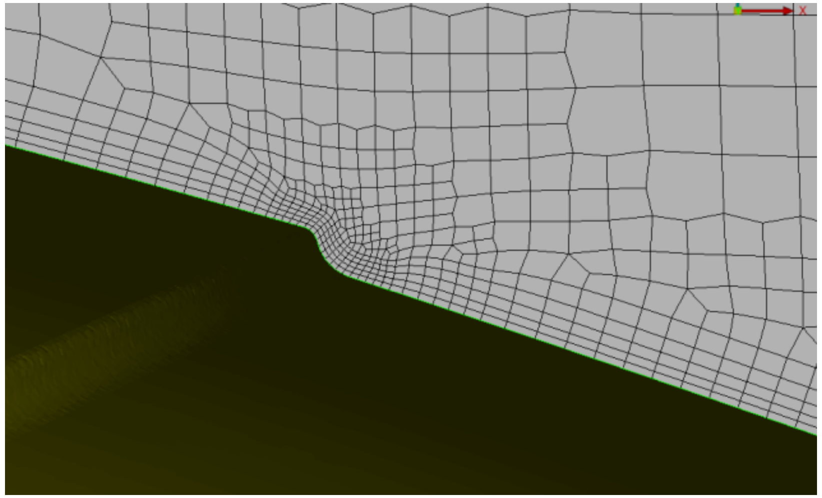
Testcase 2a/b: ANSA Mesh Update – Overview (3/5)

Revised for AutoCFD4

	AutoCFD4	AutoCFD5
Volume Mesh Changes		
		

Testcase 2a/b: ANSA Mesh Update – Overview (4/5)

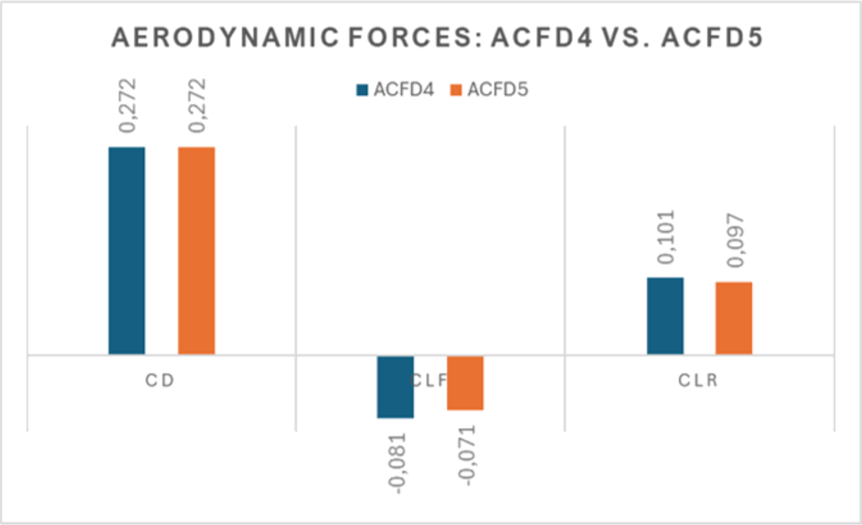
Revised for AutoCFD4

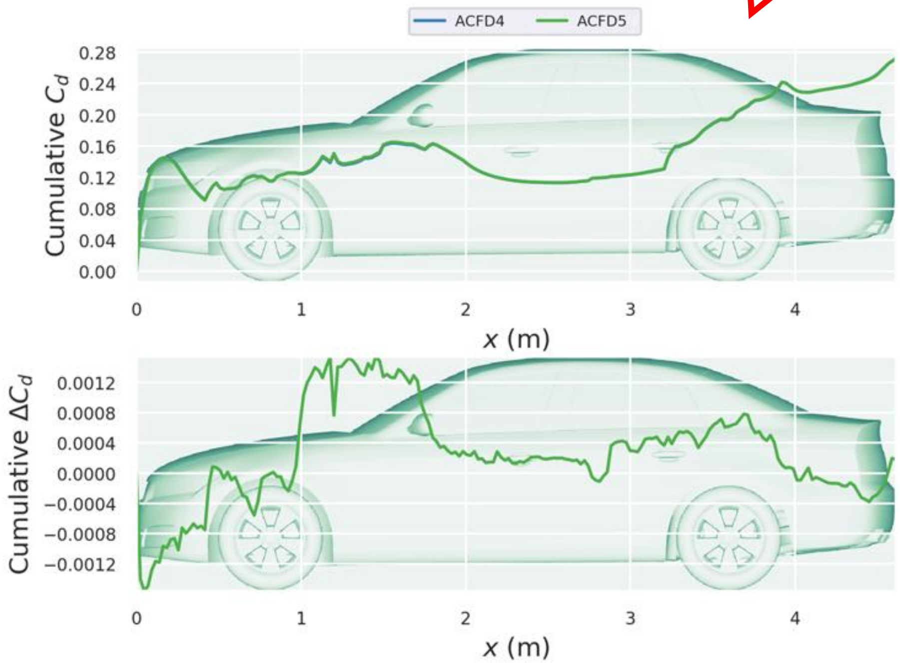
	AutoCFD4	AutoCFD5
Volume Mesh Changes		
		

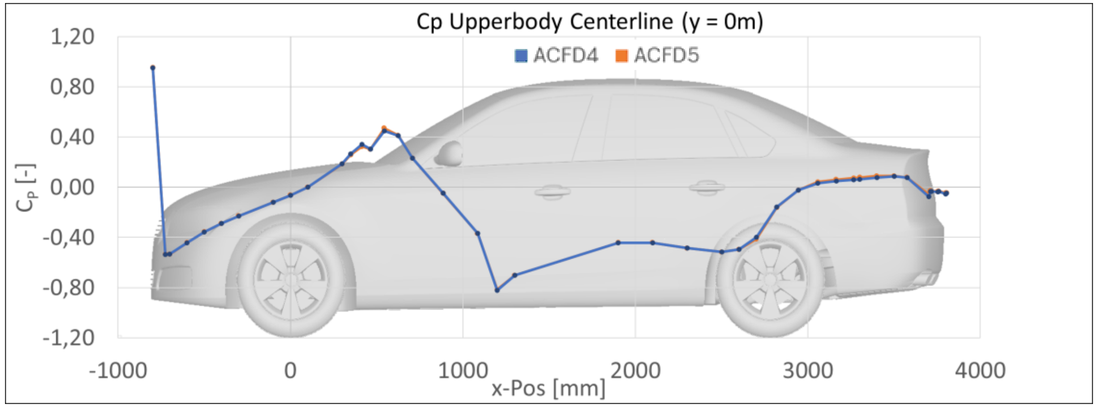
Testcase 2a/b: ANSA Volume Mesh – Overview (5/5)

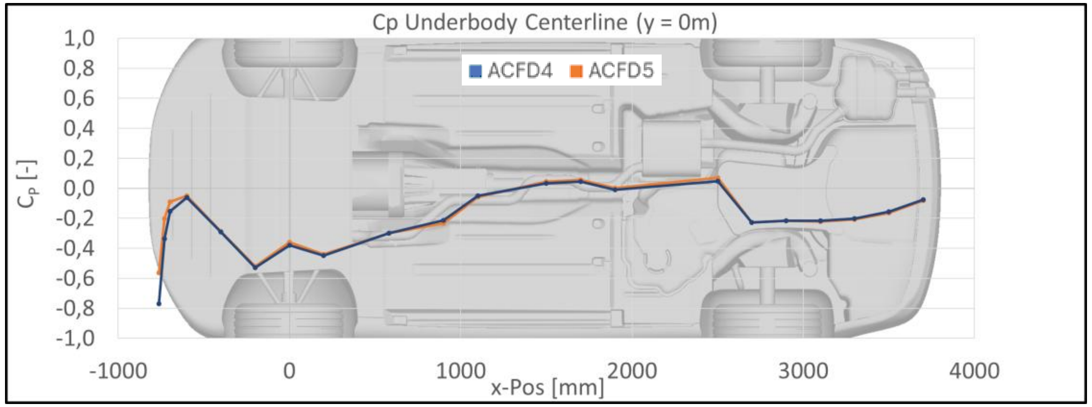
Revised for AutoCFD4

ANSA surface & volume mesh changes (ACFD4 → ACFD5) result in minimal changes to CFD results





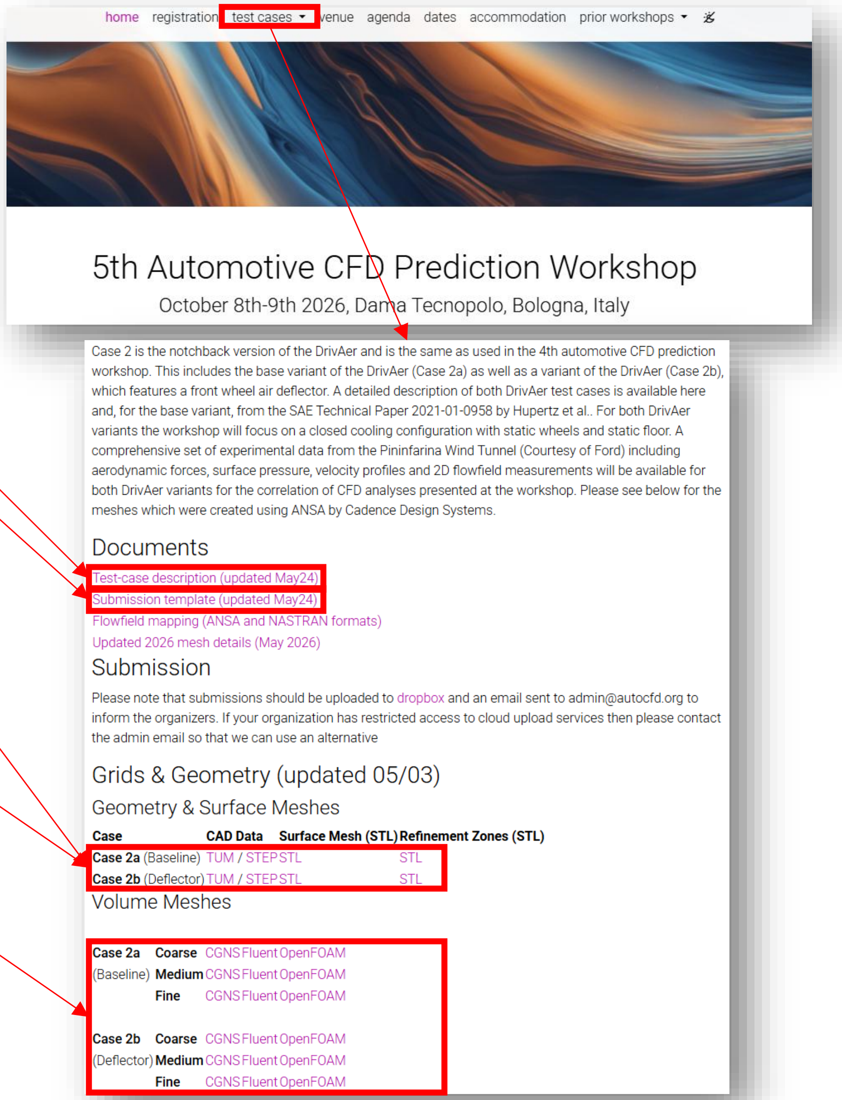




Testcase 2a/b: Data Availability via AutoCFD Web-Side

Testcase 2 information available via AutoCFD Web-Side:

- **Testcase 2a/b description**
- **Post-Processing Template**
- **DrivAer CAD: Testcase 2a/b**
  (for further details s. slides 35 - 38)
  - TUM DrivAer CAD
  - Ford DrivAer Add-on Parts CAD
  - Tire Plinth CAD
- **Surface Mesh: Testcase 2a/b**
  - STL
- **Volume mesh: Testcase 2a/b**
  - CGNS
  - OpenFOAM
  - Fluent



home registration test cases venue agenda dates accommodation prior workshops

5th Automotive CFD Prediction Workshop

October 8th-9th 2026, Dama Tecnopolo, Bologna, Italy

Case 2 is the notchback version of the DrivAer and is the same as used in the 4th automotive CFD prediction workshop. This includes the base variant of the DrivAer (Case 2a) as well as a variant of the DrivAer (Case 2b), which features a front wheel air deflector. A detailed description of both DrivAer test cases is available here and, for the base variant, from the SAE Technical Paper 2021-01-0958 by Hupertz et al.. For both DrivAer variants the workshop will focus on a closed cooling configuration with static wheels and static floor. A comprehensive set of experimental data from the Pininfarina Wind Tunnel (Courtesy of Ford) including aerodynamic forces, surface pressure, velocity profiles and 2D flowfield measurements will be available for both DrivAer variants for the correlation of CFD analyses presented at the workshop. Please see below for the meshes which were created using ANSA by Cadence Design Systems.

Documents

Test-case description (updated May24)
Submission template (updated May24)
Flowfield mapping (ANSA and NASTRAN formats)
Updated 2026 mesh details (May 2026)

Submission

Please note that submissions should be uploaded to dropbox and an email sent to admin@autocfd.org to inform the organizers. If your organization has restricted access to cloud upload services then please contact the admin email so that we can use an alternative

Grids & Geometry (updated 05/03)

Geometry & Surface Meshes

Case	CAD Data	Surface Mesh (STL)	Refinement Zones (STL)
Case 2a (Baseline)	TUM / STEP	STL	STL
Case 2b (Deflector)	TUM / STEP	STL	STL

Volume Meshes

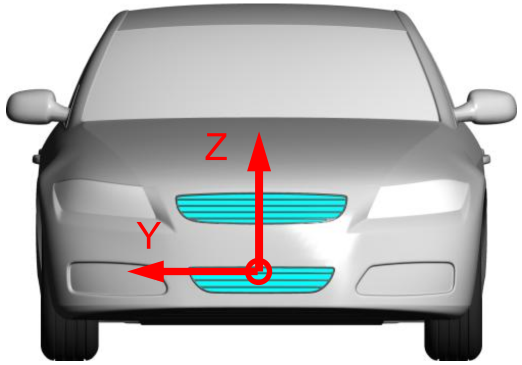
Case 2a	**Coarse**	CGNS	Fluent	OpenFOAM
(Baseline)	**Medium**	CGNS	Fluent	OpenFOAM
	Fine	CGNS	Fluent	OpenFOAM
Case 2b	**Coarse**	CGNS	Fluent	OpenFOAM
(Deflector)	**Medium**	CGNS	Fluent	OpenFOAM
	Fine	CGNS	Fluent	OpenFOAM

Testcase 2a/b: CFD Result Correlation

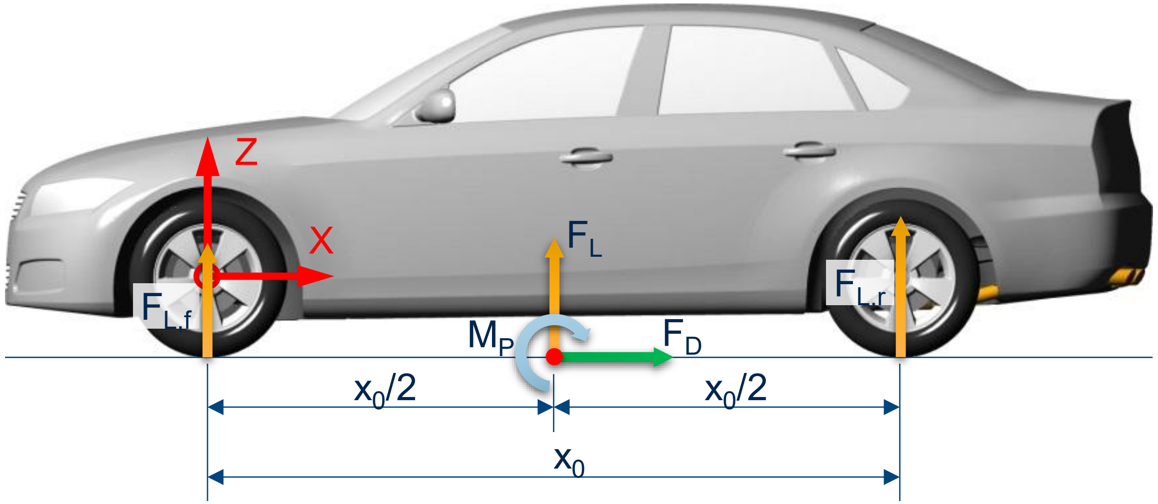
- A comprehensive experimental data set is available for CFD result correlation from tests conducted in the Pininfarina Wind Tunnel (Courtesy of Ford).
  The experimental data includes:
  - Aerodynamic forces (Drag, Lift (front & rear))
  - Surface Pressure (209 probes, s. slide 14 & 15)
  - Velocity Profiles (11 profiles, s. slide 16)
  - Flowfield (Cpt, Cp, V/V_∞, C_{DL}) (4 planes, s. slide 17)

- A review of the experimental data for Testcase 2a is available via the following SAE Technical Paper. The paper includes a detailed discussion of the reliability and relevance of the DrivAer test data.
  - Hupertz, B., Chalupa, K., Lewington, N., Howard, K. et al., "On the Aerodynamics of the Notchback Open Cooling DrivAer: A Detailed Investigation of Wind Tunnel Data for Improved Correlation and Reference," SAE Technical Paper 2021-01-0958, 2021

Aerodynamic Force Calculation



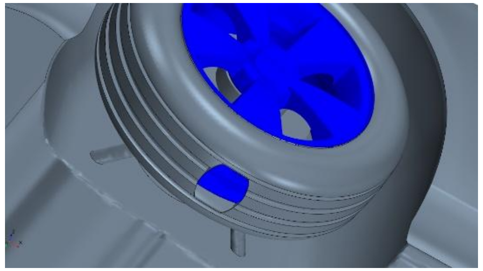
Frontal Area A_x: 2.17m²



Wheelbase x_0 = 2.7862m

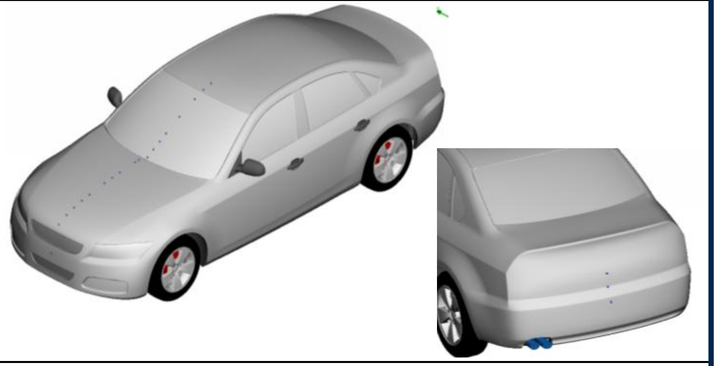
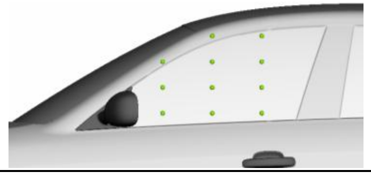
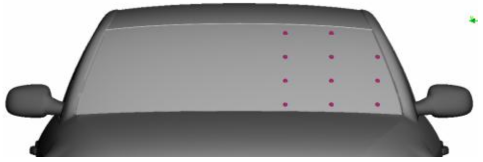
Attention: Force Calculation

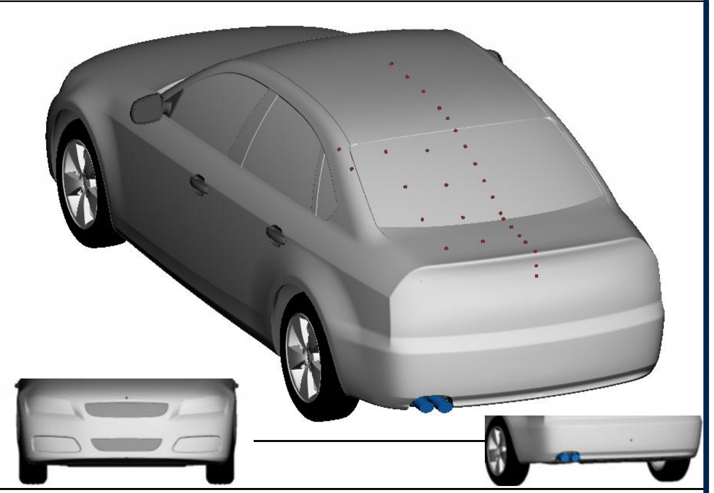
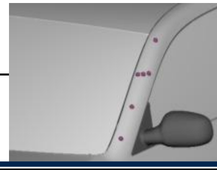
In case the force calculation is based on absolute rather than relative pressure it will be required to pay special attention to the force, specifically lift, calculation. The „hole“ at the bottom of the tire caused by the intersection with the floor required special consideration.



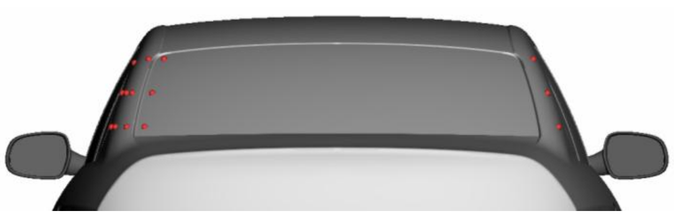
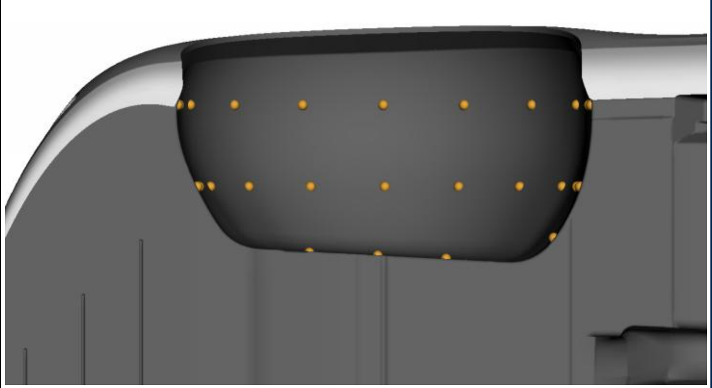
Drag Coefficient Calculation:	Lift Coefficient calculation:
$C_D = \dfrac{F_D}{\rho/2\ V_\infty^2\ A_x}$	$F_L = F_{L,f} + F_{L,r}$ $M_P = \left(F_{L,f} - F_{L,r}\right)\dfrac{x_0}{2}$ $C_L = \dfrac{F_L}{\rho/2\ V_\infty^2 A_x}$

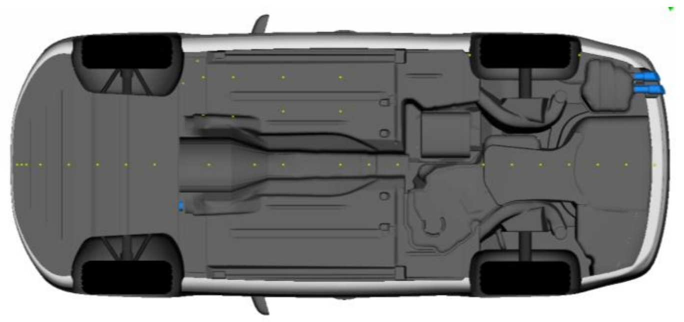
Testcase 2a/b: Pressure Probe Location (1)

	ANSA PID	# of Probes	Probe # (CAE)	X [mm]	Y [mm]	Z [mm]	Picture
Upperbody Centerline (TUM)	600 - PROBES - TUM Main body centerline	23	1	-798,25	0	150	
			2	-700	0	406,35	
			3	-600	0	462,63	
			4	-500	0	499,45	
			5	-400	0	527,7	
			6	-300	0	550,85	
			7	-100	0	587,73	
			8	0	0	603,05	
			9	100	0	616,9	
			10	300	0	640,83	
			11	350	0	645,93	
			12	413,1	0	625	
			13	464,13	0	625	
			14	543,18	0	675	
			15	624,25	0	725	
			16	707,88	0	775	
			17	885,33	0	875	
			18	1084,9	0	975	
			19	1199	0	1025	
			20	1300	0	1051,5	
			21	3752,7	0	450	
			22	3757,9	0	350	
			23	3804,1	0	250	
Sidewall z = 150mm (TUM)	601 - PROBES - TUM Main body z-plane 150mm	20	24	-793,1	-200	150	
			25	-758,35	-400	150	
			26	-671,63	-600	150	
			27	-526,25	-800	150	
			28	500	-880,55	150	
			29	700	-883,25	150	
			30	900	-889,2	150	
			31	1100	-893,23	150	
			32	1300	-895,28	150	
			33	1500	-895,4	150	
			34	1700	-893,55	150	
			35	1900	-889,7	150	
			36	2100	-883,78	150	
			37	2300	-883,98	150	
			38	3300	-830,78	150	
			39	3500	-777,73	150	
			40	3656,8	-700	150	
			41	3712,5	-600	150	
			42	3765,4	-400	150	
			43	3791,3	-200	150	
Side Window (TUM)	602 - PROBES - TUM Side Window	11	44	1100	-681,75	875	
			45	1300	-630,23	975	
			46	1100	-723,63	775	
			47	1300	-681,85	875	
			48	1100	-761,53	675	
			49	1300	-766,35	675	
			50	1300	-728,8	775	
			51	1500	-769,13	675	
			52	1500	-731,85	775	
			53	1500	-685,2	875	
			54	1500	-628,05	975	
Front Window (TUM)	603 - PROBES - TUM Front Window	11	55	553,5	-200	675	
			56	718,28	-200	775	
			57	895,8	-200	875	
			58	1095,9	-200	975	
			59	589,2	-400	675	
			60	754,38	-400	775	
			61	932,43	-400	875	
			62	1134,9	-400	975	
			63	661,1	-600	675	
			64	827,65	-600	775	
			65	1007,9	-600	875	

	ANSA PID	# of Probes	Probe # (CAE)	X [mm]	Y [mm]	Z [mm]	Picture
Notchback (TUM)	604 - PROBES - TUM Notchback	28	107	1900	0	1102,4	
			108	2100	0	1100,28	
			109	2300	0	1090,3	
			110	2500	0	1067,15	
			111	2600	0	1047,75	
			112	2700	0	1017,73	
			113	2820,15	0	975	
			114	2944,43	0	925	
			115	3057,9	0	875	
			116	3164,15	0	825	
			117	3265,23	0	775	
			118	3300	0	757,33	
			119	3400	0	746,1	
			120	3500	0	735,35	
			121	3575,25	0	725	
			122	3700	0	717,45	
			123	3709,73	0	650	
			124	3715,28	0	600	
			125	2803,68	-200	975	
			126	3042,9	-200	875	
			127	3251,25	-200	775	
			128	3500	-200	731,48	
			129	2743,55	-400	975	
			130	2989,1	-400	875	
			131	3200,9	-400	775	
			132	3500	-400	721,2	
			133	2619,5	-600	975	
			134	2778,4	-600	925	
Mainbody Centerline (Ford)	610 - PROBES - Ford Main body centerline	3	191	-804,8	0	-103	
			193	3799,3	0	150	
			195	-724,8	0	384,1	
Sidewall z = 150mm (Ford)	611 - PROBES - Ford Main body z-plane 150mm	12	196	-453	-843,4	150	
			197	375	-887,8	150	
			198	3588	-748	150	
			199	3300	830,8	150	
			200	3500	777,7	150	
			201	3656,8	700	150	
			202	-592	-730,5	150	
			203	-394	-859,9	150	
			204	2400	-888,9	150	
			205	3208	-855,5	150	
			206	3588	748	150	
			207	3765	400	150	
Side Window (Ford)	612 - PROBES - Ford Side Window	11	208	1020	-759	675	
			209	1020	-741,1	725	
			210	1020	-720,9	775	
			211	1100	-698,8	830	
			212	1200	-676,7	880	
			213	1300	-654,5	925	
			214	1400	-641,8	950	
			215	1200	-706,5	820	
			216	1200	-724,4	780	
			217	1400	-681,2	880	
			218	1400	-728,5	780	
A-Pillar (Ford)	613 - PROBES - Ford A-Pillar	6	219	728,2	-733	675	
			220	874,3	-701,5	775	
			221	1034,3	-664,5	875	
			222	1219	-617	975	
			223	1018,3	-648,7	875	
			224	1060	-675,8	875	

Testcase 2a/b: Pressure Probe Location (2)

	ANSA PID	# of Probes	Probe # (CAE)	X [mm]	Y [mm]	Z [mm]	Picture
Rearend z = 500mm (Ford)	614 - PROBES - Ford Main body z-plane 500mm	10	225	3300	-782,4	500	
			226	3425	-762,3	500	
			227	3525	-743,3	500	
			228	3599,5	-690	500	
			229	3646,2	-600	500	
			230	3300	782,4	500	
			231	3425	762,3	500	
			232	3525	743,3	500	
			233	3599,5	690	500	
			234	3646,2	600	500	
Notchback (Ford)	615 - PROBES - Ford Notchback	14	259	2930,6	-689,8	775	
			260	3008,4	-677,2	775	
			261	3085,5	-643,1	775	
			262	2753,8	-656,6	875	
			263	2831,7	-643,3	875	
			264	2872,8	-625,7	875	
			265	2561,2	-619,1	963,8	
			266	2664,2	-576	975	
			267	3099,9	-588,4	775	
			268	2897,9	-565,2	875	
			269	2667,9	-529,1	975	
			270	3008,4	677,2	775	
			271	2831,7	643,3	875	
			272	2619,5	600	975	
Wheelhouse (Ford)	624 - PROBES - Ford Front Wheelhouse	26	550	-380,29	-750	-115	
			551	-343,04	-600	-115	
			552	-130	-479	-155	
			553	0	-473,4	-155	
			554	130	-467,81	-155	
			555	334,9	-506,09	-115	
			556	384,79	-600	-115	
			557	406	-750	-115	
			558	-377,67	-750	43,15	
			559	-356,53	-750	199	
			560	-272,73	-750	331,81	
			561	-143,05	-750	420,67	
			562	10,68	-750	452,54	
			563	164,46	-750	420,88	
			564	293,38	-750	330,82	
			565	378,34	-750	198,6	
			566	401,96	-750	43,11	
			567	-339,45	-600	30,23	
			568	-318,19	-600	173,58	
			569	-245,15	-600	298,08	
			570	-127,79	-600	381,66	
			571	13,6	-600	409,76	
			572	154,19	-600	378,11	
			573	270,12	-600	291,95	
			574	351,02	-600	171,73	
			575	379,08	-600	30,12	

	ANSA PID	# of Probes	Probe # (CAE)	X [mm]	Y [mm]	Z [mm]	Picture
Detailed Underbody Open Cooling (Ford)	625 - PROBES - Ford OCDA Detailed Underbody	34	600	-762,5	0	-111,2	
			601	-729,72	0	-115	
			602	-697	0	-118,78	
			603	-600	0	-130	
			604	-400	0	-153,125	
			605	-200	0	-165,55	
			606	0	0	-170,725	
			607	200	0	-170,475	
			608	580	0	211,4	
			609	900	0	154,8	
			610	1100	0	109,15	
			611	1500	0	85,27	
			612	1700	0	76,43	
			613	1900	0	67	
			614	2500	0	-82,77	
			615	2700	0	-123,43	
			616	2900	0	-118,44	
			617	3100	0	-104,17	
			618	3300	0	-89,08	
			619	3500	0	-68,5	
			620	3700	0	-31,07	
			621	540	-339,3	-120	
			622	750	-328,45	-120	
			623	1100	-590	-155,66	
			624	1500	-360	-150,12	
			625	400	-550	-159,6	
			626	500	-700	-159,7	
			627	540	-590	-164,6	
			628	750	-590	-160,05	
			629	1100	-360	-155,66	
			630	1500	-590	-150,12	
			631	2403,7	-740	-97,1	
			632	2793,2	-740	461,5	
			633	3172,9	-740	185,2	

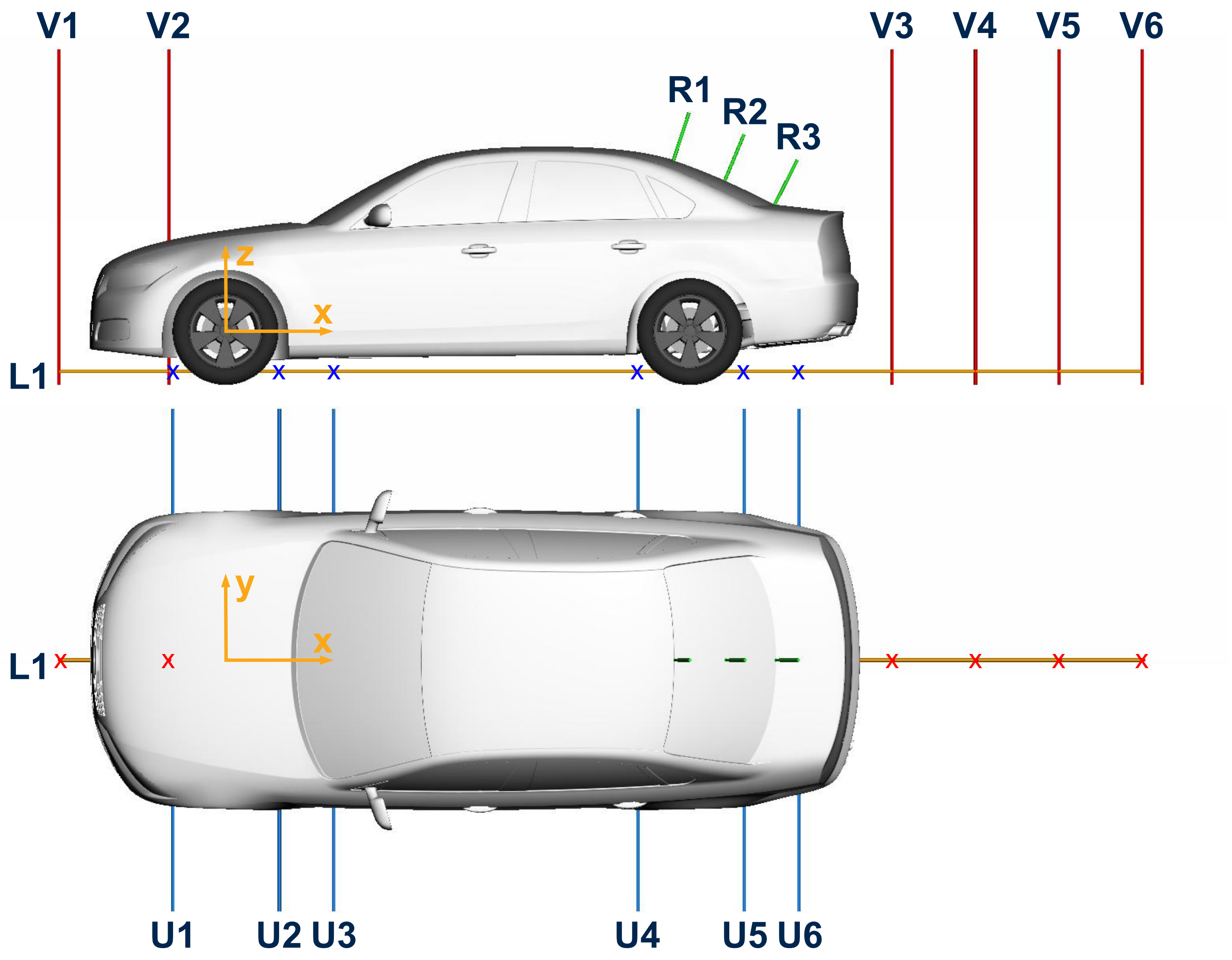
Unchanged vs. AutoCFD4

Testcase 2a/b: Velocity Profiles

Normalized velocity magnitude V/V_{∞}@ following locations:

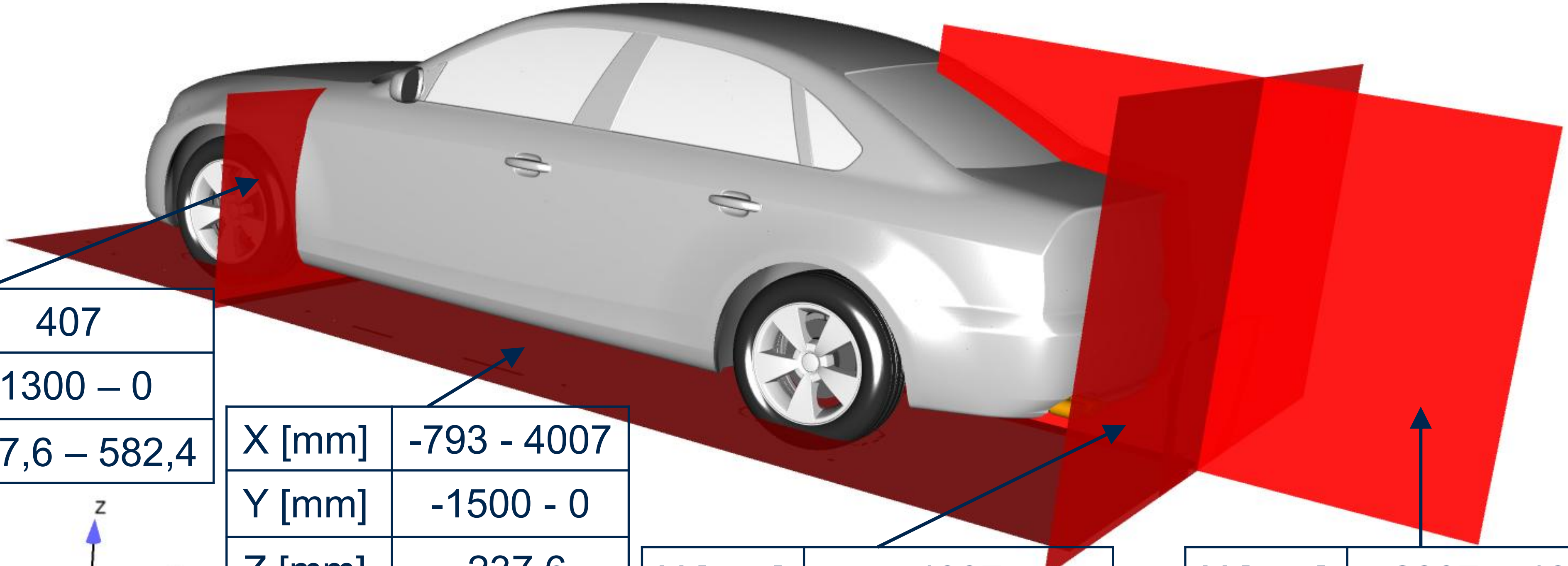
Profile	Start Point	End Point
V1*	(-993; 0; -317.6)	(-993; 0; 1682.4)
V2*	(-333; 0; -317.6)	(-333; 0; 1682.4)
V3**	(4007; 0; -317.6)	(4007; 0; 1682.4)
V4	(4657; 0; -317.6)	(4657; 0; 1682.4)
V5**	(5007; 0; -317.6)	(5007; 0; 1682.4)
V6	(5507; 0; -317.6)	(5507; 0; 1682.4)
U1*	(-343; -1500; -237.6)	(-343; 1500; -237.6)
U2**	(357; -1500; -237.6)	(357; 1500; -237.6)
U3**	(707; -1500; -237.6)	(707; 1500; -237.6)
U4*	(2457; -1500; -237.6)	(2457; 1500; -237.6)
U5**	(3157; -1500; -237.6)	(3157; 1500; -237.6)
U6**	(3507; -1500; -237.6)	(3507; 1500; -237.6)
L1**	(-993; 0; -237.6)	(5507; 0; -237.6)
R1	(2694.298; 0; 1019.591)	(2787.561; 0; 1304.727)
R2	(3002.831; 0; 899.739)	(3123.960; 0; 1174.199)
R3	(3301.378; 0; 756.610)	(3438.062; 0; 1023.664)

* Experimental data available for correlation for Case 2a
** Experimental data available for correlation for Case 2a & b



Testcase 2a/b: Flowfield Measurements

- **14-hole probe measurements have been conducted in 4 planes (Testcase 2a). For Testcase 2b flowfield measurement in 2 planes (x = 407mm / z = -237,6mm) are available.**
- **The total pressure coefficient (C_{pt}), the static pressure coefficient (C_p), the normalized velocity magnitude (V/V_∞) and the microdrag (C_{DL}) are available for CAE correlation.**

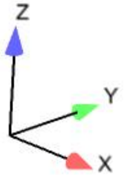


X [mm]	407
Y [mm]	-1300 – 0
Z [mm]	-267,6 – 582,4

X [mm]	-793 - 4007
Y [mm]	-1500 - 0
Z [mm]	-237,6

X [mm]	4007
Y [mm]	-1500 - 1500
Z [mm]	-267,6 – 1182,4

X [mm]	2807 – 4607
Y [mm]	0
Z [mm]	-267,6 – 1182,4



Testcase 2a/b: Post-Processing

- To maximize the outcome of the workshop a structured post-processing approach, which is based on the approach successfully used for AutoCFD4, will be used for AutoCFD5. The structured approach supports:
  - a direct comparison of CFD results to wind tunnel test data for testcase 2a & b
  - a direct evaluation of the A – B prediction capability vs. wind tunnel test data
  - cross-plotting of CFD results contributed by different participants

- To enable a structured data processing all participants are requested to use the provided spreadsheet (AutoCFD5_DrivAer_Result_Template) to deliver their results.
  - In case result data is not provided in the required format the data can not be considered during the test data and CFD result comparison.

Post-Processing: Background (1/2)

- To maximize the outcome of the workshop for the automotive CFD community and every workshop participant a structure simulation post-processing approach was developed. The structured approach will ensure that:
  - simulation results can be compared to available wind tunnel test data
  - solutions from different participants can be compared
  - the organizing committee will be able to process all incoming data
- To enable a structured data processing all participants are requested to use the provided spreadsheet (AutoCFD5_DrivAer_Result_Template) to deliver their results.
  - In case result data is not provided in the required format the data can not be considered during the test data and CFD result comparison.

Post-Processing: Background (2/2)

- All participants of the workshop are requested to use a provide Excel template to report their simulation results:
  - Aerodynamic forces
  - Surface pressure
  - Skin friction (SRS-TFG request; Upperbody centerline only)
  - Velocity profile (limited ability to compare with test data)
  - Flowfield results (EnSight compatible: EnSight Gold, Tecplot binary .plt, Kitware .vtk)

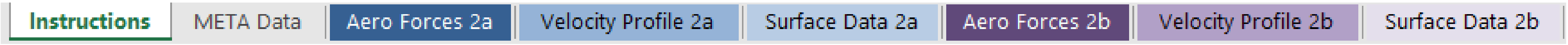
- After the workshop a full set of test results will be available to all participants which delivered results via the Excel template.

Unchanged vs. AutoCFD4

Post-Processing – Overview (1/2)

Structure of the Excel template:

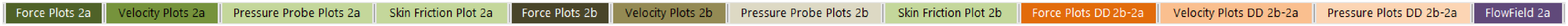
- **Information / Input section:**
  - **Instructions:** Instructions how to work with the Spreadsheet
  - **META Data:** Input Description of simulation method
  - **Aero Forces 2a:** Input calculated Aerodynamic Forces, Force Development & Time history for testcase 2a
  - **Velocity Profile 2a:** Input calculated velocity profile data for testcase 2a
  - **Surface Data 2a:** Input calculated surface pressure & skin friction data for testcase 2a
  - **Aero Forces 2b:** Input calculated Aerodynamic Forces, Force Development & Time history for testcase 2b
  - **Velocity Profile 2b:** Input Calculated velocity profile data for testcase 2b
  - **Surface Data 2b:** Input Calculated surface pressure & skin friction data for testcase 2b



Post-Processing – Overview (2/2)

Structure of the Excel template:

- **Output section:**
  - **Force Plots 2a:** Test to CAE comparison of aerodynamic forces for testcase 2a
  - **Velocity Plots 2a:** Test to CAE comparison of velocity profile for testcase 2a
  - **Pressure Plots 2a:** Test to CAE comparison of surface pressure for testcase 2a
  - **Skin Friction Plot 2a:** CAE_{Ref} to CAE comparison of skin friction for testcase 2a
  - **Force Plots 2b:** Test to CAE comparison of aerodynamic forces for testcase 2b
  - **Velocity Plots 2b:** Test to CAE comparison of velocity profile for testcase 2b
  - **Pressure Plots 2b:** Test to CAE comparison of surface pressure for testcase 2b
  - **Skin Friction Plot 2b:** CAE_{Ref} to CAE comparison of skin friction for testcase 2b
  - **Force Plots DD 2b-2a:** Test to CAE comparison of aerodynamic force difference between testcase 2b & 2a
  - **Velocity Plots DD 2b-2a:** Test to CAE comparison of velocity profile difference between testcase 2b & 2a
  - **Pressure Plots DD 2b-2a:** Test to CAE comparison of surface pressure difference between testcase 2b & 2a

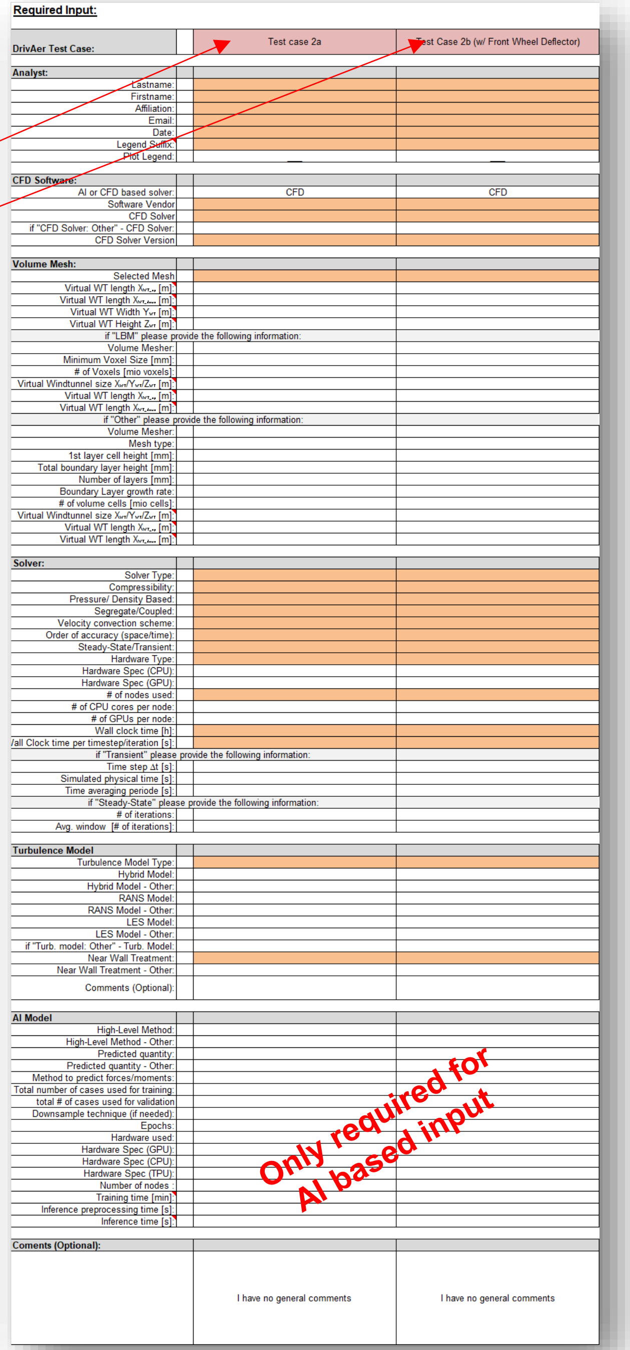


Post-Processing – Instructions (1/7)

Unchanged vs. AutoCFD4

Instructions how to fill out the Excel template:

- Sheet: META DATA
  - The sheet collects the META for testcase 2a & b
  - All marked fields need to be filled out
  - In most case pull-down menus can be used to provide input
  - Cell E17 & F17 (Plot Legend) will be automatically defined based on the user input
  - Some fields (e.g. E33-49, E89-105) will only be required in exceptional cases
  - Data provided via this sheet will be used
    - » to enable data filtering for cross-plotting
    - » to define the legend for all graphs

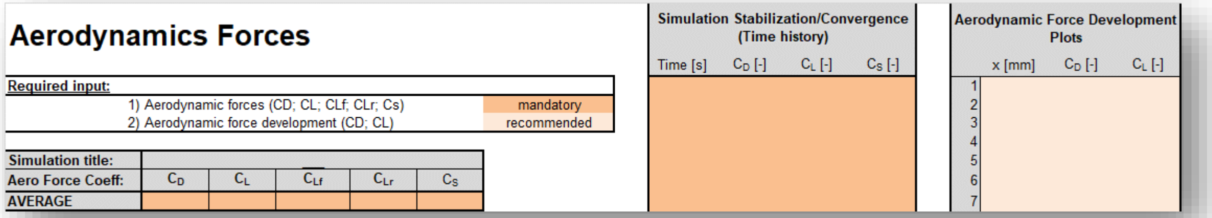


Post-Processing – Instructions (2/7)

Instructions how to fill out the Excel template:

- Sheets: Aero Forces 2a / Aero Forces 2b
  - Simulation title (D8) will be filled out automatically based on input in “META DATA”
  - Final predicted aerodynamic force coefficients (e.g. time averaged) should be provided in cells (D10 – H10). The lift coefficient should be split in a front and rear lift coefficient.
  - Column L – O should be populated with the C_D, C_L & C_S time history of the analysis. This data will be used to monitor analysis convergence/stabilization.

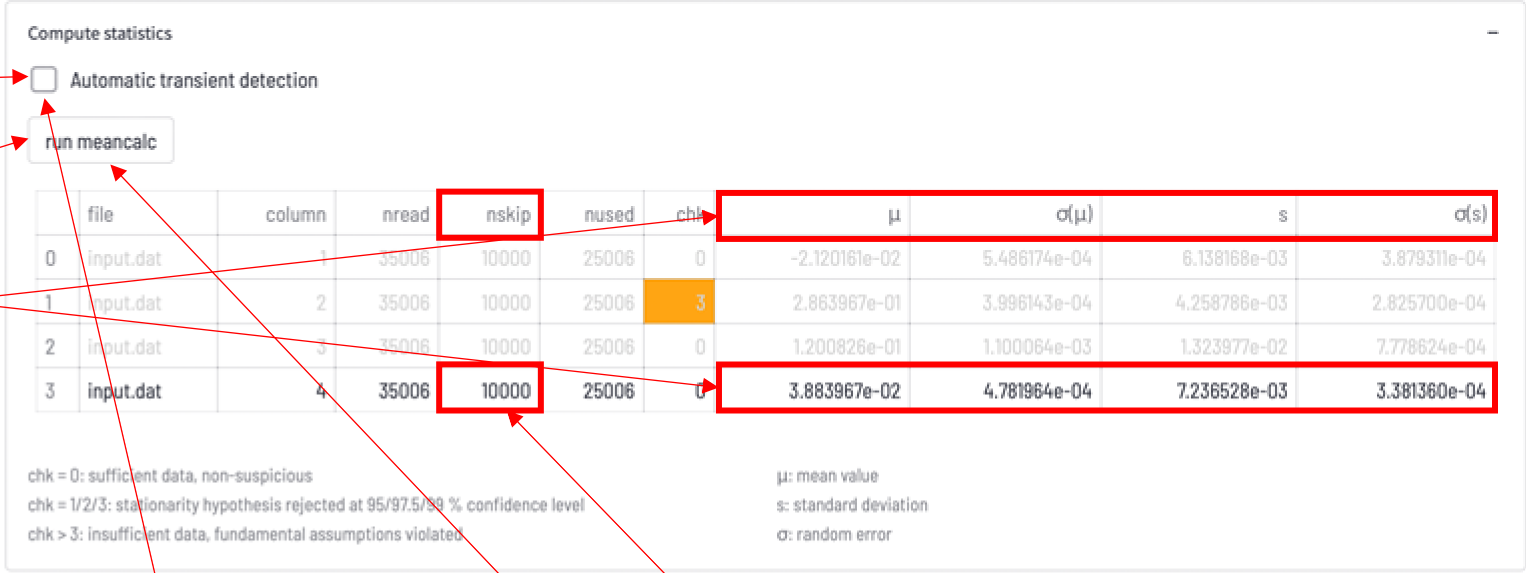
  Optional (as this data can not be use for comparison with test data):
  - Analyzing the force development along the length (x-axis) is a useful and well established post-processing technique, specifically useful when comparing different CFD results.
  - Input for the force development can be provided in column R, S and T
    - » R: x-pos starting with x=0mm at the front of the vehicle
    - » S/T: Cumulative drag C_D and lift C_L from vehicle front to x-position



Post-Processing – Instructions (3/7)

Meancalc „User Guide“

1. **Access Meancalc via: https://meancalc.app.upstream-cfd.com**
2. **Define start point of averaging period (timestep) via "Constrain index range"**
   Chosen timestep should match the timestep selected to calculate the aero force averages (D10 - H10)
3. **Deactivate "Automatic transient detection„**
4. **Run Meancalc for each of the aerodynamic forces (C_D, C_L, C_S)**
5. **Enter Meancalc output into Excel Template: Aero Forces 2a / Aero Forces 2b (s. next slide)**
   (Mean Value (m), Error Mean Value s(m) and Standard Deviation (s))



Compute statistics

Automatic transient detection

run meancalc

	file	column	nread	nskip	nused	chk	μ	σ(μ)	s	σ(s)
0	input.dat	1	35006	10000	25006	0	-2.120161e-02	5.486174e-04	6.138168e-03	3.879311e-04
1	input.dat	2	35006	10000	25006	3	2.863967e-01	3.996143e-04	4.258786e-03	2.825700e-04
2	input.dat	3	35006	10000	25006	0	1.200826e-01	1.100064e-03	1.323977e-02	7.778624e-04
3	input.dat	4	35006	10000	25006	0	3.883967e-02	4.781964e-04	7.236528e-03	3.381360e-04

chk = 0: sufficient data, non-suspicious
chk = 1/2/3: stationarity hypothesis rejected at 95/97.5/99 % confidence level
chk > 3: insufficient data, fundamental assumptions violated

μ: mean value
s: standard deviation
σ: random error

6. **Copy the C_D stabilization plot and past it into the Excel Template: Aero Forces 2a / Aero Forces 2b (s. next slide)**
7. **Activate "Automatic transient detection“**
   (Data parts with variable time-step size are not supported and must be excluded via "Constrain index range" feature)
8. **Rerun Meancalc for each of the aerodynamic forces (C_D, C_L, C_S)**
9. **Enter Meancalc recommended averaging start time (nskip) into Excel template (s. next slide)**

Unchanged vs. AutoCFD4

Post-Processing – Instructions (4/7)

Instructions how to fill out the Excel template:

- **Sheets: Aero Forces 2a / Aero Forces 2b**
- **Analysis convergence/stabilization monitoring**
  - **Meancalc output will not be used for aero force reporting and comparison!**
  - **Meancalc output will be used for result quality checking and statistical error reporting**
- **Enter output from Meancalc (s. next slide):**
  - **D25: Enter "Averaging start time [sec]"**
  - **D26: Enter "Averaging start time [timestep]"**
  - **D27: Enter "Averaging end time [sec]"**
  - **D/E/H29: Enter "Mean Value" for C_D, C_L (& C_S)**
  - **D/E/H30: Enter "Error Mean Value"**
  - **D/E/H31: Enter "Standard deviation"**
  - **D/E/H37: Enter "Averaging start timestep [nskip]"**

Standardized **Meancalc** based evaluation of aero dynamic force time traces

- Meancalc output will not be used for aero force reporting and comparison!
- Meancalc output will be used for result quality checking and statistical error reporting
- Access Meancalc via:
  https://meancalc.app.upstream-cfd.com
- Define start point of averaging period (timestep)
  Chosen timestep should match the timestep selected to calculate the aero force averages (D10 - H10)
- Deactivate "Automatic transient detection"
- Run Meancalc for each of the aerodynamic forces (C_D, C_L, C_S)
- Capture Meancalc output in table below

Averaging start time [sec]					
Averaging start time [timestep]					
Averaging end time [sec]					
Length of averaging interval [sec]	0,00000				
Mean value μ					
Error Mean Value $\sigma(\mu)$					
Standard deviation s					
Error Standard Deviation $\sigma(s)$	0,0000	0,0000			0,0000

- Activate "Automatic transient detection"
- Rerun Meancalc for each of the aerodynamic forces (C_D, C_L, C_S)
- Capture Meancalc recommended averaging start timestep (nskip) in table below

Averaging start timestep [nskip]					

Input picture of **Meancalc** anaylsis of aerodynamic drag C_D time trace

Post-Processing – Instructions (5/7)

Instructions how to fill out the Excel template:

- Sheets: Velocity Profile 2a / Velocity Profile 2b
  - Simulation title (B8) will be filled out automatically based on input in "META DATA"
  - Columns B – AG should be populated with velocity profile data at the locations defined in slide 20
    - » Velocity data columns should include local velocity magnitude V data normalized by the vehicle speed V_∞
    - » The "Distance" should show <u>the distance from the origin</u> ("Start Point" as defined on slide 20) of each profile. Therefore, for all profile the distance starts at "0.0".
    - » The number of data point for each profile can be defined by each user but should be sufficient to accurately represent the velocity profiles.

Velocity Profiles

Required input:
1) Normalized velocity magnitude profiles — mandatory
Distance referes to starting point of the individual profiles (s. note)

L1		R1		R2		R3		U1		U2	
V_{mag}/V_∞ [-]	Distance [m]	V_{mag}/V_∞ [-]	Distance [m]	V_{mag}/V_∞ [-]	Distance [m]	V_{mag}/V_∞ [-]	Distance [m]	V_{mag}/V_∞ [-]	Distance [m]	V_{mag}/V_∞ [-]	Distance [m]
0,6909	0,0000	0,0910	0,0000	0,1022	0,0000	0,0153	0,0000	0,9711	0,0000	0,9935	0,0000
0,6923	0,0031	0,1007	0,0006	0,1289	0,0006	0,0172	0,0006	0,9708	0,0201	0,9935	0,0201
0,6976	0,0131	0,1178	0,0012	0,1656	0,0012	0,0209	0,0012	0,9728	0,0601	0,9965	0,0601
0,7036	0,0231	0,0952	0,0020	0,1839	0,0019	0,0221	0,0019	0,9752	0,1001	1,0002	0,1001
0,7102	0,0331	0,2049	0,0027	0,2026	0,0027	0,0230	0,0025	0,9780	0,1401	1,0045	0,1401
0,7176	0,0431	0,2692	0,0028	0,2127	0,0030	0,0234	0,0027	0,9814	0,1801	1,0096	0,1801
0,7257	0,0531	0,7083	0,0056	0,2485	0,0056	0,0255	0,0037	0,9851	0,2201	1,0161	0,2201

U3		U4		U5		U6		V1		V2	
V_{mag}/V_∞ [-]	Distance [m]	V_{mag}/V_∞ [-]	Distance [m]	V_{mag}/V_∞ [-]	Distance [m]	V_{mag}/V_∞ [-]	Distance [m]	V_{mag}/V_∞ [-]	Distance [m]	V_{mag}/V_∞ [-]	Distanc
0,9852	0,0000	0,9320	0,0000	0,9111	0,0000	0,8933	0,0000	0,3206	0,0000	0,7324	
0,9842	0,0201	0,9289	0,0201	0,9066	0,0201	0,8882	0,0201	0,3529	0,0015	0,7997	
0,9850	0,0601	0,9189	0,0601	0,8935	0,0601	0,8738	0,0601	0,3965	0,0031	0,8968	
0,9862	0,1001	0,9053	0,1001	0,8779	0,1001	0,8562	0,1001	0,4157	0,0050	0,9424	
0,9876	0,1401	0,8920	0,1401	0,8644	0,1401	0,8398	0,1401	0,4319	0,0070	0,9702	
0,9892	0,1801	0,8813	0,1801	0,8532	0,1801	0,8258	0,1801	0,4568	0,0100	0,9981	
0,9914	0,2201	0,8738	0,2201	0,8454	0,2201	0,8180	0,2201	0,4971	0,0200	1,0296	

Post-Processing – Instructions (6/7)

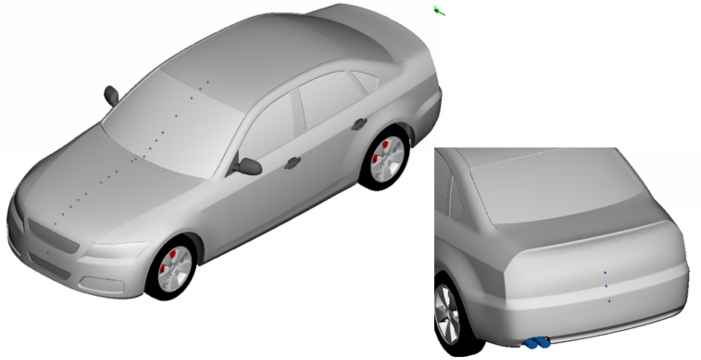
Instructions how to fill out the Excel template:

- **Sheets: Surface Data 2a / Surface Data 2b**
  - **Simulation title (F8) will be filled out automatically based on input in "META DATA"**
  - **Column I should be populated with the static pressure coefficient data (Cp) at the pressure probe locations defined in column F – H**
    - » **The pressure probe numbering is provided in column E and is consistent with the pressure probe definition discussed in slides 10 – 12**
  - **Column J should be populated with the skin friction coefficient magnitude data (Cf) at some of the pressure probe locations defined in column F – H (only upperbody centerline, J10-32 & J75-92 & J103-105)**

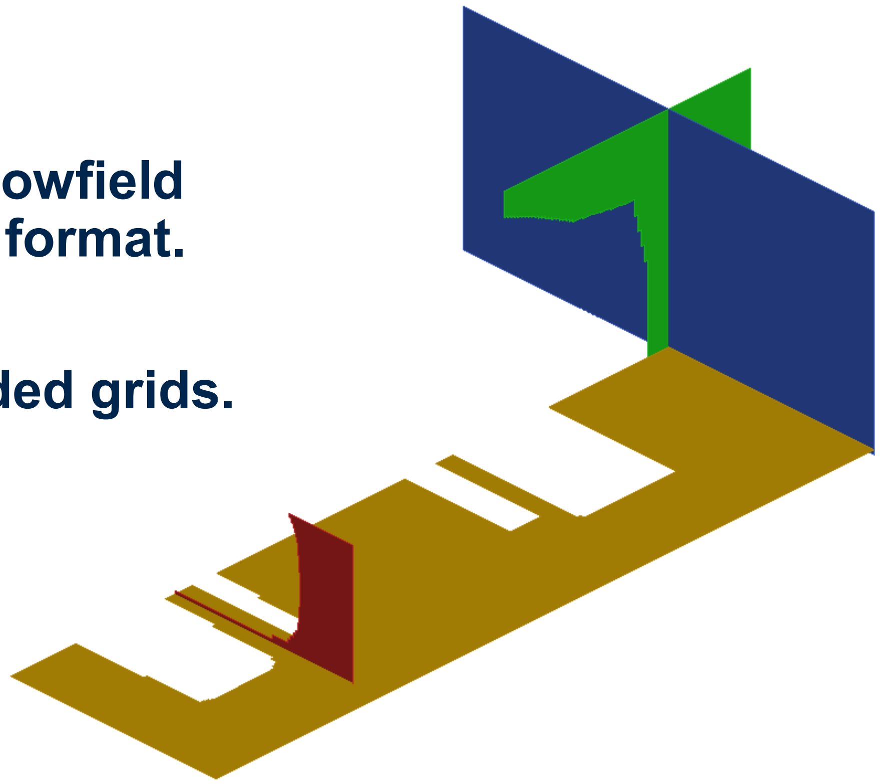
Surface Pressure

Required input:
1) Time averaged static pressure coefficient Cp at all pressure probe locations — mandatory
2) Time averaged upperbody skin centerline friction coefficient magnitude (Cf) at marked locations — mandatory

Simulation title: ___

	ANSA PID	# of Probes	Probe #	X [mm]	Y [mm]	Z [mm]	Cp [-]	Cf [-]	Picture
Upperbody Centerline (TUM)	600 - PROBES - TUM Main body centerline	23	1	-798,25	0	150			
			2	-700	0	406,35			
			3	-600	0	462,63			
			4	-500	0	499,45			
			5	-400	0	527,7			
			6	-300	0	550,85			
			7	-100	0	587,73			
			8	0	0	603,05			
			9	100	0	616,9			
			10	300	0	640,83			
			11	350	0	645,93			
			12	413,1	0	625			
			13	464,13	0	625			
			14	543,18	0	675			
			15	624,25	0	725			
			16	707,88	0	775			
			17	885,33	0	875			
			18	1084,9	0	975			
			19	1199	0	1025			
			20	1300	0	1051,5			
			21	3752,7	0	450			
			22	3757,9	0	350			
			23	3804,1	0	250			

Post-Processing – Instructions (7/7)



Instructions how to post-process flowfield data

- **Grids which exactly represent the grids used for the flowfield measurements will be shared in ANSA and NASTRAN format.**
  - The grids are scaled in meters.
- **Participants should map flowfield data onto the provided grids.**
  - The data should be mapped to the nodes of the grid as measurements have been taken at the node locations.
- **The following flowfield data will be available for comparison:**
  - Static pressure coefficient: Cp
  - Total pressure coefficient: Cpt
  - Normalized velocity magnitude: V/V_∞
  - Microdrag or Local Drag: $C_{DL} = 1 - C_{pt} - \left(1 - \frac{V_x}{V_\infty}\right)^2 + \left(\frac{V_y^2+V_z^2}{V_\infty^2}\right)$
- **The grids and the mapped flowfield data should be exported in EnSight readable format (e.g. EnSight Gold, Tecplot binary .plt, Kitware .vtk).**
  - Data not readable in EnSight can not be included in the test data comparison.

APPENDIX

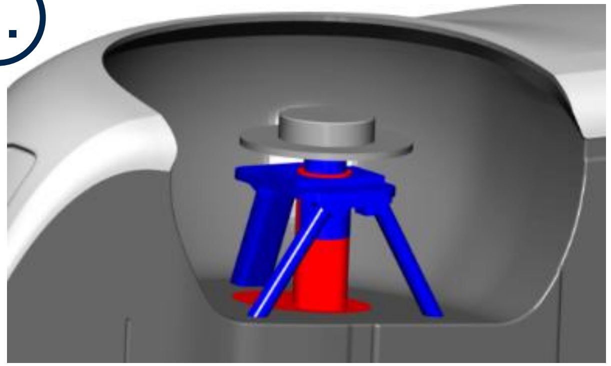
Clarification: Open Cooling DrivAer vs. „Original“ DrivAer

Original DrivAer = DrivAer introduced by Heft et al [1]

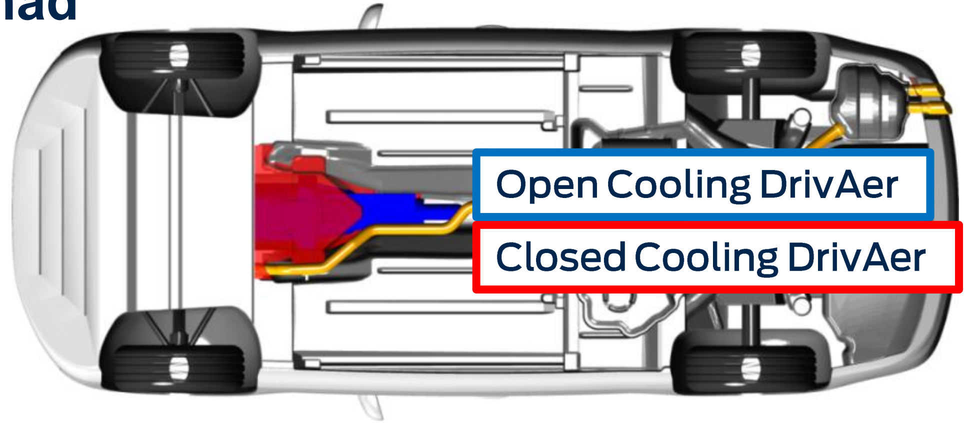
Open Cooling DrivAer = DrivAer introduced by Hupertz et al [2]

- **Integrating the underhood flow domain with the original DrivAer required two changes to the original DrivAer geometry:**
  1. **To enable airflow from the engine bay into the front wheelhouse a revised wheel mounting concept had to be introduced.**
  2. **The simplified transmission extending into the tunnel of the original DrivAer had to be replaced by a new transmission which connects to the Open Cooling DrivAer Powertrain and enable airflow from the engine bay into the tunnel**
- **Because of these two differences we have to differentiate between the original DrivAer (which is close cooling) and the closed cooling version of the Open Cooling DrivAer**

1.



2.

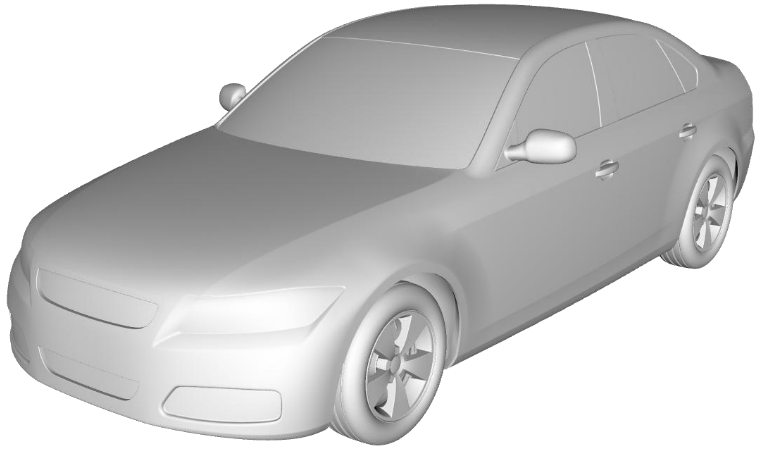


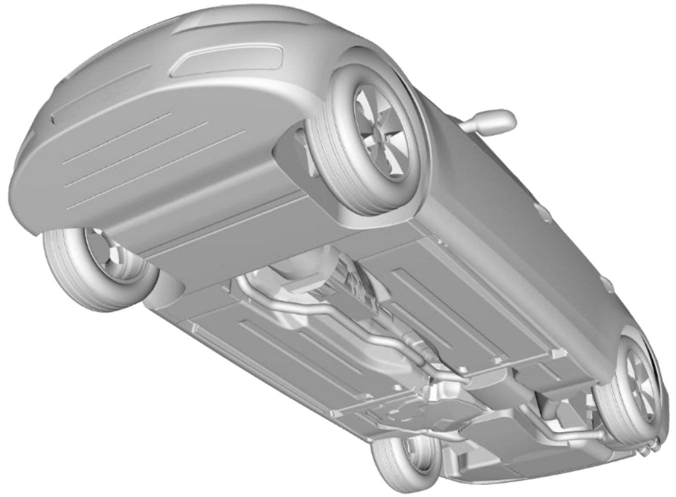
[1] Heft, A., Indinger, T., and Adams, N., "Introduction of a New Realistic Generic Car Model for Aerodynamic Investigations," SAE Technical Paper 2012-01-0168, 2012, doi:10.4271/2012-01-0168.

[2] Hupertz, B., Krüger, L., Chalupa, K. et al., "Introduction of a new Open Cooling Version of the DrivAer Generic Car Model" 11th FKFS Conference "Progress in Vehicle Aerodynamics and Thermal Management", Stuttgart, 2017.

DrivAer Notchback – CAD Geometry

- **Original DrivAer CAD Data can be downloaded from TUM website after registration:**
  [Download - Chair of Aerodynamics and Fluid Mechanics (tum.de)]
- **Out of the 24 available CAD parts, the 8 highlighted parts are needed to construct the AutoCFD Testcase 2a geometry**
- **Comments:**
  - **The CAD included in 09_EngineAndGearbox_EngineBayFlow.igs is only partially required to construct the Testcase 2a geometry**
  - **Two additional CAD parts are required to construct the Ford DrivAer model which has been used for correlation testing (s. next page)**

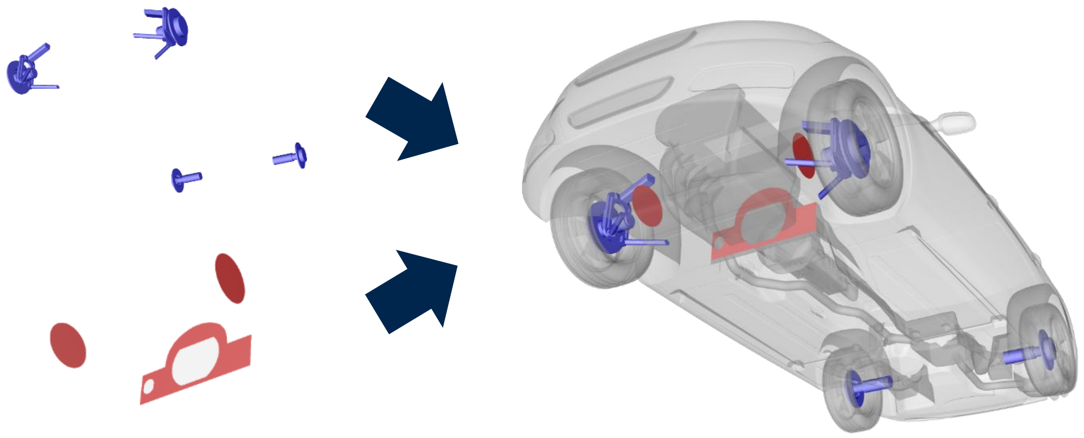




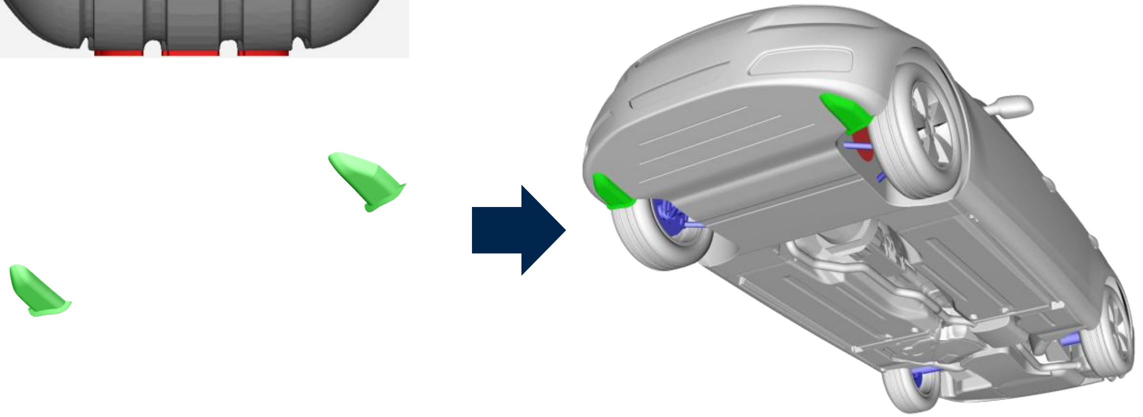
- 01_Body.igs
- 01_Body_Closed.igs
- 01_Body_Open_EngineBayFlow.igs
- 02_Underbody_Detailed.igs
- 02_Underbody_EngineBayFlow.igs
- 02_Underbody_Smooth.igs
- 03_RearEnd_EstateBack.igs
- 03_RearEnd_Fastback.igs
- 03_RearEnd_Notchback.igs
- 04_ExhaustSystem.igs
- 04_ExhaustSystem_EngineBayFlow.igs
- 05_Wheels_Front.igs
- 05_Wheels_Front_Closed.igs
- 05_Wheels_Front_Smooth.igs
- 06_Wheels_Rear.igs
- 06_Wheels_Rear_Closed.igs
- 06_Wheels_Rear_Smooth.igs
- 07_Mirrors.igs
- 08_EngineBayTrim_EngineBayFlow.igs
- 09_EngineAndGearbox_EngineBayFlow.igs
- 10_FrontGrills_EngineBayFlow.igs
- 11_CoolerWithLeak_EngineBayFlow.igs
- 11_CoolerWithoutLeak_EngineBayFlow.igs
- 11B_PressureLoss_Porosity_EngineBayFlow.igs

DrivAer Notchback – CAD Geometry

- In addition to the CAD data available from TUM two additional CAD parts are required to match the geometry of the physical Ford DrivAer model which has been used for correlation testing:
  - 21_Chassis: CAD of the axle and brake system used to mount the front and rear wheels
  - 22_EngineBaySeals: CAD of the covers required to close the outlets from the engine bay
  - tyre_plinth: CAD of interface required to improve mesh quality at tire – floor intersection



- To construct the AutoCFD Testcase 2b geometry one additional CAD part is required: 23_FrontWheelDeflector.step



OCDA Notchback: Coordinate System

Attention:

Based on the original TUM DrivAer model the coordinate system used for the setup of the CAD model is not exactly located in the center of the front axle.

The front axle center is located at: x = 7mm / z = 0mm