AutoCFD3 – Test Case 2: DrivAer - Notchback

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March 08th, 2022

Change-Log

- **March 18th, 2022**
  - **Slide 23 - 32: Slides added providing additional information regarding the testcase 2 post-processing**

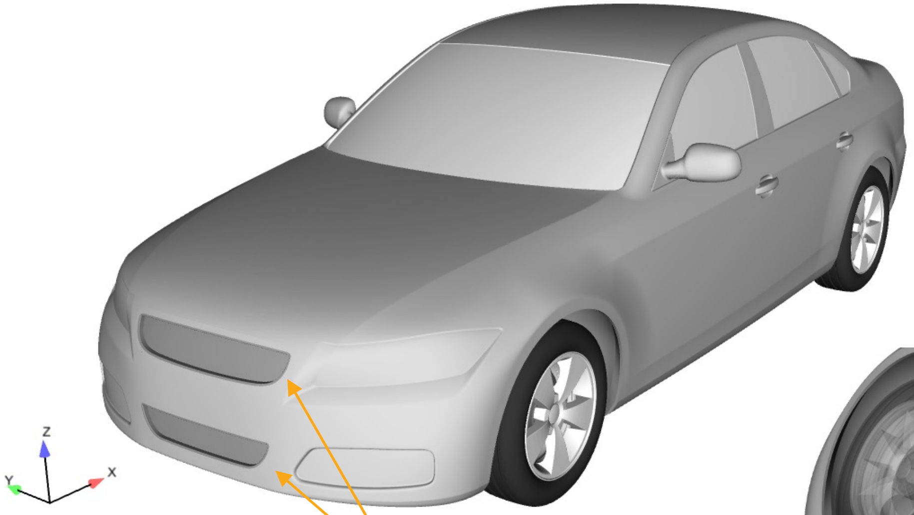
Table of Content

Introduction

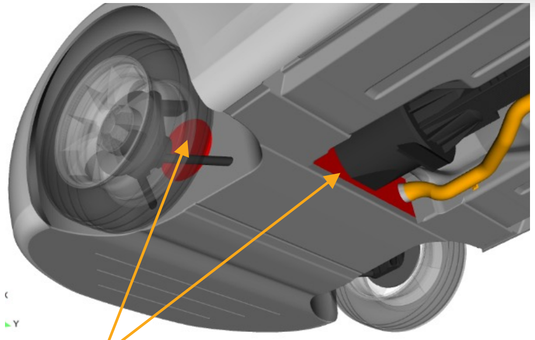
- **AutoCFD3 Test Case 2: Open Cooling DrivAer – Notchback**
  - **Motivation:**
    - » **Realistic test case relevant to automotive industry**
    - » **Accepted standard for automotive aerodynamic CFD correlation**
    - » **Availability of detailed surface pressure and flow field measurements**
    - » **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**

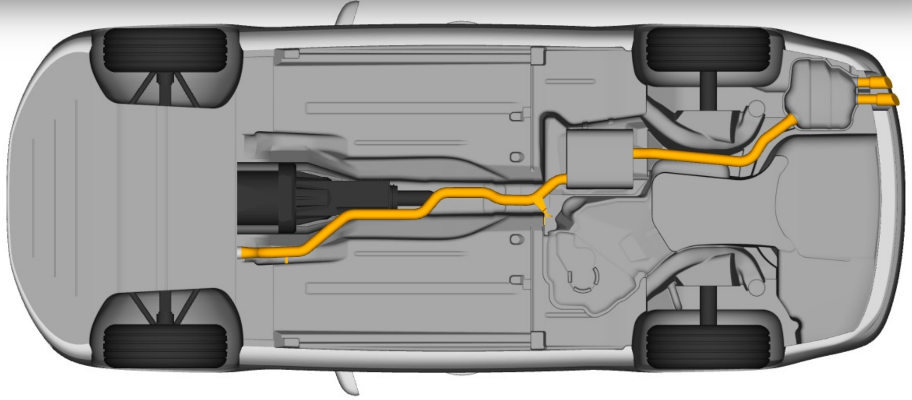


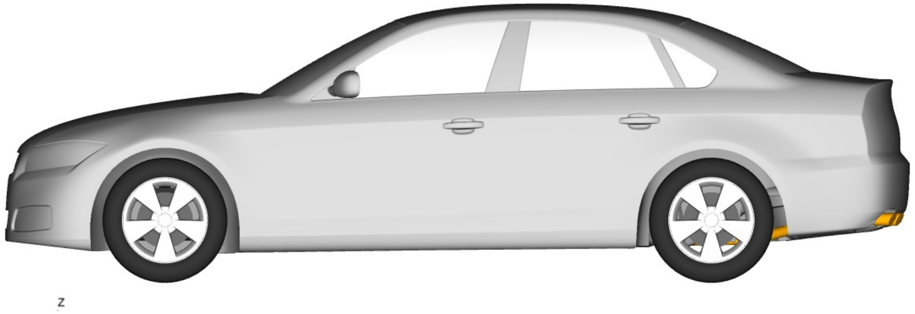
Closed Cooling[1]



Closed Engine Bay[1]

1:1 scale Ford Open Cooling DrivAer





[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.

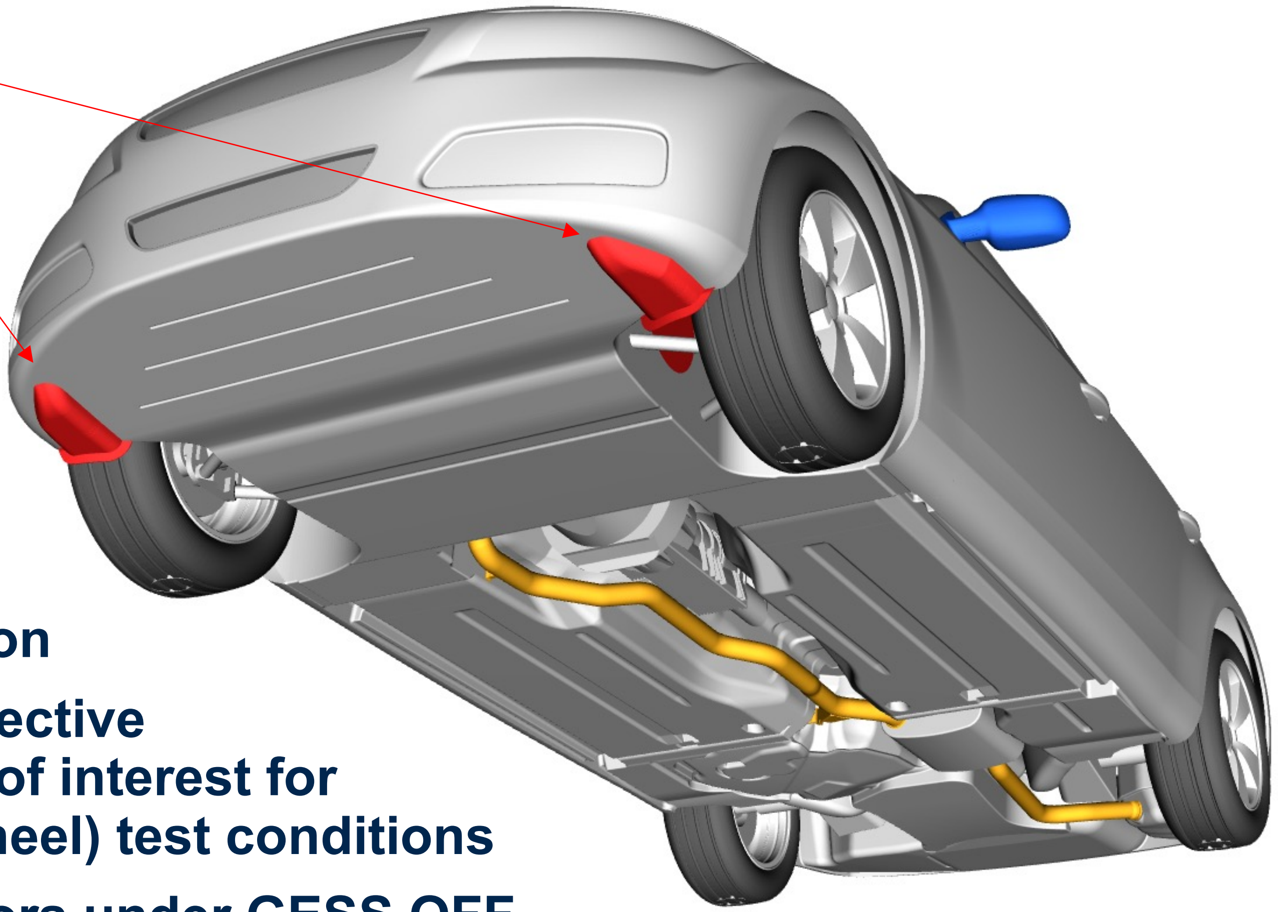
AutoCFD3 Testcase 2 – What‘s Next?

- Testcase 2a: The Ford DrivAer, remains to be one of the test cases for AutoCFD3
  - 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 (s. slide 20-21)

- 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
- AutoCFD3: Use front wheel air deflectors under GESS OFF conditions (avoid complexity resulting from GESS ON test condition)

Unchanged vs. AutoCFD2

Testcase 2a/b: DrivAer Configuration & Test Condition

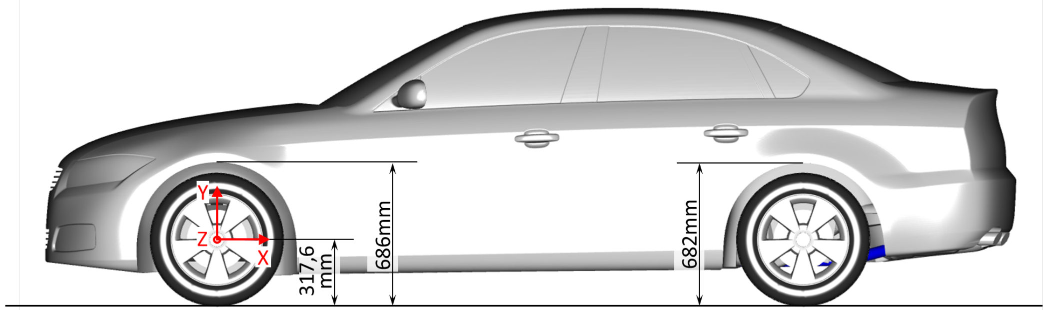
DrivAer Configuration

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

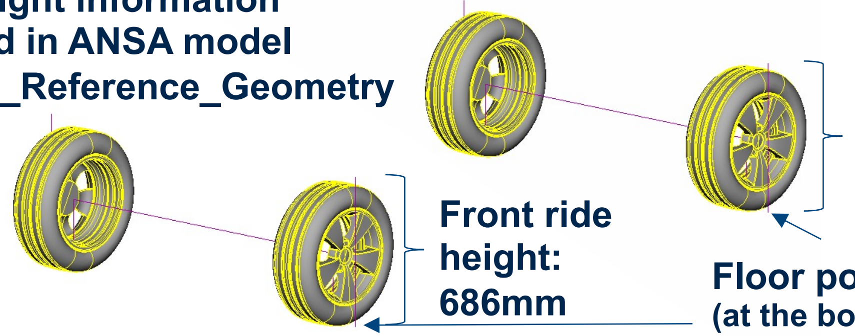
Wind tunnel setup (Pininfarina)

- 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
- Ambient Air Density: 1,204kg/m³
- Dynamic viscosity: 1.8138E-5Pa*s

  (Ambient Air Temperature: 20,08°C)



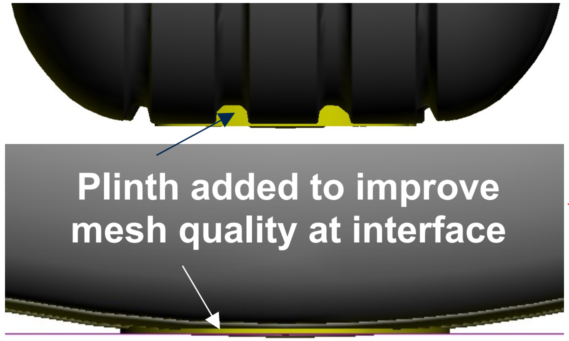
Ride height information included in ANSA model
Part: 79_Reference_Geometry

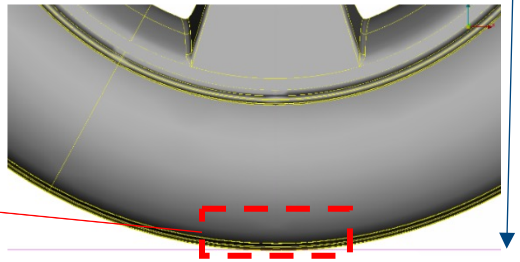


Rear ride height: 682mm

Front ride height: 686mm

Floor position (at the bottom of ride height line @ z = -317.6mm)





Minimal interference between tire and floor

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.)

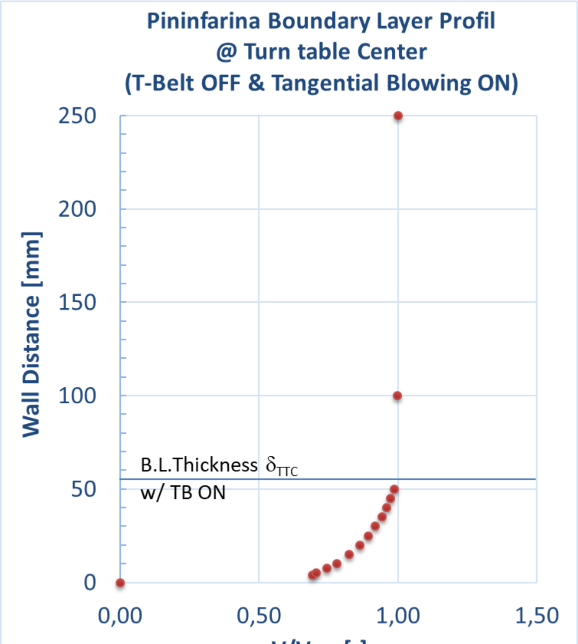


Figure 1

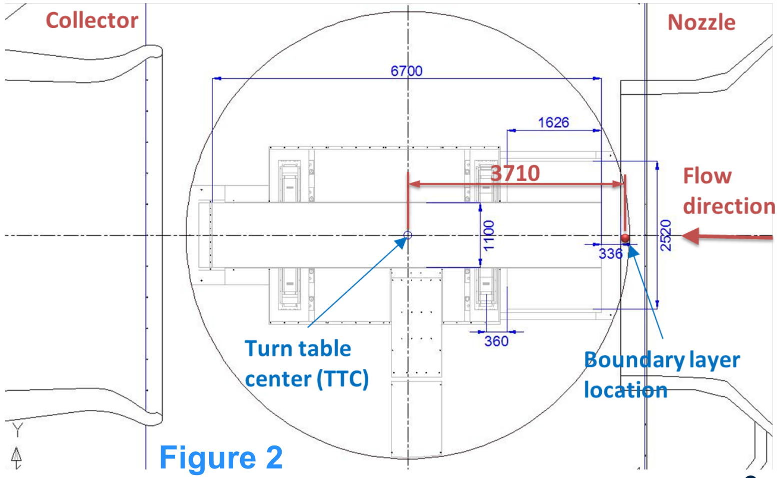
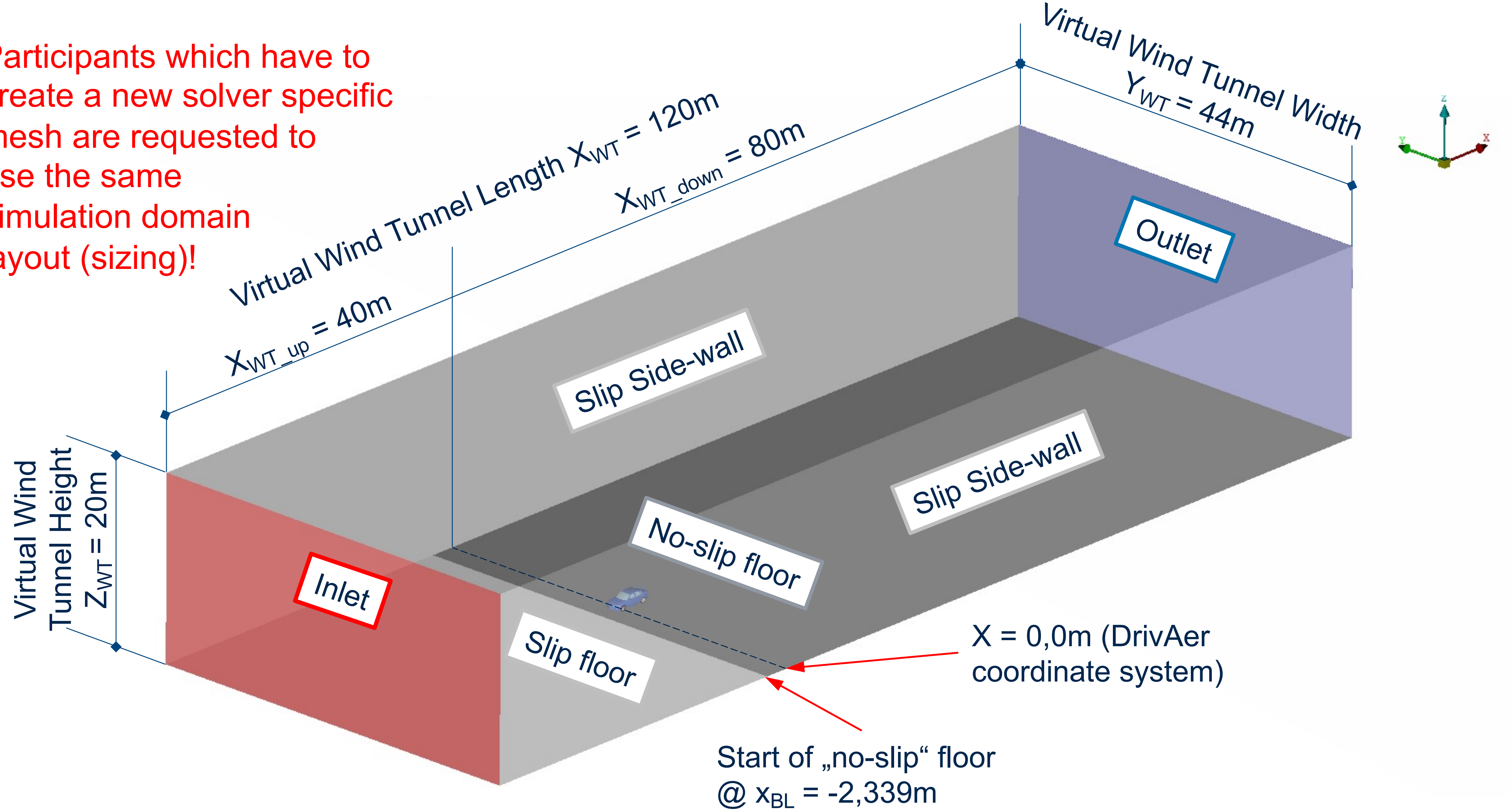


Figure 2

Unchanged vs. AutoCFD2

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

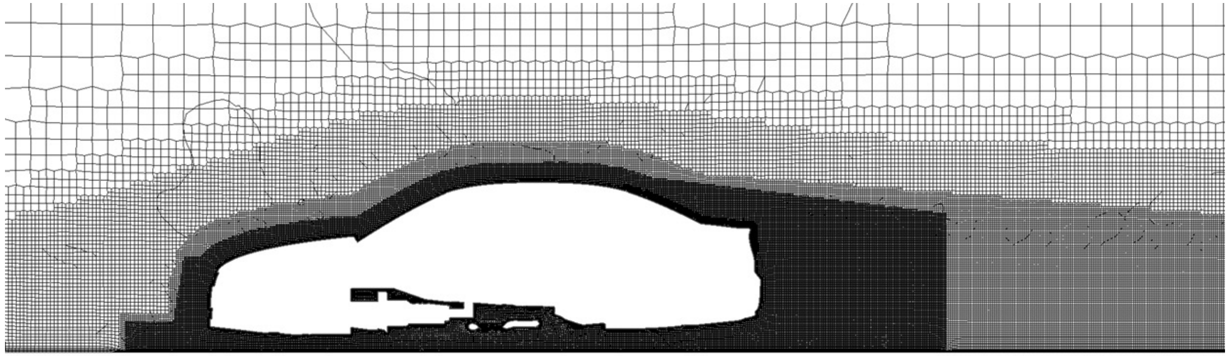
Participants which have to create a new solver specific mesh are requested to use the same simulation domain layout (sizing)!

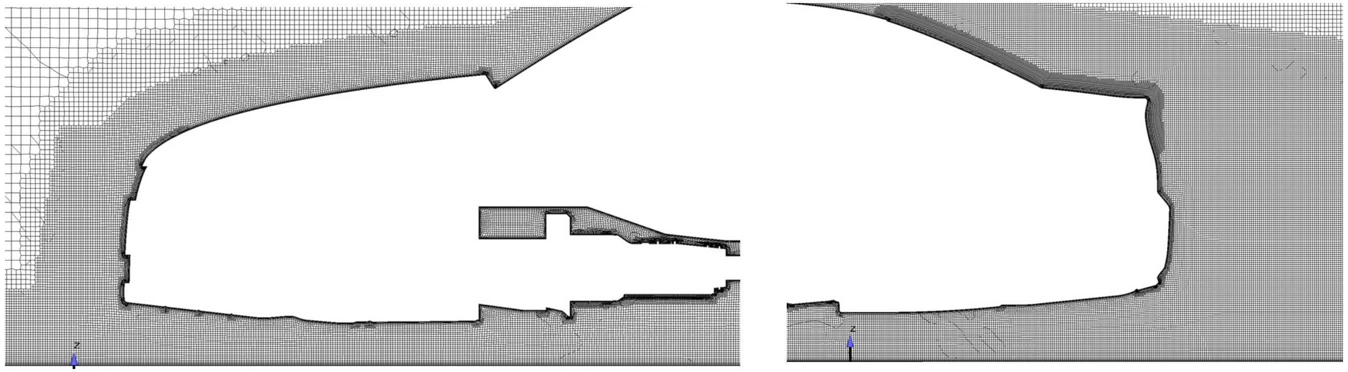


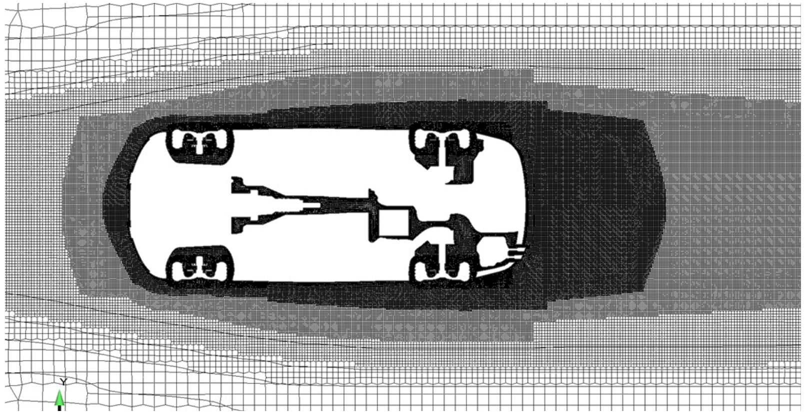
Unchanged vs. AutoCFD2

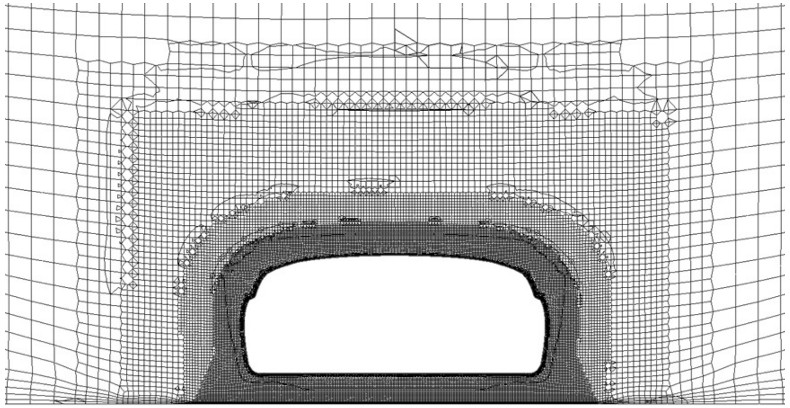
Testcase 2a/b: ANSA Volume Mesh - Overview

- **ANSA meshes will be provided for both test case two variants:**
  - **High-Re ($y^+ \sim 30$)***
- **The meshes for both variants are identical except for the front wheel air deflector region**
- **The mesh for Testcase 2a is identical to the AutoCFD2 mesh**
- **The mesh for Testcase 2b is identical to 2a except for the Front Wheel Deflector area**
- **Mesh size Testcase 2a/b:**
  - **High-Re: ~128mio.**
- **Mesh type: Octree**





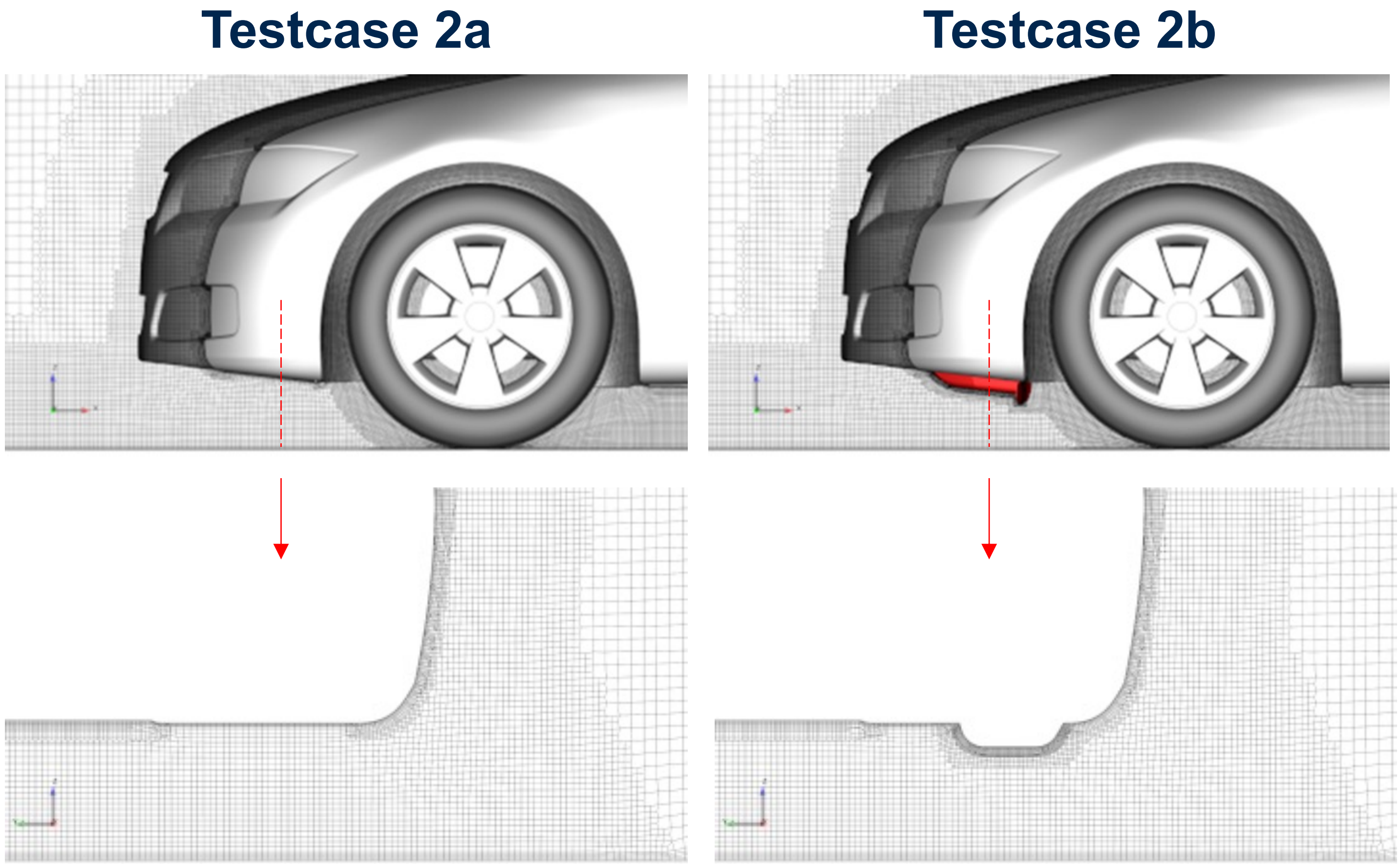




* Based on the outcome of the AutoCFD2 workshop the committee decide to drop the low-Re mesh

Testcase 2a/b: ANSA Volume Mesh @ Front Wheel Deflector

- ANSA meshes will be provided for both test case two variants:
  - High-Re ($y^+ \sim 30$)*
- The meshes for both variants are identical except for the front wheel air deflector region
- The mesh for Testcase 2a is identical to the AutoCFD2 mesh
- The mesh for Testcase 2b is identical to 2a except for the Front Wheel Deflector area
- Mesh size Testcase 2a/b:
  - High-Re: ~128mio.
- Mesh type:
  Octree

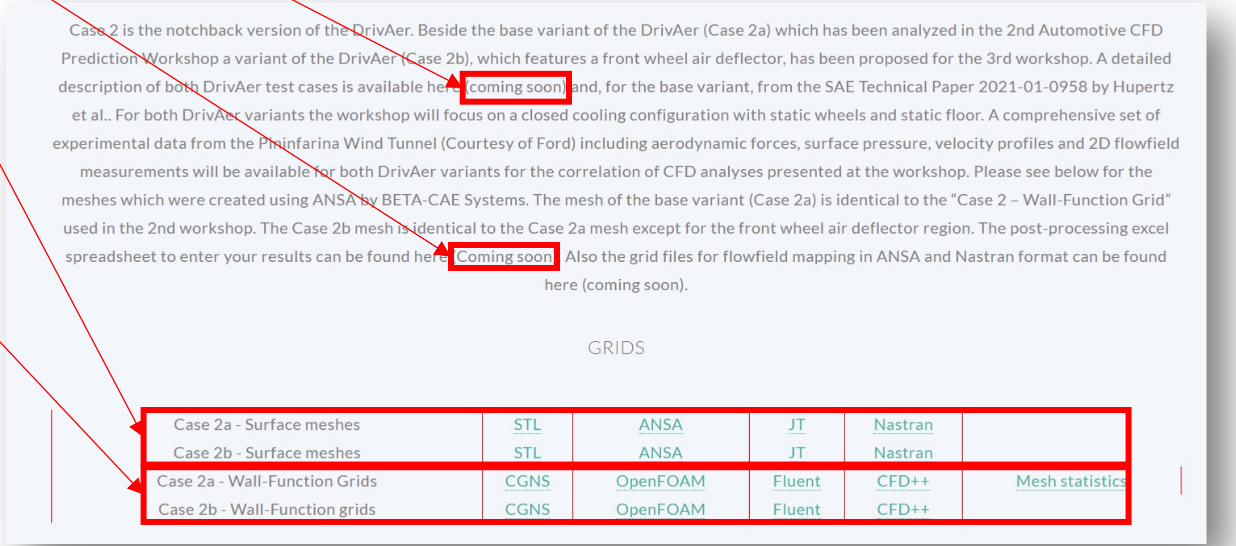


* Based on the outcome of the AutoCFD2 workshop the committee decide to drop the low-Re mesh

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

Testcase 2 information available via AutoCFD Web-Side:

- **Testcase 2a/b description**
- **Post-Processing Template**
  (will be available until Mar 18th)
- **DrivAer Geometry: Testcase 2a/b**
  - ANSA
  - STL
  - JT
  - Nastran
- **Computational mesh: Testcase 2a/b**
  - CGNS
  - OpenFOAM
  - Fluent
  - CFD++


Case 2 is the notchback version of the DrivAer. Beside the base variant of the DrivAer (Case 2a) which has been analyzed in the 2nd Automotive CFD Prediction Workshop a variant of the DrivAer (Case 2b), which features a front wheel air deflector, has been proposed for the 3rd workshop. A detailed description of both DrivAer test cases is available here (coming soon) 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 BETA-CAE Systems. The mesh of the base variant (Case 2a) is identical to the "Case 2 – Wall-Function Grid" used in the 2nd workshop. The Case 2b mesh is identical to the Case 2a mesh except for the front wheel air deflector region. The post-processing excel spreadsheet to enter your results can be found here (Coming soon). Also the grid files for flowfield mapping in ANSA and Nastran format can be found here (coming soon).

GRIDS

Case 2a - Surface meshes	STL	ANSA	JT	Nastran	
Case 2b - Surface meshes	STL	ANSA	JT	Nastran	
Case 2a - Wall-Function Grids	CGNS	OpenFOAM	Fluent	CFD++	Mesh statistics
Case 2b - Wall-Function grids	CGNS	OpenFOAM	Fluent	CFD++	

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)

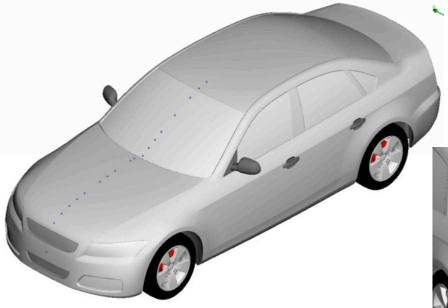
- A review of the experimental data for Testcase 2a is available via the following SAE Technical Paper. The paper includes a detailed discussion of the reliability and relevance of the DrivAer test data.
  - Hupertz, B., Chalupa, K., Lewington, N., Howard, K. et al., "On the Aerodynamics of the Notchback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

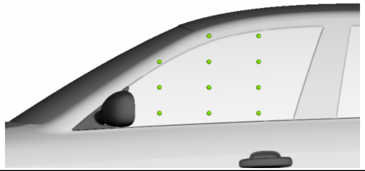
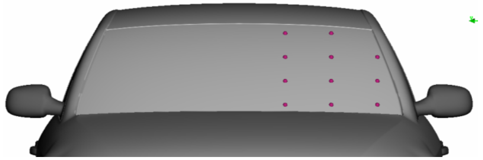
Unchanged vs. AutoCFD2

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

	ANSA PID	# of Probes	Probe # (CAE)	X [mm]	Y [mm]	Z [mm]
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

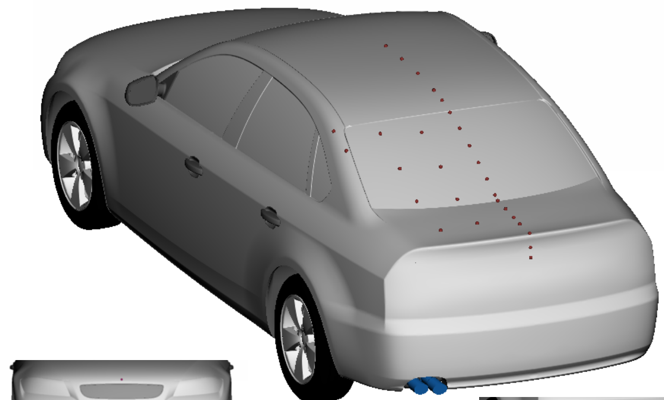
Picture



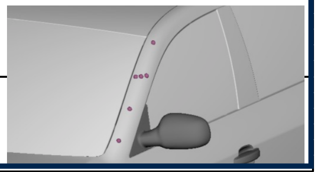




	ANSA PID	# of Probes	Probe # (CAE)	X [mm]	Y [mm]	Z [mm]
Notchback (TUM)	604 - PROBES - TUM Notchback	28	107	1900	0	1102,4
			108	2100	0	1100,28
			109	2300	0	1090,3
			110	2500	0	1067,15
			111	2600	0	1047,75
			112	2700	0	1017,73
			113	2820,15	0	975
			114	2944,43	0	925
			115	3057,9	0	875
			116	3164,15	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

Picture

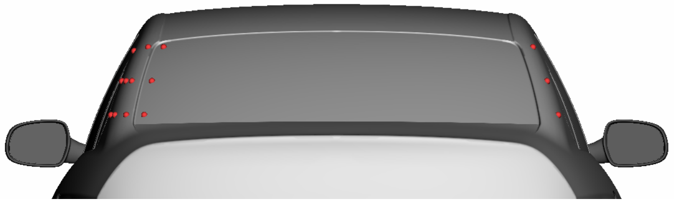
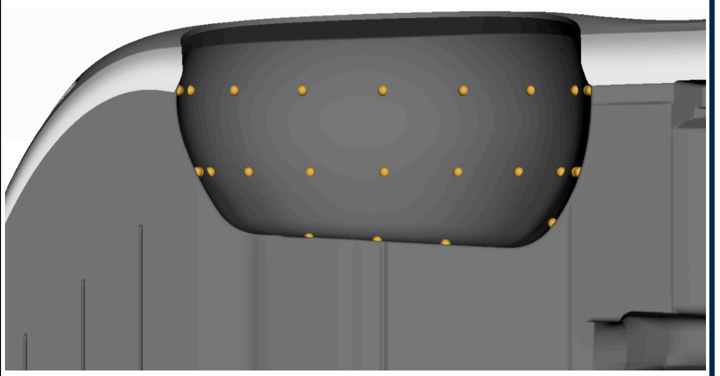


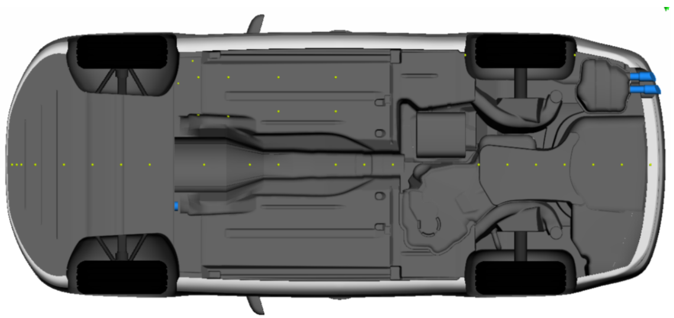


Unchanged vs. AutoCFD2

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	

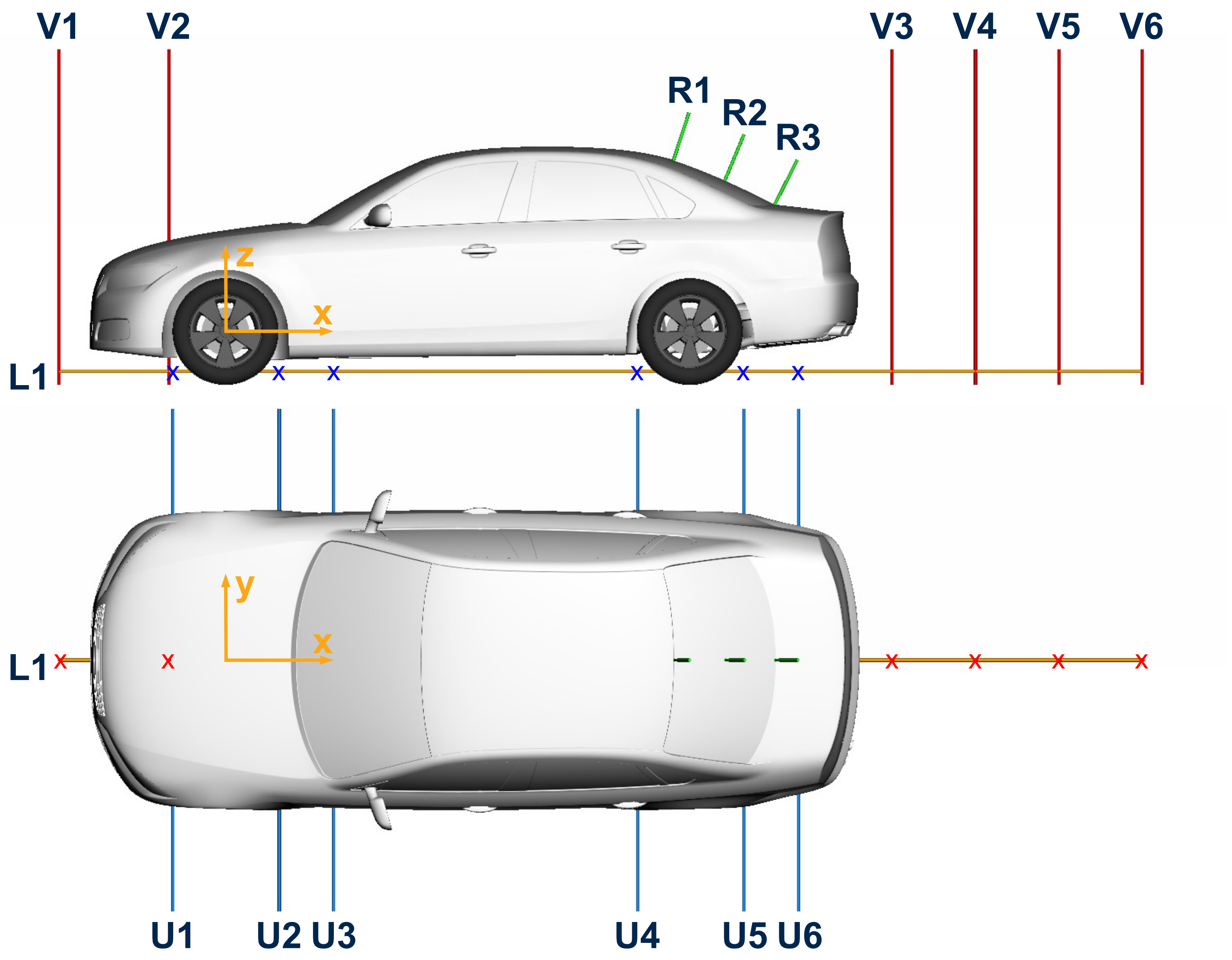
	ANSA PID	# of Probes	Probe # (CAE)	X [mm]	Y [mm]	Z [mm]	Picture
Detailed Underbody Open Cooling (Ford)	625 - PROBES - Ford OCDA Detailed Underbody	34	600	-762,5	0	-111,2	
			601	-729,72	0	-115	
			602	-697	0	-118,78	
			603	-600	0	-130	
			604	-400	0	-153,125	
			605	-200	0	-165,55	
			606	0	0	-170,725	
			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	

Testcase 2a/b: Velocity Profiles

Normalized velocity magnitude V/V_∞@ following locations:

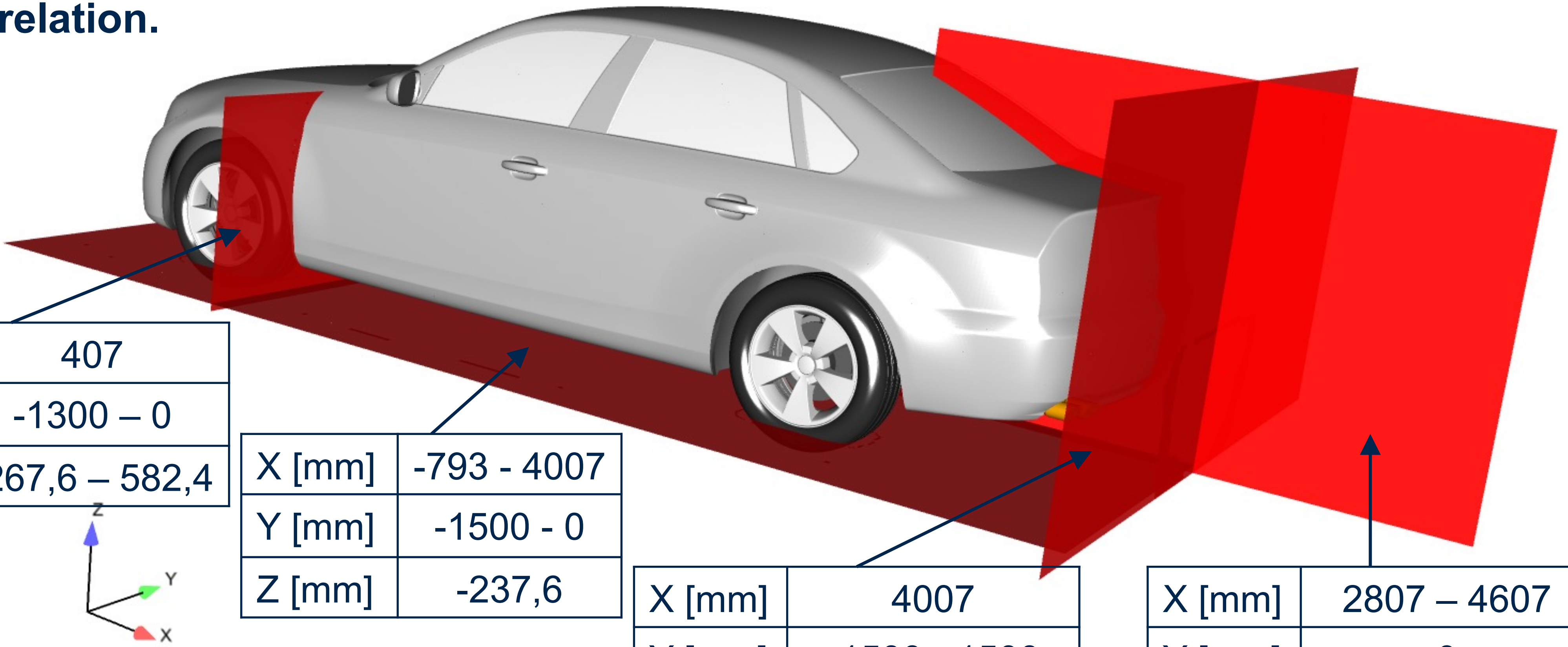
Profile	Start Point	End Point
V1*	(-993; 0; -317.6)	(-993; 0; 1682.4)
V2*	(-333; 0; -317.6)	(-333; 0; 1682.4)
V3**	(4007; 0; -317.6)	(4007; 0; 1682.4)
V4*	(4657; 0; -317.6)	(4657; 0; 1682.4)
V5	(5007; 0; -317.6)	(5007; 0; 1682.4)
V6	(5507; 0; -317.6)	(5507; 0; 1682.4)
U1*	(-343; -1500; -237.6)	(-343; 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 (Tastcase 2a only).**
- **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

AutoCFD3 – Testcase 2a/b: Value Proposition

- How does the AutoCFD(3) workshop add value?
  - Establishing standard testcases for Automotive Aero CFD method development supported with high quality test data
  - Focused effort supported by CFD experts from OEMs, Research, Software Developers & Engineering Service Providers
  - Cross-plotting of CFD results from all participants and comparison to a comprehensive set of test data enables insights which typically cannot be assessed by individual participants/organizations.
- To further expand the value of the workshop the organizing committee:
  - added an additional testcase (2b) as an enabler for assessments of A-to-B prediction capabilities of CFD methodologies
  - encourage participants to conduct numerical studies beyond just a Best Practice based testcase 2a/b analysis. The intent is to evaluate the prediction sensitivities to CFD setup changes related to turbulence modeling, meshing and simulation acceleration (s. next slides).

AutoCFD3 – Testcase 2a/b: Study Themes

1. Turbulence Modeling: Result variability of Scale-Resolving Hybrid Turb-Mods

Background:

- » Transient simulations based on these Tu-Mod’s are commonly used by OEMs
- » Previous AutoCFD workshops identified a strong variability of these Tu-Mods

Proposal:

- » Investigate “new” Scale-Resolving Hybrid Turbulence models
- » Investigate impact of details of Tu-Mod implementation in different CFD codes

2. Simulation acceleration

Background:

- » Transient simulations are commonly used by OEMs
- » Transient simulations are still too time consuming and must be accelerated

Proposal:

- » Investigate measure (e.g. CFL #, inner iterations opt., …) to accelerate “classical” simulation approaches
- » Investigate impact of run initialization process on result quality and run-time
- » Study “new” CFD methods/tools (e.g. GPU based codes, AI) focused on simulation acceleration

AutoCFD3 – Testcase 2a/b: Study Themes

3. Mesh sensitivity

Background:

- » AutoCFD2&3 meshes have been carefully designed to minimize the result mesh dependency
- » Understanding mesh sensitivity of CFD results and identifying opportunities to optimize the computational mesh setup is mandatory to balance CFD simulation quality vs. run-time

Proposal:

- » Investigate different meshing strategies incl. adaptive mesh refinement and quantify impact on results

4. Computational “noise factors”

Background:

- » The expectations regarding the predictive capability of CFD in aerodynamics in constantly increasing
- » Several computational noise factors (e.g. model partitioning, hardware dependency, CFD model “organization”, …) causing a variability of the CFD results

Proposal:

- » Investigate computational noise factors, identify root causes and quantify impact on results

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 AutoCFD2, will be used for AutoCFD3. 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 (AutoCFD3_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 (AutoCFD3_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)

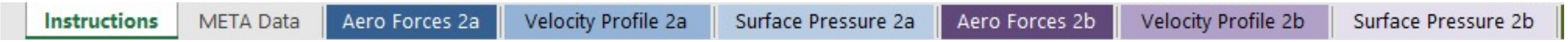
- All participants of the workshop are requested to use a provide Excel template to report their simulation results:
  - Aerodynamic forces
  - Surface pressure
  - Velocity profile (limited ability to compare with test data)
  - Flowfield results (EnSight compatible: EnSight Gold, Tecplot binary .plt,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

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

Post-Processing – Overview (1/2)

Structure of the Excel template:

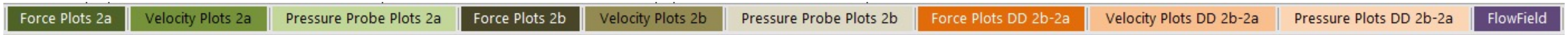
- **Information / Input section:**
  - **Instructions:** Instructions how to work with the Spreadsheet
  - **META Data:** Input Description of simulation method
  - **Aero Forces 2a:** Input Calculated Aerodynamic Forces, Force Development & Time history for testcase 2a
  - **Velocity Profile 2a:** Input Calculated velocity profile data for testcase 2a
  - **Pressure Profile 2a:** Input Calculated surface pressure 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
  - **Pressure Profile 2b:** Input Calculated surface pressure 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 2b
  - **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
  - **Force Plots DD 2b-2a:** Test to CAE comparison of aerodynamic force difference between testcase 2b and 2a
  - **Velocity Plots DD 2b-2a:** Test to CAE comparison of velocity profile difference between testcase 2b and 2a
  - **Pressure Plots DD 2b-2a:** Test to CAE comparison of surface pressure difference between testcase 2b and 2a



Post-Processing – Instructions (1/5)

Instructions how to fill out the Excel template:

- **Sheet: META DATA**
  - The sheet collects the META for testcase 2a & b
  - A "Copy META data" macro enables participants to copy META data from testcase 2a to testcase 2b
  - All marked field need to be filled out
  - In most case pull-down menus can be used to provide input
  - Cell E13 (Plot Legend) will be automatically defined based on the user input
  - Some fields (e.g. E27-43) 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

Required Input:

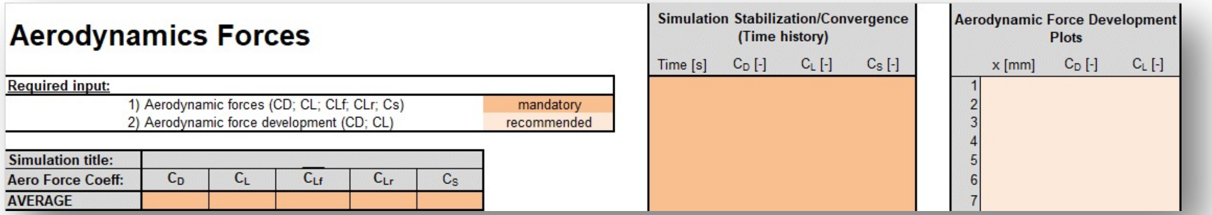
DrivAer Test Case:		2a (w/o Front Wheel Deflector)	2b (w/ Front Wheel Deflector)
Analyst:			
Lastname:			
Firstname:			
Affiliation:			
Email:			
Date:			
Legend Suffix:		Try 2a	Try 2b
Plot Legend:		___Try 2a	___Try 2b
CFD Software:			
Software Vendor			
CFD Solver			
if "CFD Solver: Other" - CFD Solver:			
CFD Solver Version			
Volume Mesh:			
Selected Mesh			
Virtual WT length X_{WT}[illegible] [m]:			
Virtual WT length X_{WT}[illegible] [m]:			
Virtual WT Width Y_{WT} [m]:			
Virtual WT Height Z_{WT} [m]:			
if "LBM" please provide the following information:			
Volume Mesher:			
Minimum Voxel Size [mm]:			
# of Voxels [mio voxels]:			
Virtual Windtunnel size $X_{WT}/Y_{WT}/Z_{WT}$ [m]:			
Virtual WT length X_{WT}[illegible] [m]:			
Virtual WT length X_{WT}[illegible] [m]:			
if "Other" please provide the following information:			
Volume Mesher:			
Mesh type:			
Boundary Layer Resolution:			
1st layer cell height [mm]:			
Boundary Layer growth rate:			
# of volume cells [mio cells]:			
Virtual Windtunnel size $X_{WT}/Y_{WT}/Z_{WT}$ [m]:			
Virtual WT length X_{WT}[illegible] [m]:			
Virtual WT length X_{WT}[illegible] [m]:			
Solver:			
Solver Type:			
Compressibility:			
Pressure/ Density Based:			
Solver:			
Segregate/Coupled:			
Velocity convection scheme:			
Order of accuracy (space/time):			
Steady-State/Transient:			
Hardware:			
# of CPUs used:			
Simulation time [CPUh]:			
Simulation time per iteration [s]:			
if "Transient" please provide the following information:			
Time step Δt [s]:			
Simulated physical time [s]:			
Time averaging periode [s]:			
if "Steady-State" please provide the following information:			
# of iterations:			
Avg. window [# of iterations]:			
Turbulence Model			
Turbulence model Type:			
Turbulence Model:			
if "Turb. model: Other" - Turb. Model:			
Near Wall Treatment:			
Comments (Optional):			

Post-Processing – Instructions (2/5)

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_{Lf} ,C_{Lr} & 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 (3/5)

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 (4/5)

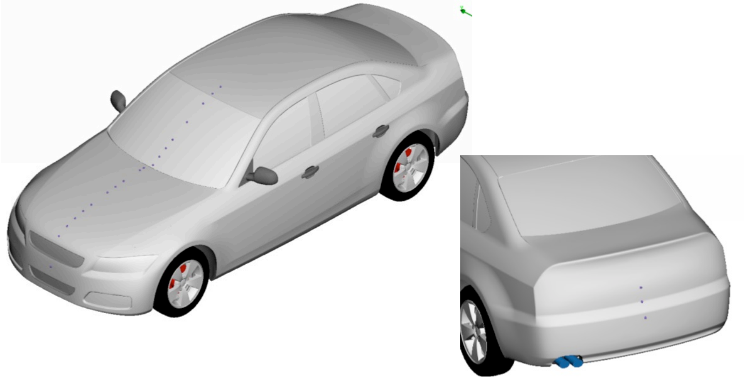
Instructions how to fill out the Excel template:

- **Sheet 3: Surface Pressure**
  - Simulation title (F8) will be filled out automatically based on input in "META DATA"
  - Columns 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
    - It is recommended to provide the Cp values with 3 decimal places

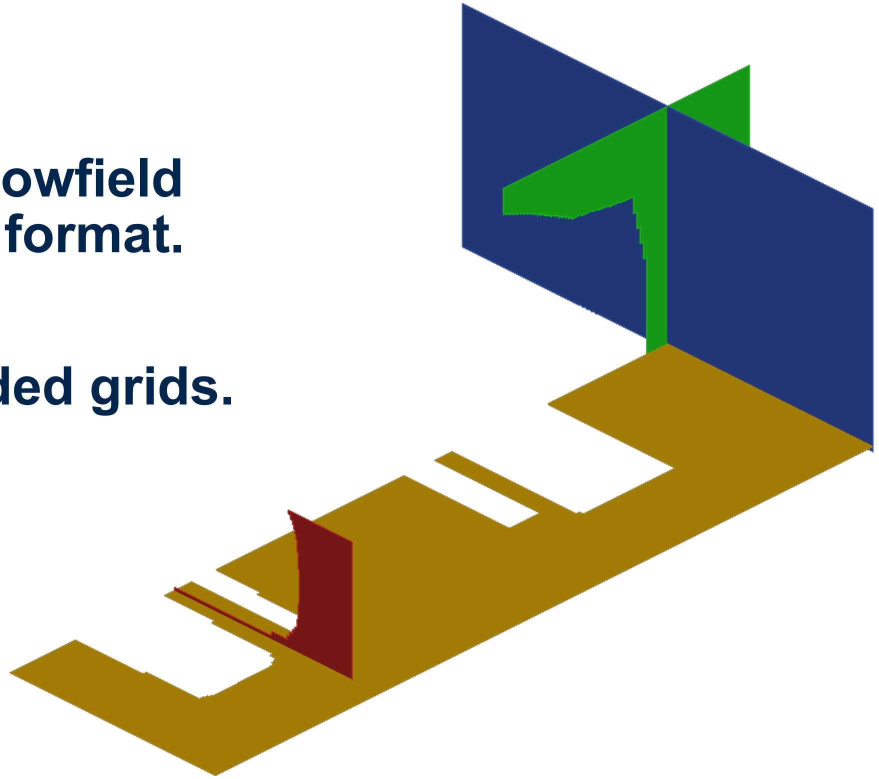
Surface Pressure

Required input:
1) Static pressure coefficient Cp at all pressure probe locations — mandatory

	ANSA PID	# of Probes	Probe #	X [mm]	Y [mm]	Z [mm]	Cp [-]	Picture
		Simulation title:		___				
Upperbody Centerline (TUM)	600 - PROBES - TUM Main body centerline	23	1	-798,25	0	150	0,966	
			2	-700	0	406,35	-0,535	
			3	-600	0	462,63	-0,457	
			4	-500	0	499,45	-0,359	
			5	-400	0	527,7	-0,304	
			6	-300	0	550,85	-0,217	
			7	-100	0	587,73	-0,132	
			8	0	0	603,05	-0,060	
			9	100	0	616,9	-0,010	
			10	300	0	640,83	0,177	
			11	350	0	645,93	0,251	
			12	413,1	0	625	0,346	
			13	464,13	0	625	0,311	
			14	543,18	0	675	0,517	
			15	624,25	0	725	0,381	
			16	707,88	0	775	0,225	
			17	885,33	0	875	-0,047	
			18	1084,9	0	975	-0,367	
			19	1199	0	1025	-0,921	
			20	1300	0	1051,5	-0,707	
			21	3752,7	0	450	-0,063	
			22	3757,9	0	350	-0,054	
			23	3804,1	0	250	-0,056	



Post-Processing – Instructions (5/5)



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.

BACKUP

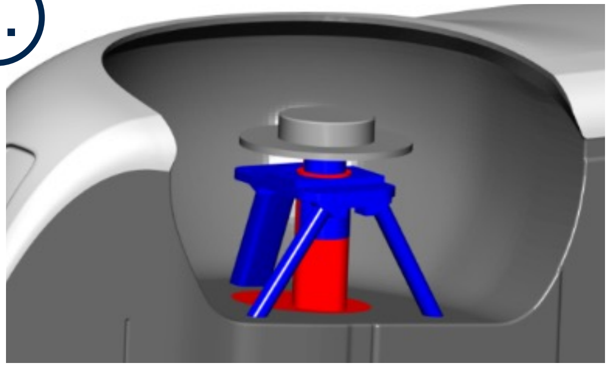
Clarification: Open Cooling DrivAer vs. „Original“ DrivAer

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

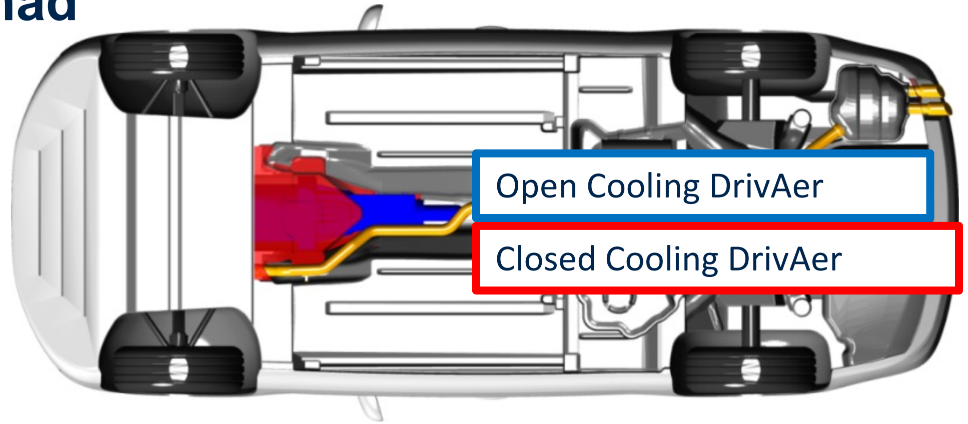
Open Cooling DrivAer = DrivAer introduced by Hupertz et al [2]

- **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.

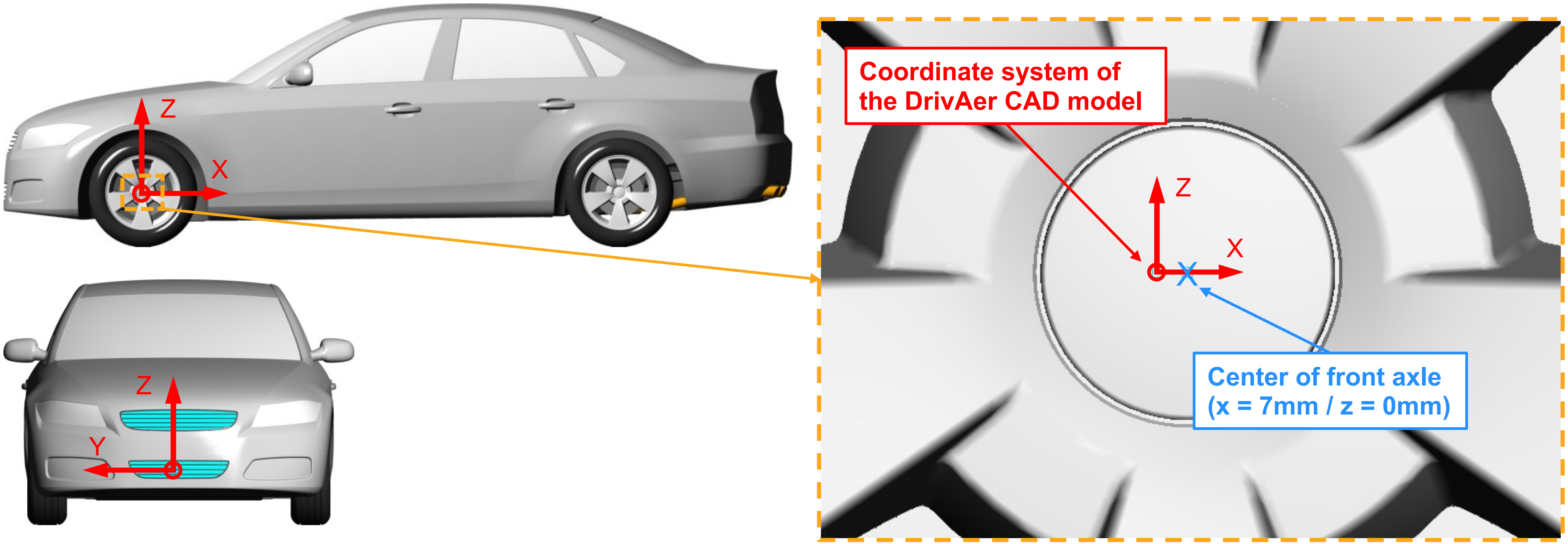
[2] Hupertz, B., Krüger, L., Chalupa, K. et al., "Introduction of a new Open Cooling Version of the DrivAer Generic Car Model" 11th FKFS Conference "Progress in Vehicle Aerodynamics and Thermal Management", Stuttgart, 2017.

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

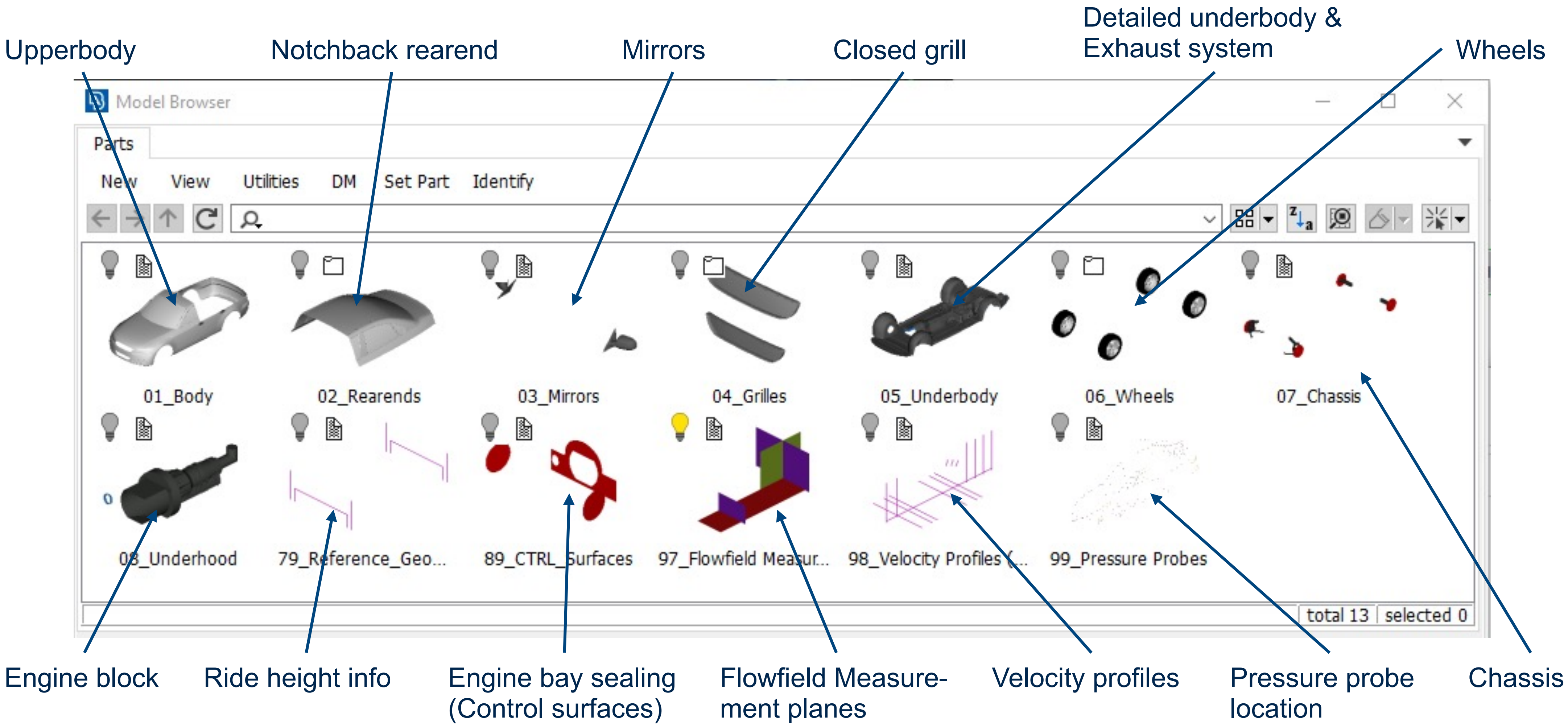


OC DrivAer – ANSA Model

- **A CAD model (ANSA) of the Ford DrivAer is available via the ECARA web-site: https://www.ecara.org/drivaer**
- **The 1:1 Ford DrivAer wind tunnel model is fully representative of the CAD model.**
  The ANSA model includes:
  - **3 bodystyles**
  - **Open & closed cooling**
  - **Ride height**
  - **Pressure probes**
  - **Measurement planes & profiles**
- **A CAD model of the AutoCFD2 version of the DrivAer is available via: https://autocfd.eng.ox.ac.uk/**

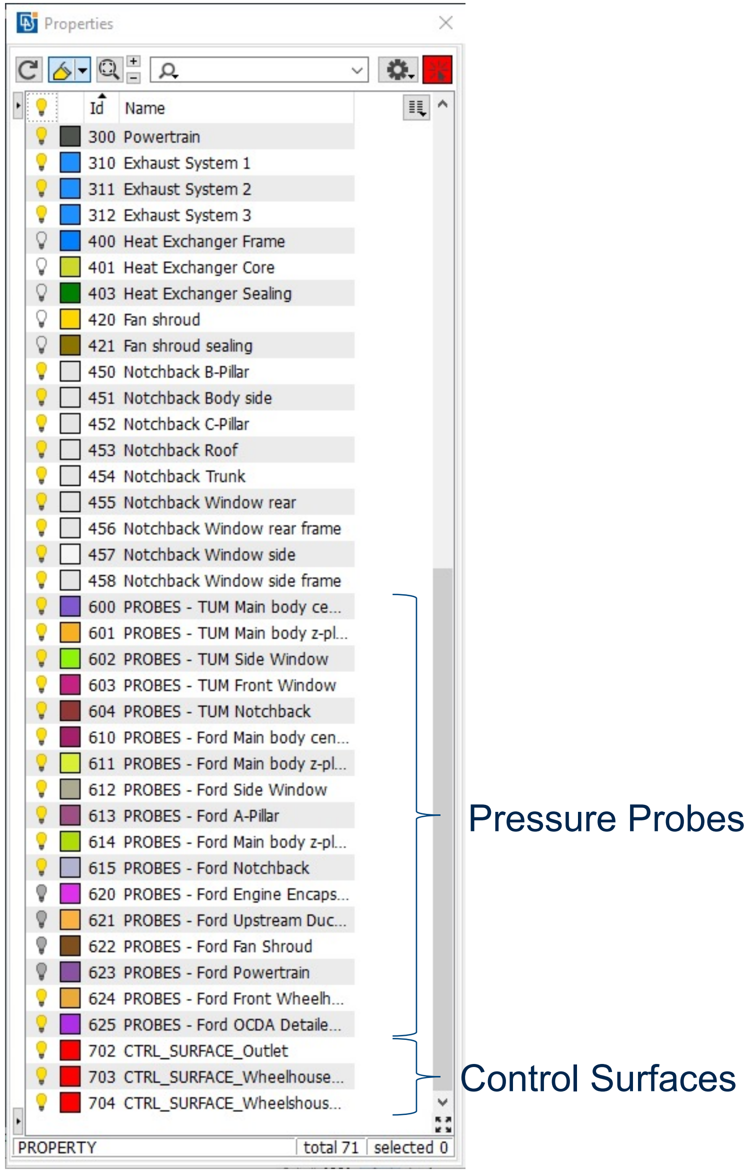
ANSA Model Structure – Part Manager

- **DrivAer model structure in ANSA Part Manager**



ANSA Model Structure – Property Manager

- **DrivAer model structure in ANSA Property Manager**
- **For improved model management the DrivAer models are broken down in several PIDs**
- **Transparent naming of PIDs enables selection of all parts which belong to a specific DrivAer variant**
- **Separate PIDs are create for the pressure probes:**
  - **Pressure probe PIDs distinguish between probes defined by TUM and additional probes added by Ford.**
- **Separate PIDs for (Control) Surfaces used to close the engine bay (in addition to grill blankings)**
  - **For the AUTOCFD2 test case Control Surfaces are turned into actual DrivAer model surfaces as the engine bay has been excluded in the AUTOCFD2 testcase.**



Pressure Probe Representation

Locations of 209 pressure probes are marked in the ANSA model using ANSA POINTS (s. slide 11/12).

A list of all pressure probes including their x,y,z coordinate is available via the ANSA Database Manager:

- **Press F12 to open the Database Manager**
- **Select POINTS**
- **Right click on POINTS and chose „Open“**
- **A window will open which lists all the points included in the ANSA model**
  (x/y/z coordinates can be displayed via the „Hide/Show column“ filter

For better visualization spheres have been created around each POINTs. The spheres are grouped into different PIDs (s. previous page)