

# STEEL WHEELS VS **ALCOA® ALUMINUM WHEELS\***

\*For wheel details see section 4.2.

## SUMMARY:

**Fuel Savings:** 0.29l /100km (1.29 %)

Constant Speed test runs (CST) with a heavy-duty semi-trailer combination, based on Annex VIII of Commission Regulation (EU) 2017/2400 and additional fuel consumption test results.

*Applicant* : Howmet Aerospace Inc., Cleveland, OH, US  
*Purpose* : Track Measurement of Steel wheel vs Aluminum wheel Performance  
*Test Vehicle* : FORD F-Max 500 / Schmitz Cargobull S3B / Payload  
*VIN* : NMOKCXT6KMP95004 / WSM00000005238560

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## Technical Measurement Report

Execution of Constant Speed test runs (CST) with a heavy-duty semi-trailer combination, based on Annex VIII of Commission Regulation (EU) 2017/2400 and additional fuel consumption tests, in order to evaluate the impact on air drag resistance and fuel consumption between aluminum and steel rims.

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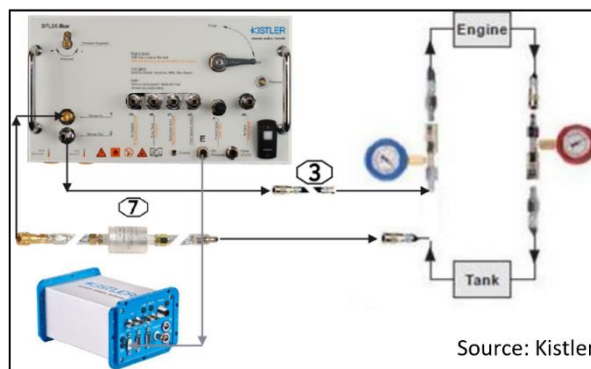
**1. Methodology for testing**

**1.1. Core values and measurements**

1.1.1. Diesel engine fuel consumption : Result in unit [l/100 km]

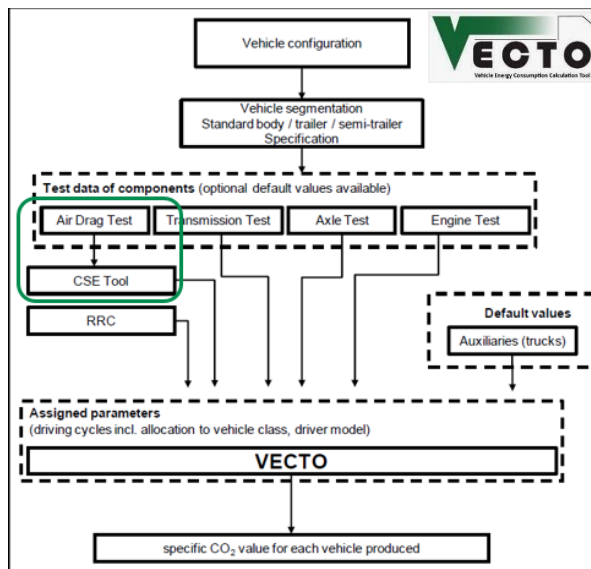
Kistler fuel flow meter DFL3x-5bar implemented into diesel engine fuel circuit. It contains 2 temperature sensors, a heat exchanger and is installed in between feed line to the engine and return line to the tank. Diesel flow rate measured in [l/h].

The fuel consumption run was implemented into the CST warm up and misalignment phase. Common 2x 45min were extended to 1x45min, change of driving direction and 1x 90min fuel consumption stint.

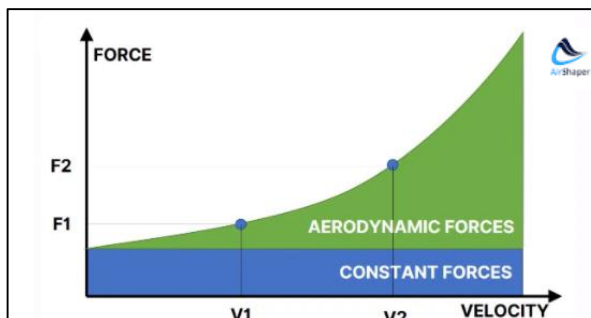


1.1.2. Aerodynamic resistance coefficient  $cd \cdot A$  : Result in unit [m<sup>2</sup>]

Equals the product of air drag coefficient  $cd$  and frontal surface area  $A$  of the vehicle. It's calculated in VECTO Airdrag, which is a sub tool of the European VECTO tool, according to Annex VIII of Commission Regulation (EU) 2017/2400, to calculate CO<sub>2</sub> emissions and energy consumption.



Two forces  $F_1$  and  $F_2$  to be measured during Constant Speed Test (CST), operating at low speed ( $v_1=15\text{km/h}$ ) and high speed ( $v_2=90\text{km/h}$ ).



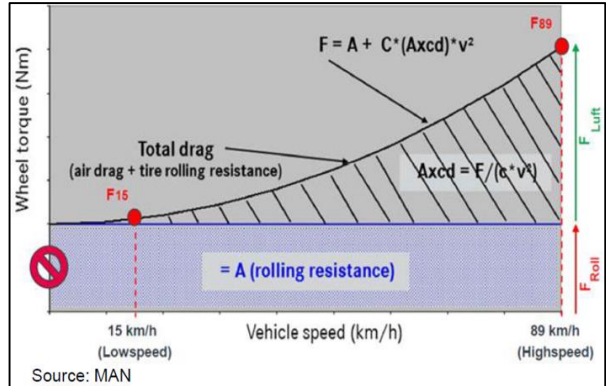
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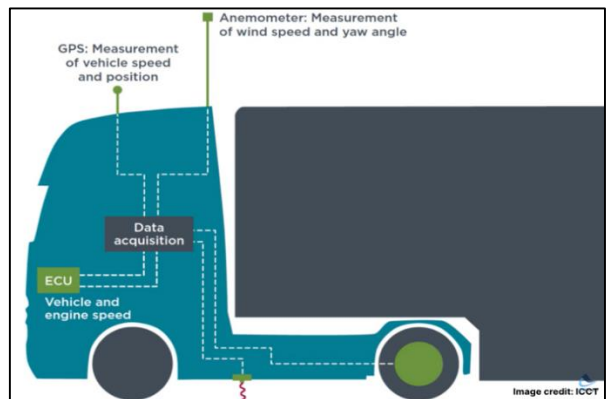
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Rolling resistance are constant forces. Air drag force follows a square interpolation over vehicle velocity. Evaluation of the 2 points of interest within the measurement.



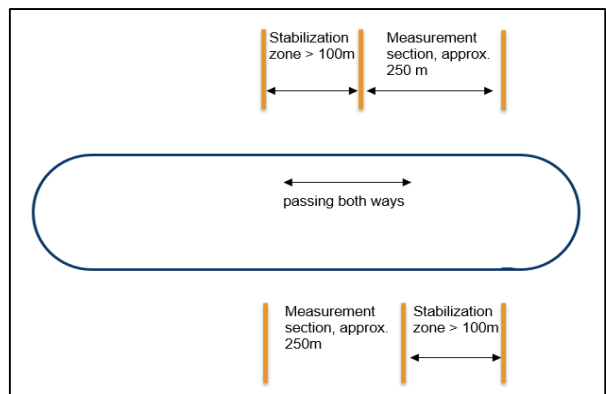
**Recorded parameters:**

- DGPS: speed and position
- Anemometer: wind speed, yaw angle
- ECU: vehicle speed, engine speed, numerous CAN parameters for vehicle/engine operating modes
- Drive axle torque wheels
- Infrared ground temperature sensor
- Temperature sensor at anemometer
- Test track weather station



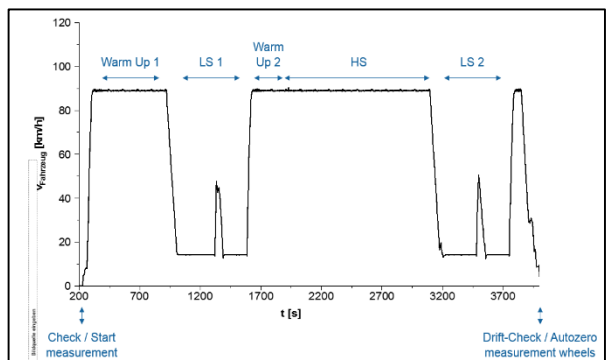
**Test track criteria's:**

Passing in both driving directions required. At least 2x 250m recording sections with 100m stabilization zone each. At DEKRA Test Track facilities all EU Annex given test track requirements are fulfilled.



**Driving cycle specifications:**

- 90min Warm Up (45min each direction, 89km/h)
- Auto Zero: Lift drive wheels off the ground.
- Standstill time < 10 min
- Warm Up 1: 10 – 20 min
- LS1: Drive through all measurement section at low speed (one direction). Maximum of 20min
- Warm Up 2: minimum of 5min
- HS: 10 valid passing's per heading at high speed
- LS2: directly after HS
- Drift-Check / Autozero



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Vehicle conditioning:

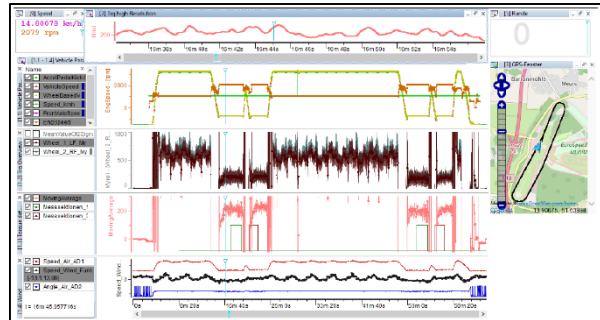
- Installation of measurement equipment, review all calibration protocols
- Vehicle preparation (tire pressure etc.)
- Determine Vehicle Data (Vehicle Height, Anemometer Height, Vehicle Mass)
- Fill in Checklist Vehicle Preparation
- Verifying all requirements according to Annex
- Checking for measurement data
- Fill in Vehicle Data of Air Drag Input Tool

Checkliste Vehicle Preparation		A	B	C
extensive modification small modification (Variant) "cleaning windcreens"	Vehicle Number / Variant	<b>Vehicle Data</b>		
	Date:			
	Auditor / Tester:	classCode	3	[-]
	FIN:	configuration with trailer	no	
	Trailer: FIN / IAV ST1	GVMMax	15000	[kg]
	Total mass:	vVehMax	90	[km/h]
	Version V 1.0.16	vehHeight	3,799	[m]
		anemometerHeight	5,116	[m]
		testMass	7405	[kg]
		gearRatio_low	9.300	[-]
		gearRatio_high	0.790	[-]
		axleRatio	3.583	[-]
		gearBox_type	AMT	
	measuring package used / wires plugged in as labeled / visible damages on / check if connection			
	PT – Mini module allocated to PT and AD modules shown			
	Set 1 only if something was changed			
	PT Modul: 15342-PTMM / Sensor BP 15 10 A 278 ; TM-P100-44-3.0 100-4000STB 3711431			
	AD Modul 15917-ADMM			
	Set 2 only if something was changed			
	PT Modul: 15952-PTMM / Sensor BP 15 10 A 277 ; TM-P100-44-3.0 100-4000STB			

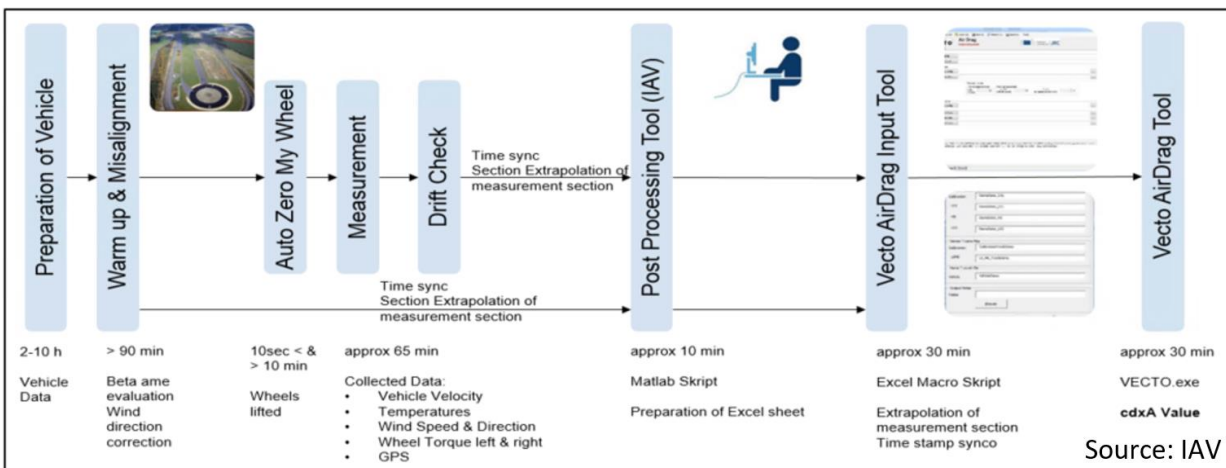
Torque wheel drift check and zeroing:  
 Driving axle to be lifted, engine off.



Data review CANape.  
 Post Processing in Matlab Script.  
 VECTO AirDrag Tool calculation.



Overview of entire CST process:



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## 2. Test vehicle specification

### 2.1. Test vehicle - Tractor

- 2.1.1. Type : CHK1
- 2.1.2. Make (trade name of manufacturer) : Ford F-Max 500 Mega Cab
- 2.1.3. Manufacturer's name and address: : Ford Otomotiv Sanayi A.Ş.  
34885 Sancaktepe / İstanbul, Turkey
- 2.1.4. Vehicle identification number : NMOKCXT6KMP95004
- 2.1.5. Registration / license plate number : Z - X 1644
- 2.1.6. Factory sign :



Ford		FORD OTOMOTIV SANAYI A.Ş.	
e9*2007/46*0089			
NMOKCXT6KMP95004			
	KG	18 000	KG
	KG	44 000	KG
1-	KG 1-	7 100	KG
2-	KG 2-	12 000	KG
3-	KG 3-		KG
4-	KG 4-		KG
	KG		KG

- 2.1.7. Vehicle photo

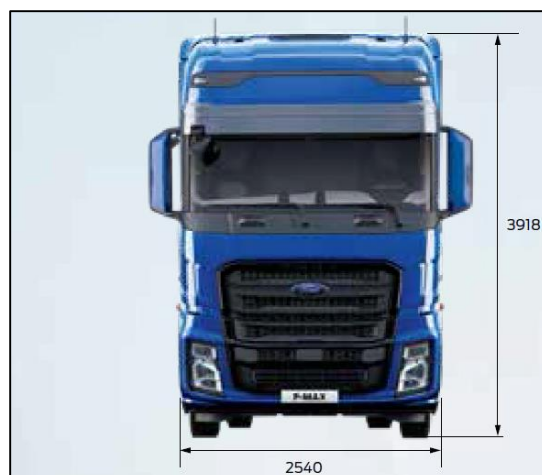
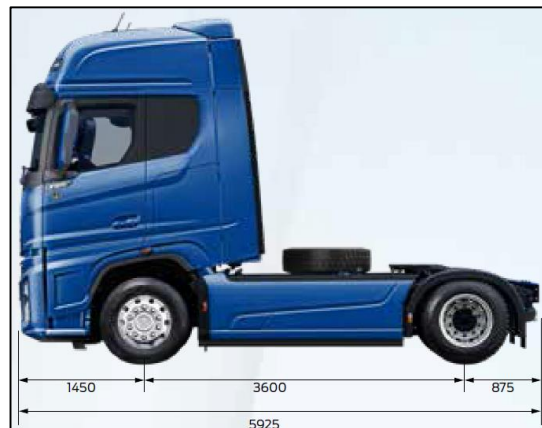


- 2.1.8. Axle : 4 x 2, RWD
- 2.1.9. Model year : 2021
- 2.1.9. Vehicle mileage : SOT 71422 km / EOT 75581 km

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- 2.1.10. Engine : Ecotorq 12.7 l, 500 hp, EU6d  
2.1.11. Transmission : ZF Traxon 12 TX 2620 TD (Automatic, 12 gears)  
Gear 2 ratio (CST-Lowspeed): 12.924  
Gear 12 ratio (CST-Highspeed): 1.0  
2.1.12. Axle Drive Ratio : 2.467  
2.1.13. Tire dimension & tire pressure : Front 315/70 R 22.5 at 130.5 PSI  
Rear 315/70 R 22.5 (dual) at 130.5 PSI  
2.1.14. Vehicle Weight [kg] : 8540 kg (ready for test, tractor only)  
GVW 18000 kg  
GVCW 44000 kg  
2.1.15. Vehicle class according (EU) 2017/2400 : 5 (4x2 tractor > 16t)  
2.1.16. Vehicle dimensions :



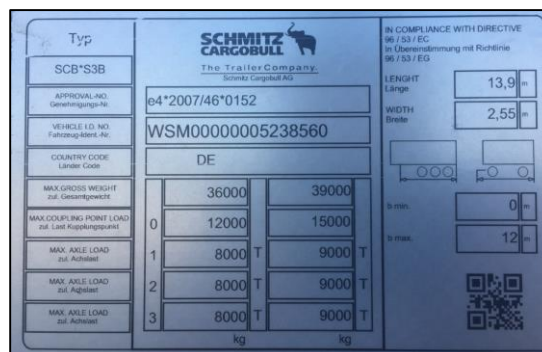


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2.1.17. Aerodynamic effecting components : Ford Mega Cab, sunscreen, cabin roof and side visors, chassis side covers, drive wheel covers, underneath engine department cover, regular side mirrors, 5<sup>th</sup> wheel height 1100mm

**2.2. Test vehicle - Trailer**

2.2.1. Type : ST1  
 2.2.2. Make (trade name of manufacturer) : SCB\*S3B  
 2.2.3. Manufacturer's name and address: : Schmitz Cargobull AG  
 48612 Horstmar, Germany  
 2.2.4. Vehicle identification number : WSM00000005238560  
 2.2.5. Registration / license plate number : B – X 3393  
 2.2.6. Factory sign :



2.2.7. Vehicle photo :

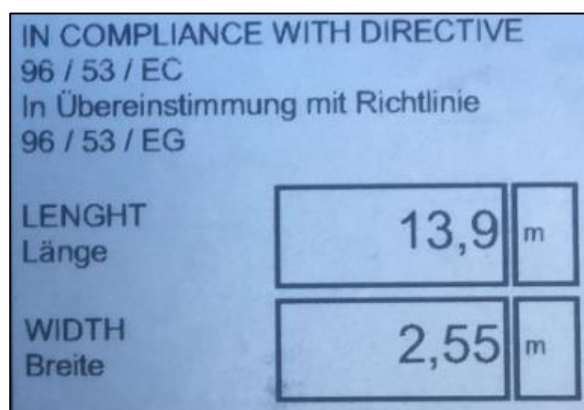


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2.2.8. Axle : 3 / first axle lifting capability blocked  
2.2.9. Model year : 2020  
2.2.10. Tire dimension & tire pressure : 385/65 R 22.5 at 130.5 [PSI]  
2.2.10. Track width : 2050 [mm]  
2.2.11. Vehicle Weight [kg] : 15915 kg (ready for test, trailer only incl. payload, steel wheel configuration)  
GVW 39000 [kg]

2.2.12. Vehicle dimensions :



2.2.13. Aerodynamic effecting components : side guards, rear guard, 2 back doors, 2 spare wheels, 1 storage case (left rear), solid side walls and roof

2.2.14. Payload documentation :



Payload located in trailer above connecting pin location and above rear trailer axles  
Payload weight: 8615 [kg]

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### 3. Test vehicle instrumentation

#### 3.1. Constant Speed Test (CST)

##### 3.1.1. Sensors

3.1.1.1. Inertial Measurement Unit : GNSS, Roll Rate, Pitch Rate, Yaw Rate  
 Racelogic VBOX IMU04 X Acceleration, Y Acceleration, Z Acceleration



3.1.1.2. Racelogic radio antenna (RTK) : (D)GPS position + RTK correction, velocity



Location of mounting : Cabin roof: RTK antenna & GNSS IMU  
 proving ground: GNSS, RTK antenna, base stat.

3.1.1.3. Temperature sensor, PT100 : Ambient temperature

Location of mounting : Above vehicle roof, at wind sensor

3.1.1.4. Temperature sensor, infrared : Ground temperature at track

Location of mounting : Below vehicle, 300 mm from ground

3.1.1.5. PDS Gill Ultrasonic Wind Sensor : Anemometer, Wind speed and direction

Location of mounting : Above trailer front, at post



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3.1.1.6. Kistler P1HT : Wheel torque measuring system  
Location of mounting : Drive axle



3.1.1.7. Vehicle data : OBD, Powertrain CAN Bus

### 3.2. Fuel consumption

3.2.1. Kistler CDS-DFL-3X / DFLX-Proc. : Diesel fuel consumption measuring system  
Location of mounting : Right front wheel housing, close to engine HPFP



### 3.3. Data acquisition and validation

3.3.1. Racelogic VBOX3i-V5 : Signal conditioning, 100 Hz data logger  
Location of mounting : inside cabin



3.3.2. Vector CANape : data acquisition software  
MathWorks Matlab : data validation software  
VECTO Air Drag : Sub tool of (EU) Vehicle Emission Calculation Tool (VECTO), calculation of  $cd \cdot A$  value

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### 3.4. Additional

- 3.4.1. Vaisala/Fin. WXTPTU : Proving ground weather station
- 3.4.2. Vaisala/Fin. WMT701 : Proving ground wind sensor
- 3.4.3. Racelogic DGNSS Base Station : Proving ground GNSS for (D)GPS on base station with RTK correction
- 3.4.4. Dini Argeo WWSE10TRF-3 : 10x 10.000 kg wireless wheel scale system with terminal



- 3.4.5. Vehicle tires : Thread depth modified for < 10 mm  
Best eco level
- Tractor : Bridgestone ECOPIA H-Steer 002 (2x) / ECOPIA H-Drive 002 (4x)
- Trailer : Goodyear Fuelmax T HL (6x)

## 4. Testing agenda and trial variants

### 4.1. General information

- 4.1.1. Testing location : High Speed Oval  
DEKRA Automobil GmbH  
Technology Center  
Lausitzallee 1  
01998 Klettwitz, Germany
- 4.1.2. Testing period : 10/04/2022 – 10/14/2022



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**4.2. Trial variants**

	Location of mounting	:	steer axle	drive axle	trailer axles
4.2.1.	<b>Steel wheel Variant</b> Steer: 22.5" x 9" OS 175 Master's Best 80122590001 steel rim with series bolt cover Drive: 22.5" x 9" dual Al torque wheels Kistler RoadDyn P1HT Trailer: 22.5" x 11.75" OS 120 Accuride KPB15133 steel rim				
4.2.2.	<b>Alcoa Aluminum wheel Variant</b> Steer: 22.5" x 9" OS 176 Alcoa Ultra One 89U510 Al rim with series bolt cover Drive: 22.5" x 9" dual Al torque wheels Kistler RoadDyn P1HT Trailer: 22.5" x 11.75" OS 120 Alcoa Ultra One LvL One 81U527 Al rim				

Tire information: Tires reused during change from steel to Al rims. Installed in the same position and moving direction at tractor and trailer.

Steer axle	Bridgestone ECOPIA H-Steer 002
Drive axle	Bridgestone ECOPIA H-Drive 002
Trailer axles	Goodyear FUELMAX T HL

**4.3. Testing Agenda**

4.3.1.	Fuel consumption run	:	1x 90 min for each variant
4.3.1.	Constant Speed Test	:	3x CST for each variant

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## 5. Trial protocols and results

### 5.1. Testing protocol at every Start of Test

1. Date of test / Vehicle mileage SOT [km] : 10/5/2022 / 71841
2. VIN : NMOKCXT6KMP95004
3. Vehicle configuration as per request : confirmed by Howmet & DEKRA engineer
4. Vehicle settings : head light on; DPF regeneration off; shifter in normal driving mode; air suspension in driving level at tractor and trailer, air conditioning off; gears: 2<sup>nd</sup> for low speed, 12<sup>th</sup> for high speed
5. Vehicle fault code / MIL status : None / off
6. Vehicle conditions : ready
7. Measurement system online : all channels are reading plausible values
8. Track conditions : dry
9. Tire pressure [psi], thread depth, cond. : 130.5, < 10 [mm], no damages
10. Vehicle weight [kg] : 24455
11. Vehicle dimensions – tractor [mm] :

Front left to ground	304
Front right to ground	299
Chassis to cabin gap front	300
Cabin rear to trailer front	538
Door front edge to ground left	1321
Door front edge to ground right	1318
Side cover to ground left	197
Side cover to ground right	193
Frame end to ground left	672
Frame end to ground right	670
12. Vehicle dimensions - trailer :

Height front left to ground:	4003
Height front right to ground:	3996
Height rear left to ground:	3927
Height rear right to ground:	3938
13. Anemometer position and orientation :

Trailer top to device:	1377	Angle: 0
[mm]		[deg]
14. Vehicle photo documentation at track : done
15. Vehicle mileage EOT [km] : 72601

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**5.2. Trial results for Steel Wheel Variant**

Date of trial : 10/4/2022  
 VIN : NMOKCXTP6KMP95004  
 Vehicle mileage SOT / EOT / Total [km] : 71422      71839      417  
 Vehicle wheel configuration:  
 Steer: 9" steel rim with series bolt cover  
 Drive: 9" dual Al torque wheels Kistler  
 Trailer: 11.75" steel rim  
 Vehicle CGVW [kg] : 24455  
 Result fuel consumption run [l/100km] : **22,35**  
 Result aerodynamic drag / cd\*A [m<sup>2</sup>] : **5,99**



Trial Steel	Date Time	cd*A [m <sup>2</sup> ]	T amb [degC]	P amb [mbar]	Rh amb [%]	V wind [m/s]
CST 1	221004_2126	5,96	9,19	1007,2	95,54	0,24
CST 2	221004_2237	6,03	8,65	1007,4	95,90	1,48
CST 3	221004_2345	5,97	8,42	1006,9	96,21	1,20
CST Mean		<b>5,99</b>	8,75	1007,2	95,88	0,97





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**5.3.1. Trial 1 results for Alcoa Aluminum wheel variant**

Date of trial : 10/7/2022  
 VIN : NMOKCXTP6KMP95004  
 Vehicle mileage SOT / EOT / Total [km] : 72606      73011      405  
 Vehicle wheel configuration:  
 Steer: 9" Alcoa Ultra One with series bolt cover  
 Drive: 9" dual Al torque wheels Kistler  
 Trailer: 11.75" Alcoa Ultra One LvL One  
 Vehicle CGVW [kg] : 24295  
 Result fuel consumption run [l/100km] : **22,07**  
 Result aerodynamic drag / cd\*A [m<sup>2</sup>] : **5,98**



Trial Alcoa #1	Date Time	cd*A [m <sup>2</sup> ]	T amb [degC]	P amb [mbar]	Rh amb [%]	V wind [m/s]
CST 1	221007_2025	5,96	8,55	1005,31	91,16	0,17
CST 2	221007_2134	5,99	8,23	1004,94	92,90	0,23
CST 3	221007_2243	6,00	8,57	1004,47	92,02	0,64
CST Mean		<b>5,98</b>	8,45	1004,91	92,02	0,35



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**5.3.2. Trial 2 results for Alcoa Aluminum wheel variant**

Date of trial : 10/12/2022  
 VIN : NMOKCXTP6KMP95004  
 Vehicle mileage SOT / EOT / Total [km] : 74174      74579      405  
 Vehicle wheel configuration:  
 Steer: 9" Alcoa Ultra One with series bolt cover  
 Drive: 9" dual Al torque wheels Kistler  
 Trailer: 11.75" Alcoa Ultra One LvL One  
 Vehicle CGVW [kg] : 24260  
 Result fuel consumption run [l/100km] : **22,05**  
 Result aerodynamic drag / cd\*A [m<sup>2</sup>] : **6,03**



Trial Alcoa #2	Date Time	cd*A [m <sup>2</sup> ]	T amb [degC]	P amb [mbar]	Rh amb [%]	V wind [m/s]
CST 1	221012_2023	6,01	7,41	1008,86	91,19	0,41
CST 2	221012_2131	6,05	6,12	1008,58	92,64	0,27
CST 3	221012_2239	6,04	5,15	1008,36	97,64	0,27
CST Mean		<b>6,03</b>	6,23	1008,60	93,83	0,32



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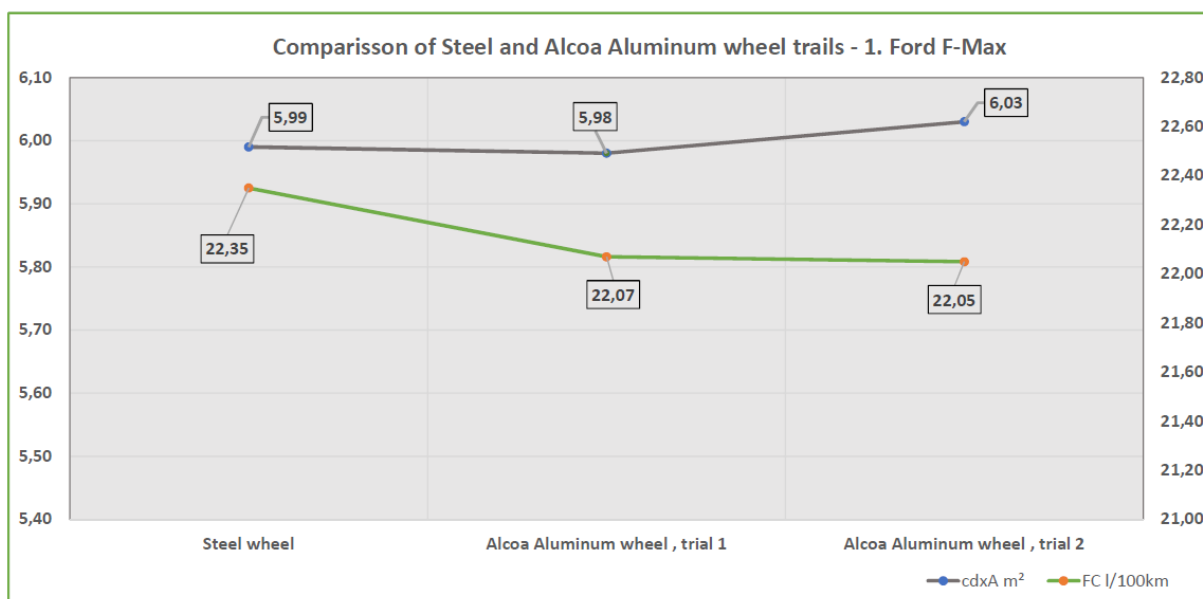
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## 6. Summary

### 6.1. General

DEKRA Automobil GmbH Klettwitz is an accredited laboratory to perform the Constant Speed Test, based on the Annex VIII of Commission Regulation (EU) 2017/2400. As an exception, based on customer request, payload was added to the trailer and a fuel consumption unit installed. Testing was not related to certification or COP purposes, but it was a mandatory target to create a fuel consumption scenario close to realistic customer conditions.

### 6.2. Results overview



The series production semi-trailer truck combination showed within the Alcoa Aluminum wheel trial, compared to the steel wheel trail, fuel savings of 0.29l/100km. As per the completed testing protocol, the fuel consumption decreased by 1.29% when replacing steel wheels with the Alcoa Aluminum wheels.