POLITECNICO DI MILANO

HEAVY TRUCK AERODYNAMICS

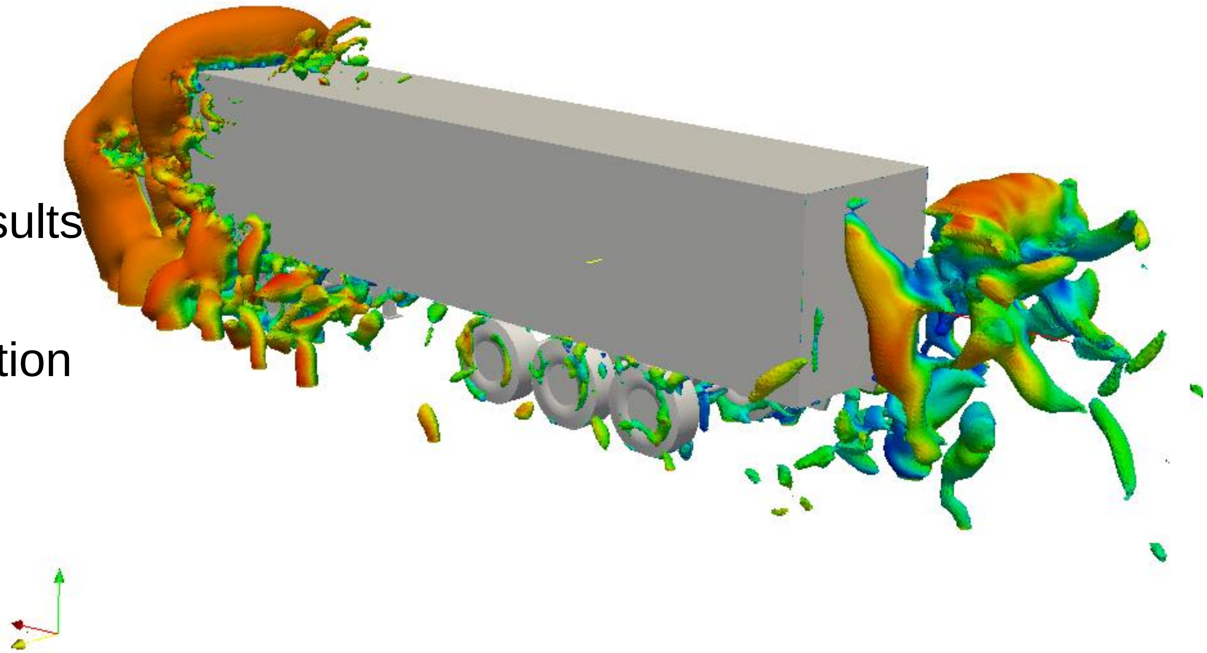
Luigi SALATI - Paolo SCHITO - Federico CHELI

paolo.schito@polimi.it

Department of Mechanical Engineering

Content

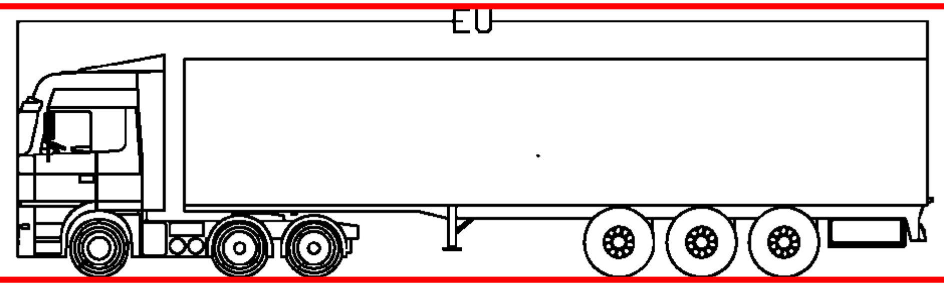
- Introduction
- Simulations Set-up
- RANS Simulation
  - Target vehicle results
  - Tested devices
  - Devices optimization
  - Crosswind
- DES Simulation
- Conclusion



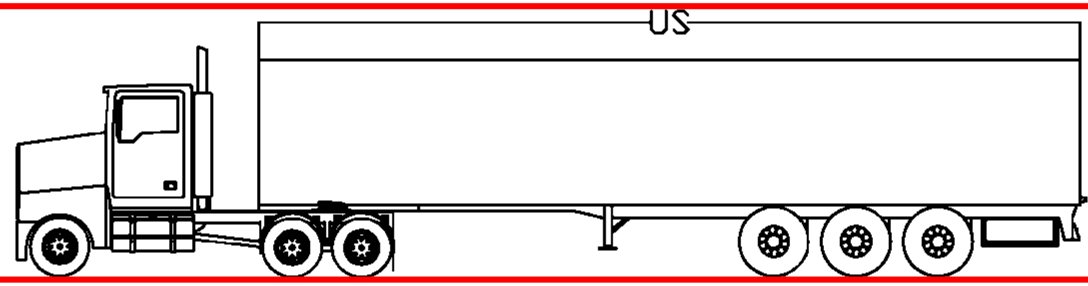
Introduction

Current regulation: Directive 96/53 EC

width < 2,55 m
height < 4,00 m
overall length < 16,50 m



width < 2,6 m
height < 4,10 m
loading length ~ 14 -18 m



European Commission – DGMOVE – Working group on Aerodynamics:.

Analyze impact on fuel consumption of :
- higher aerodynamic efficiency,
- combustion efficiency,
- energy efficiency and
- **Risks connected with the increase of the maximum permitted dimension of the vehicle.**

Fuel consumption

Fuel saving		1,00%
Fuel consumption	2,6	(Km/l)
Fuel cost	1,6	(€)
Km travelled per day	880	(Km/day)
Liter per day	338,5	(l/day)
Economical Benefit		
Liter saved per day	3,38	(l/day)
Euro saved per day	5,42	(€/day)
Working day	22	(day/month)
Saved per mounth	119	(€/month)
Saved per year	1'430	(€/truck)
Emission		
CO_2 emission per liter	2,4	(kg/l)
CO_2 emission saving	8,12	(kg/day)
CO_2 emission saving	178,71	(kg/month)
CO_2 emission saving	2144	(kg/year)

State of Art

Devices currently installed on the heavy-truck :

- cab roof fairings (drag reduction ~ 7-9%);
- side fairings (drag reduction ~ 4-6%);
- side-skirt (drag reduction ~ 4-6%)

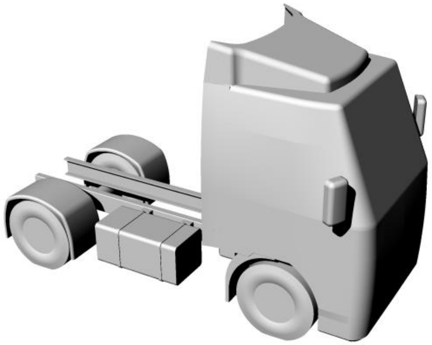
- Boat-tails (drag reduction ~ 8%)
  - Problem with the current European regulation
  - Safety issues

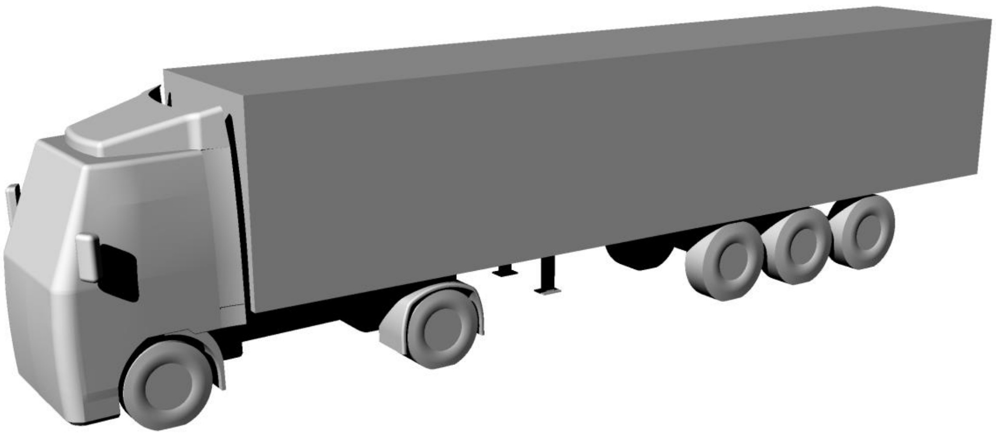
reference: http://blog.ucsusa.org/semi-tractor-trailer-truck-skirt-359

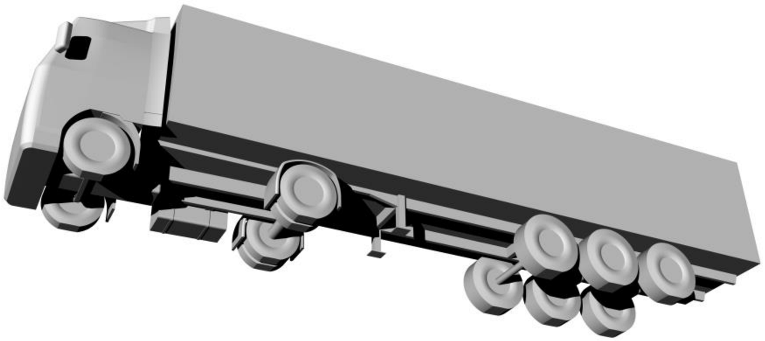
Target vehicle

Aerodynamics devices installed:

- cab roof fairings;
- side fairings;
- wheel houses for the tractor tires;
- suitable design of the front corner radius of the tractor.

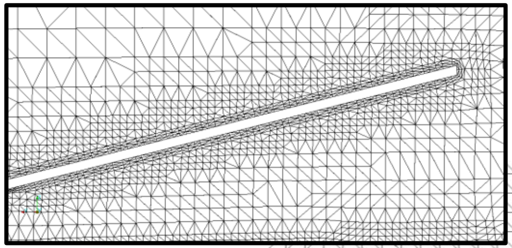


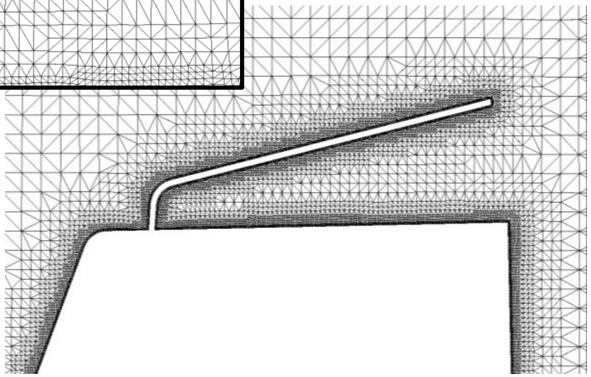




length	width	height
[m]	[m]	[m]
15,8	2,5	3,9

Simulations set-up





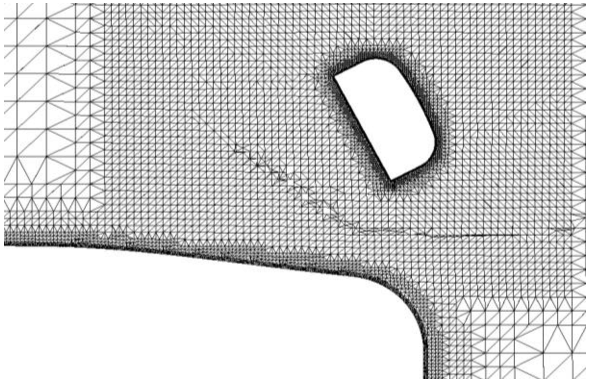
- ➢CFD Solver: OpenFOAM
- ➢Mesh: OpenFOAM - snappyHexMesh
- ➢Speed: 27,7 m/s (≈100 km/h)

➢RANS simulations:

- Turbulence model k- ω SST
- **≈10 millions cells**

➢DES simulations:

- Turbulence model S-A
- Time step=10^{-4} s
- **≈40 millions cells**



➢Approximation of the contact area wheel/ground

➢Boundary condition:

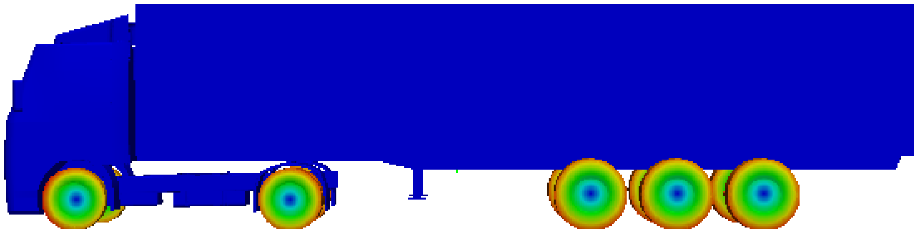
V=27.7 m/s inlet

P=0 Pa outlet

V=27.7 m/s ground

Slip wall top and lateral

Rotating wheels



Set-up

➢Computational domain:

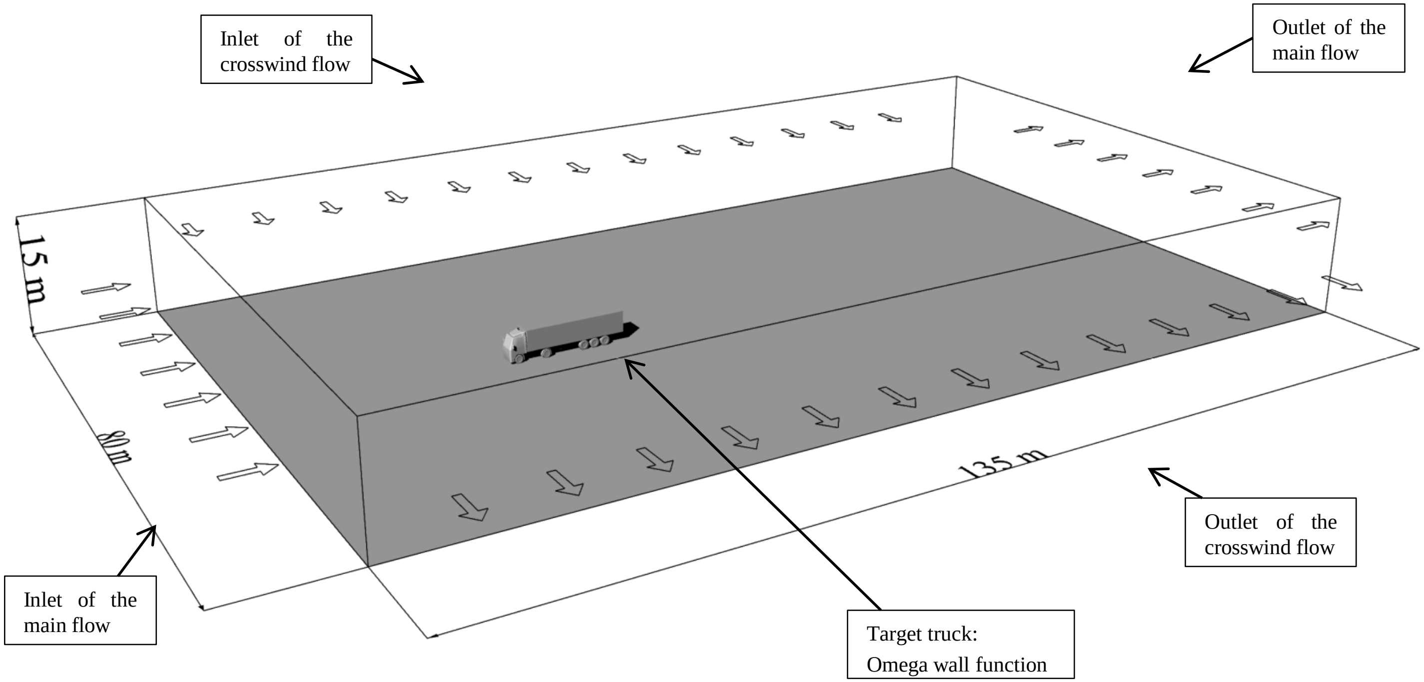
Million of elements	C_d	% C_d
10,8	0,593	
39,7	0,581	2,02
48,5	0,583	1,69

- RANS Simulations

Yaw angle 0°, 5°, 10°, 15°, 20°, 25°, 30

- DES Simulations

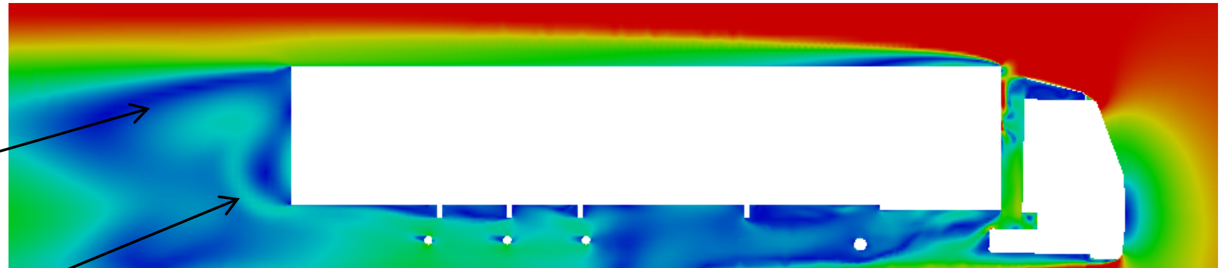
Yaw angle 0°, 5°, 10°



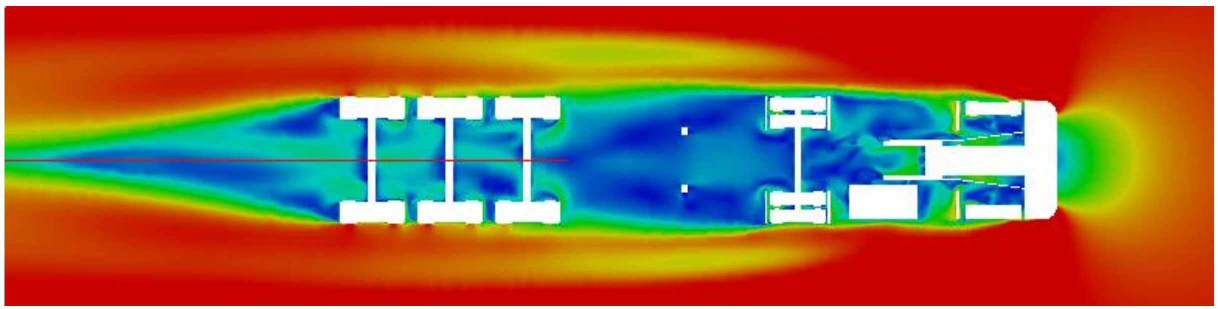
Target vehicle

Top – rear vortex

Bottom – rear vortex



Normalized magnitude velocity contour plot at y=0



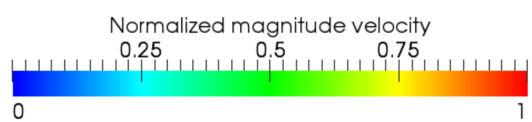
C_d
0,593

Normalized magnitude velocity contour plot at z=0.63

Side vortex

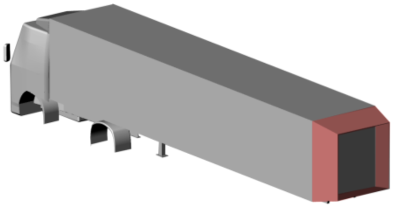
Side vortex

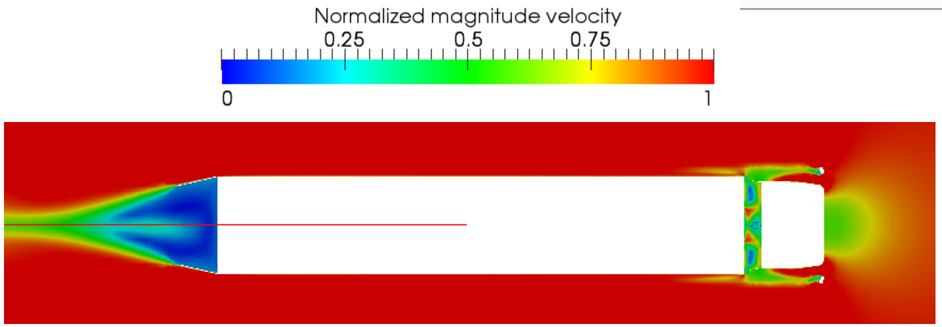
Normalized magnitude velocity contour plot at z=2.6



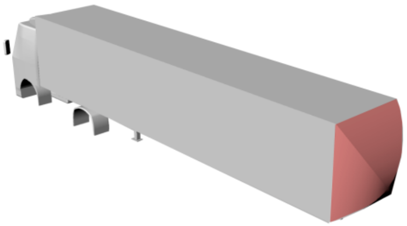
Tested devices

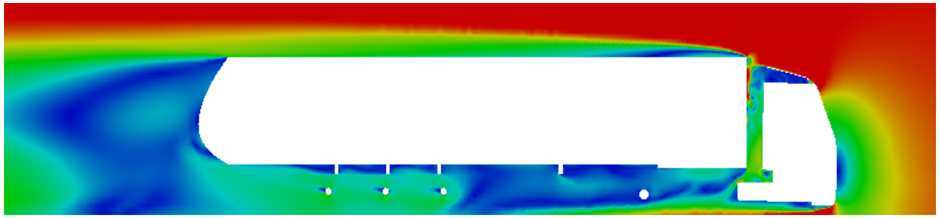
- Boat-tails (drag reduction ~ 8 %)



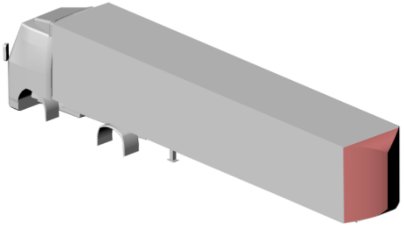


- Airbags (drag reduction ~ 4 %);

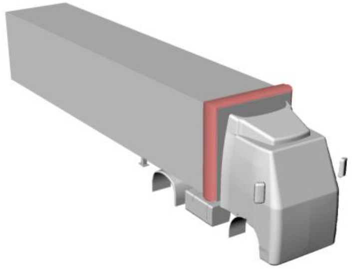


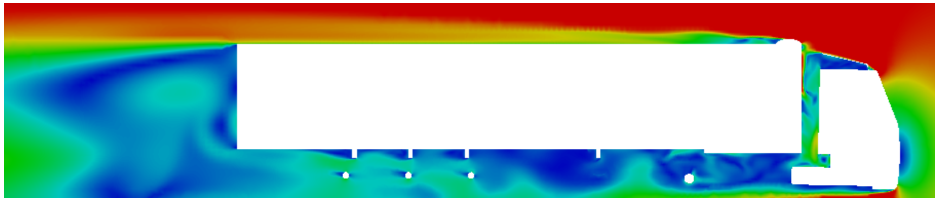


- Fins (drag reduction ~ 8 %);



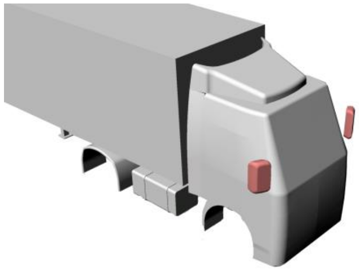
- Trailer devices (drag reduction ~ 7 %);

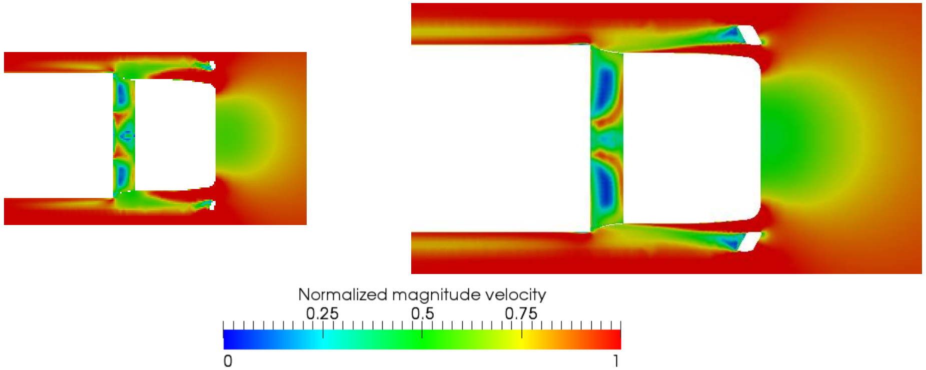




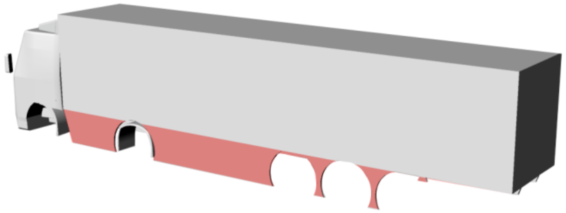
Tested devices

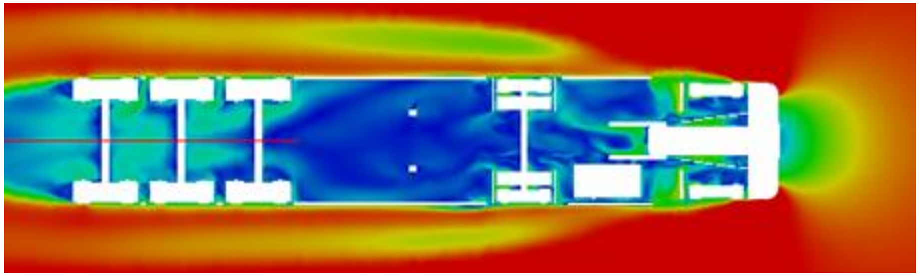
- Side mirrors design (drag reduction ~ 3 %);



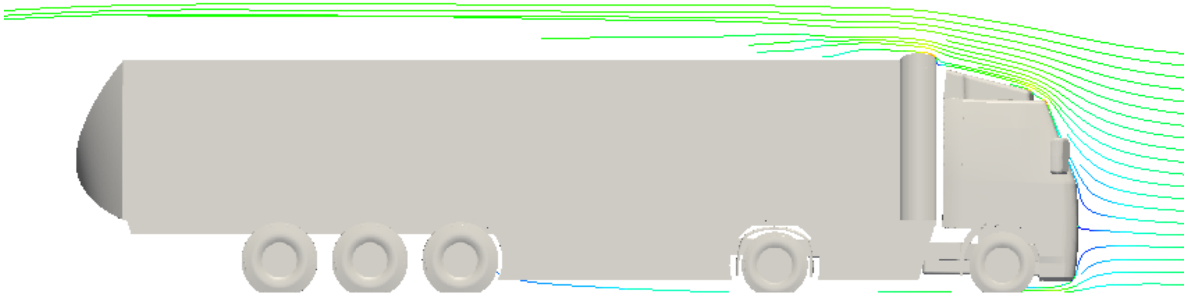


- Side skirt (drag reduction ~ 4 %);

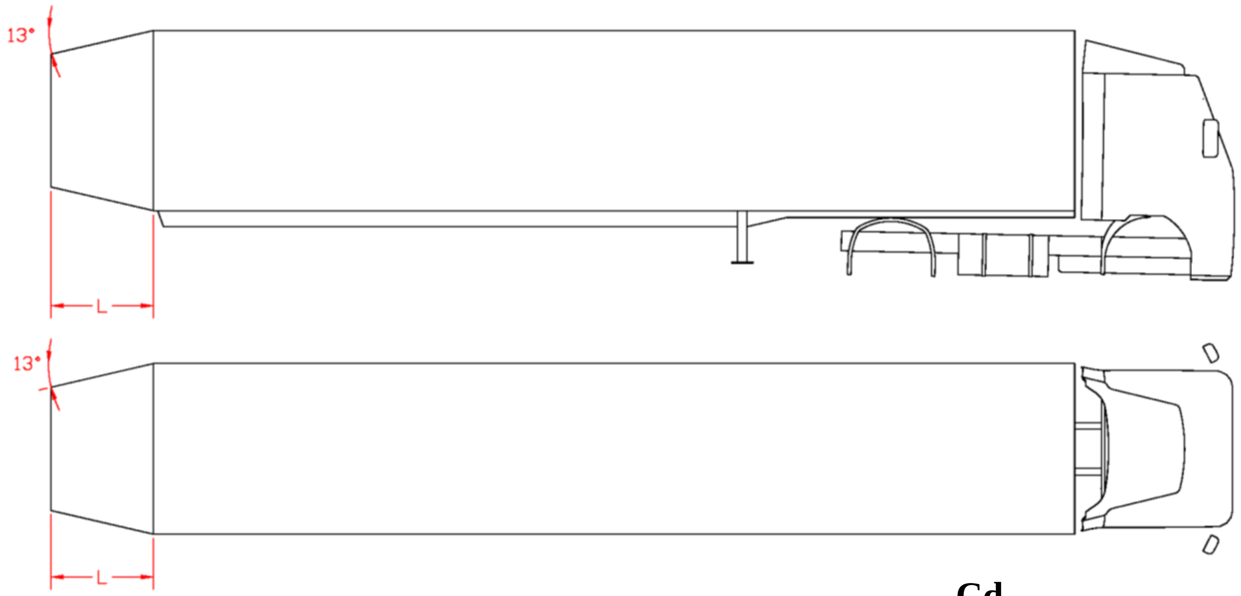




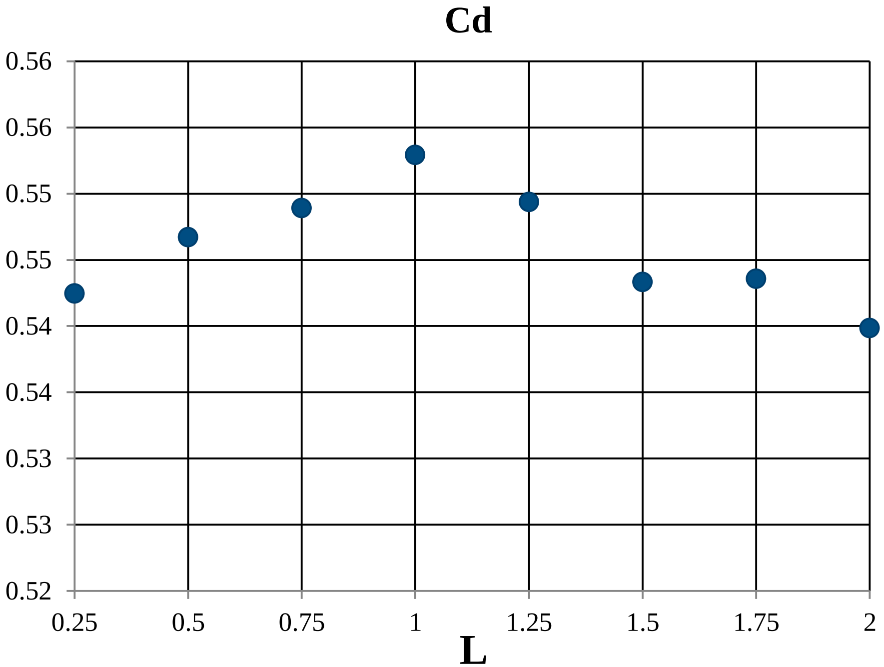
A proper mix of the previous devices installed on the heavy truck decrease the overall drag about 15%.



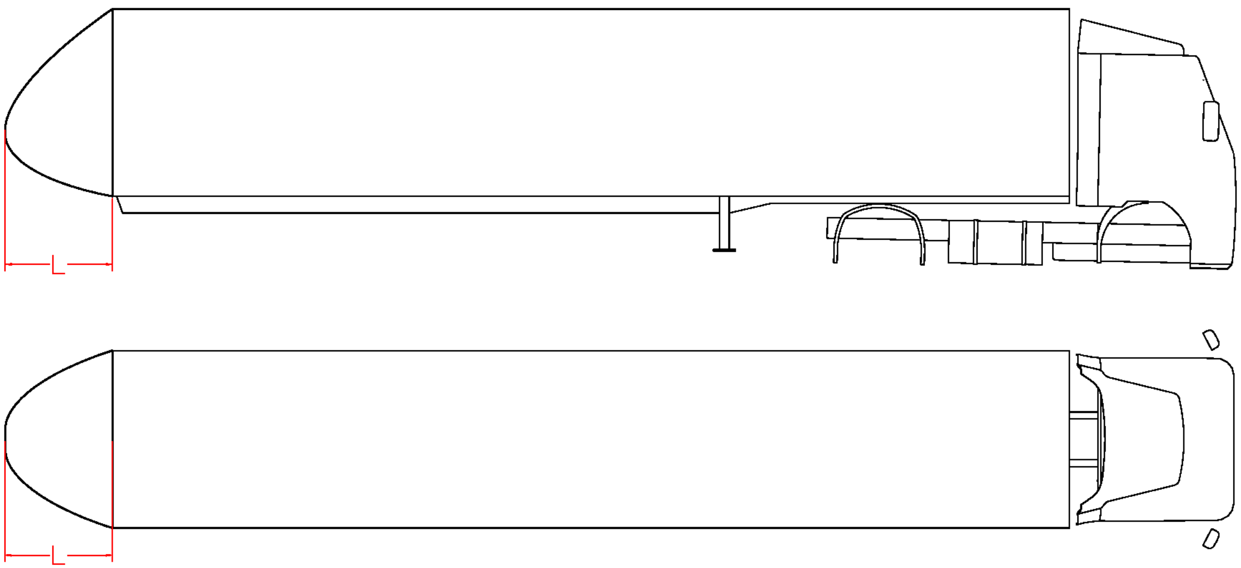
Boat-tails design optimization



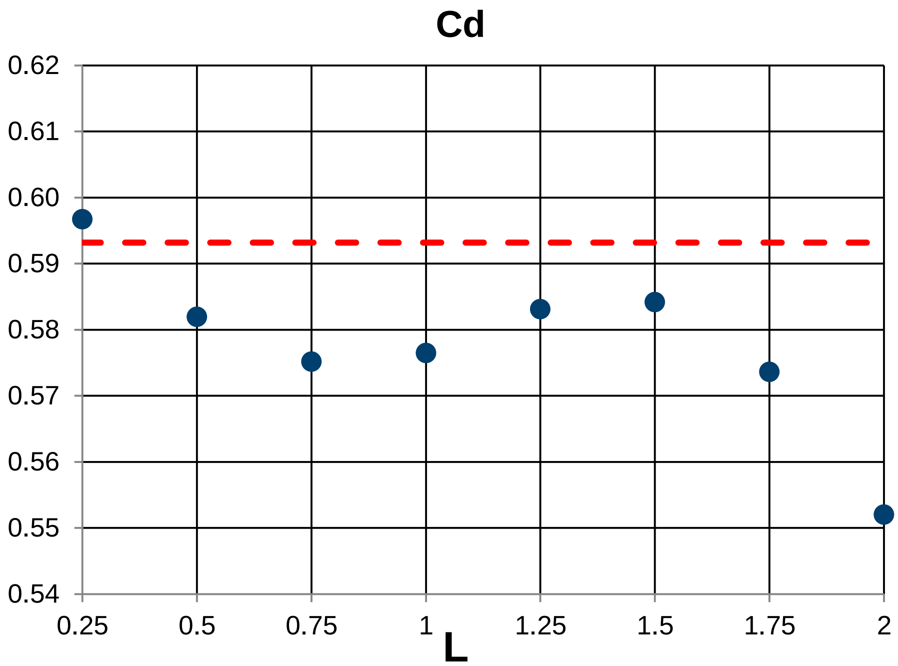
L [m]	C_d	% C_d reduction
0,25	0,54	8,55
0,5	0,55	7,83
0,75	0,55	7,46
1	0,55	6,79
1,25	0,55	7,38
1,5	0,54	8,40
1,75	0,54	8,36
2	0,54	8,99

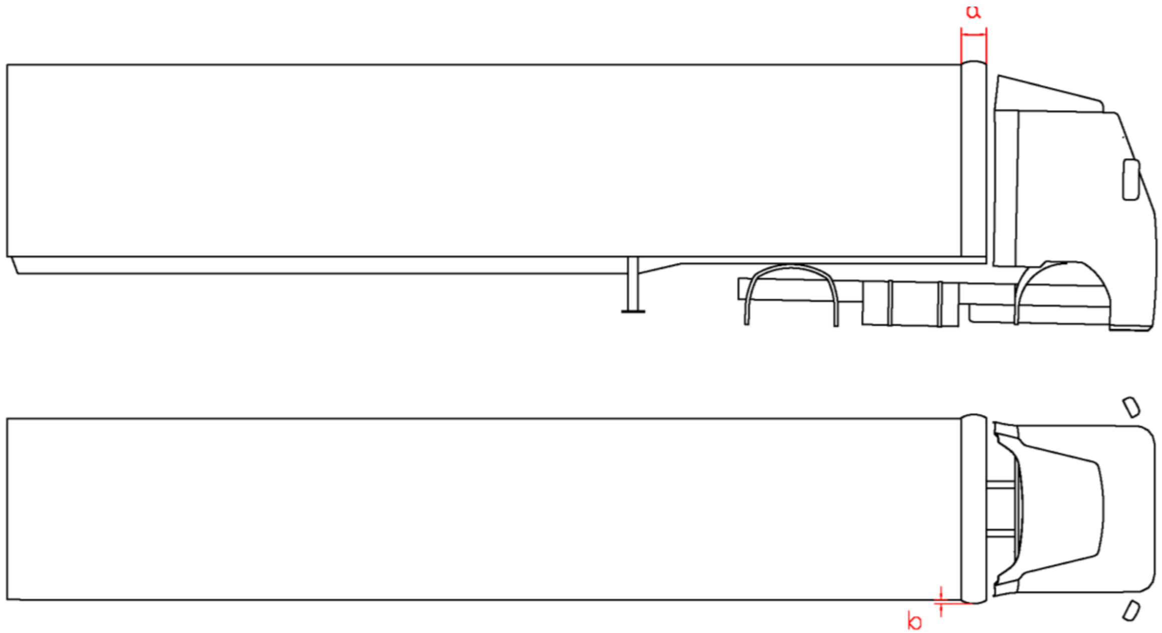


Airbags design optimization

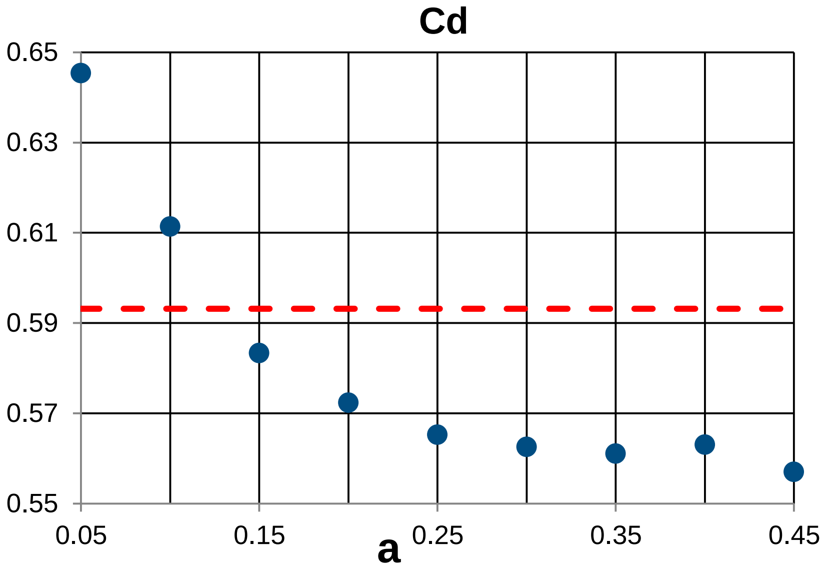


L [m]	C_d	% C_d reduction
0,25	0,60	-0,60
0,5	0,58	1,89
0,75	0,58	3,03
1	0,58	2,81
1,25	0,58	1,69
1,5	0,58	1,51
1,75	0,57	3,29
2	0,55	6,93

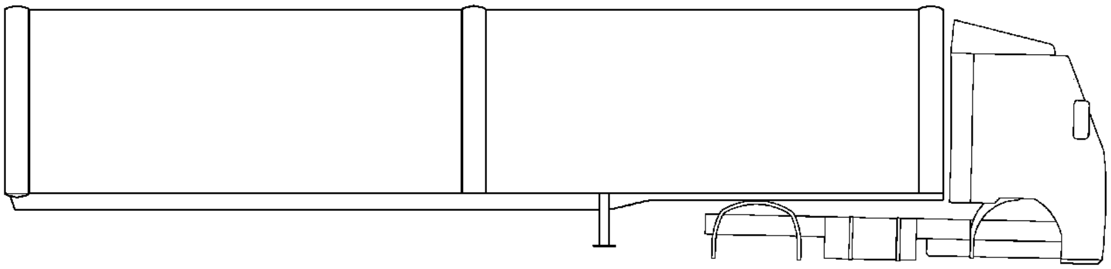


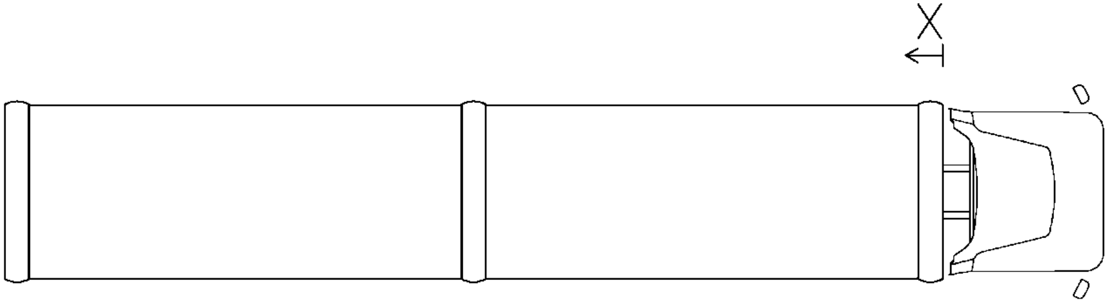


b [m]	fix	
a [m]	C_d	% C_d reduction
0,05	0,65	-8,81
0,1	0,61	-3,08
0,15	0,58	1,64
0,2	0,57	3,50
0,25	0,57	4,69
0,3	0,56	5,15
0,35	0,56	5,41
0,4	0,56	5,07
0,45	0,56	6,09

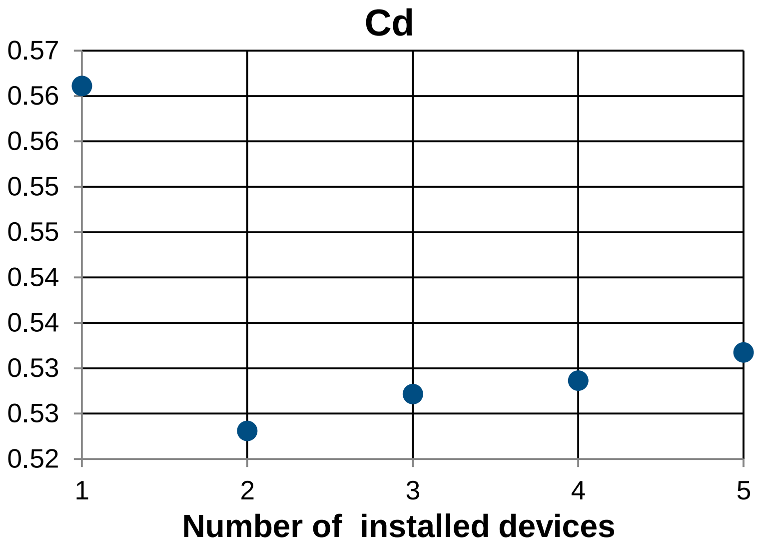


Trailer devices design optimization





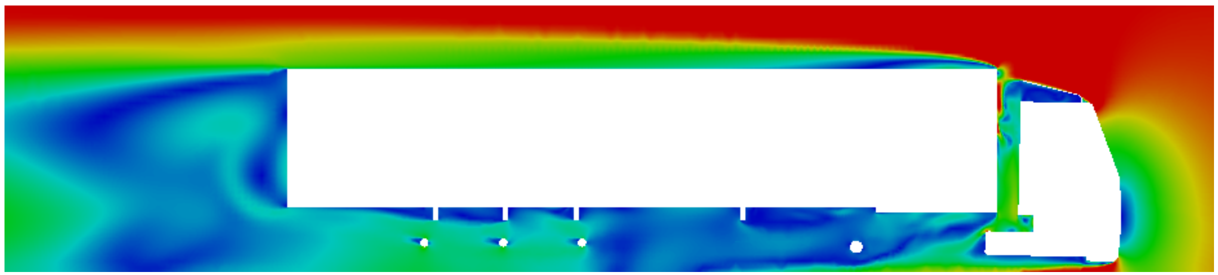
Trailer lenght	13,5	[m]
Number of devices installed	**C_d**	**% C_d reduction**
1 (X=0)	0,56	5,41
2 (X=0; X=L)	0,52	11,81
3 (X=0; X=L/2; X=L)	0,53	11,13
4 (X=0; X=L/3; X=2/3L; X=L)	0,53	10,88
5 (X=0; X=L/4; X=L/2; X=L3/4; X=L)	0,53	10,36

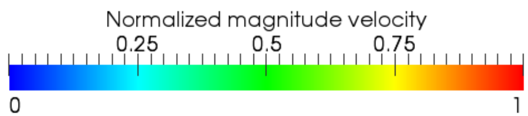


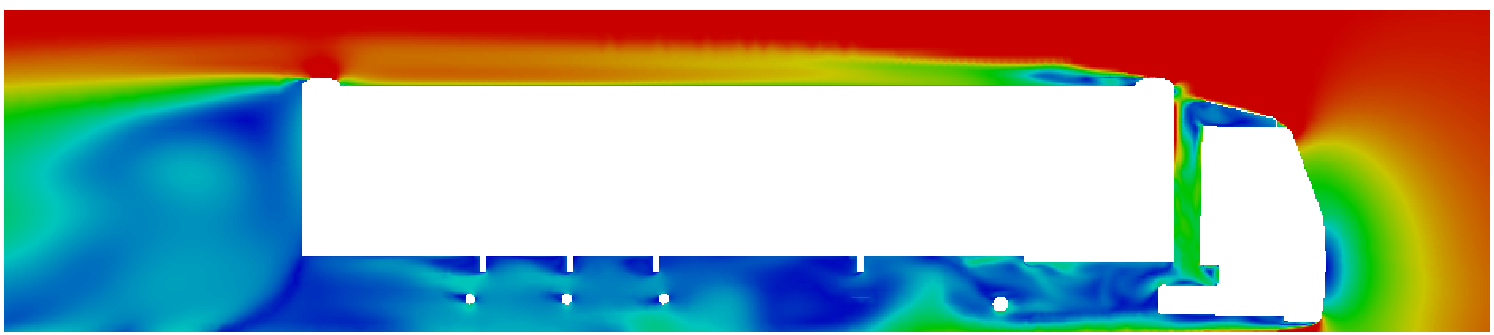
Trailer devices

2 (X=0; X=L)		
a [m]	**C_d**	**% C_d reduction**
0,35	0,52	11,81
0,45	0,518	12,73

Target vehicle





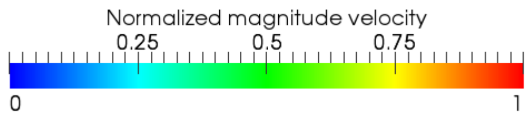


Normalized magnitude velocity contour plot at y=0

Trailer devices

2 (X=0; X=L)		
a [m]	**C_d**	**% C_d reduction**
0,35	0,52	11,81
0,45	0,518	12,73

Target vehicle



Normalized magnitude velocity contour plot at z=2.6

Cross-wind

Front trailer device (a=0,45 m)

DRAG

yaw angle	Cd	% Cd rid. tot
0	0.549	6.23%
5	0.653	4.47%
10	0.812	2.80%
15	0.975	2.51%
20	0.990	4.86%
25	0.998	1.82%
30	1.033	1.09%

Front-rear trailer device (a=0,45 m)

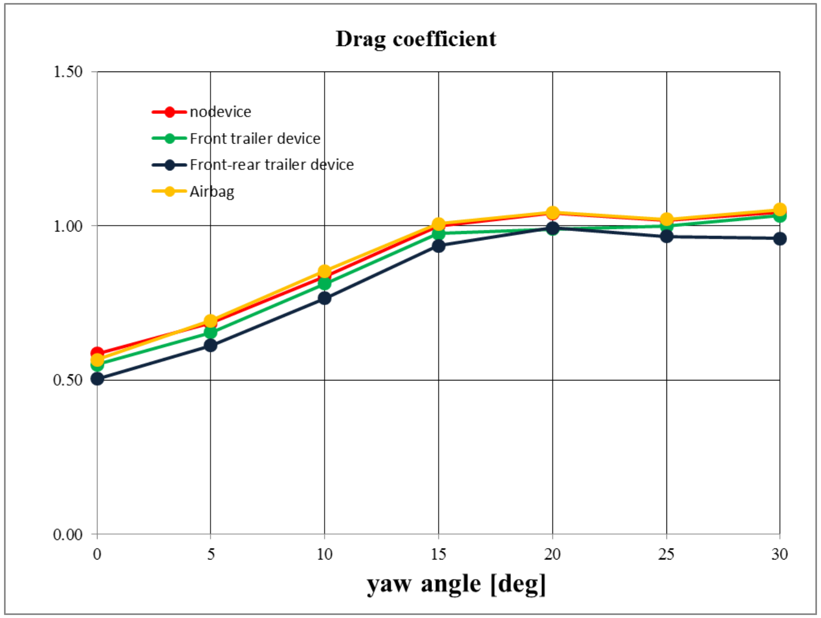
DRAG

yaw angle	Cd	% Cd rid. tot
0	0.503	14.08%
5	0.612	10.52%
10	0.765	8.45%
15	0.935	6.51%
20	0.993	4.52%
25	0.965	5.05%
30	0.959	8.12%

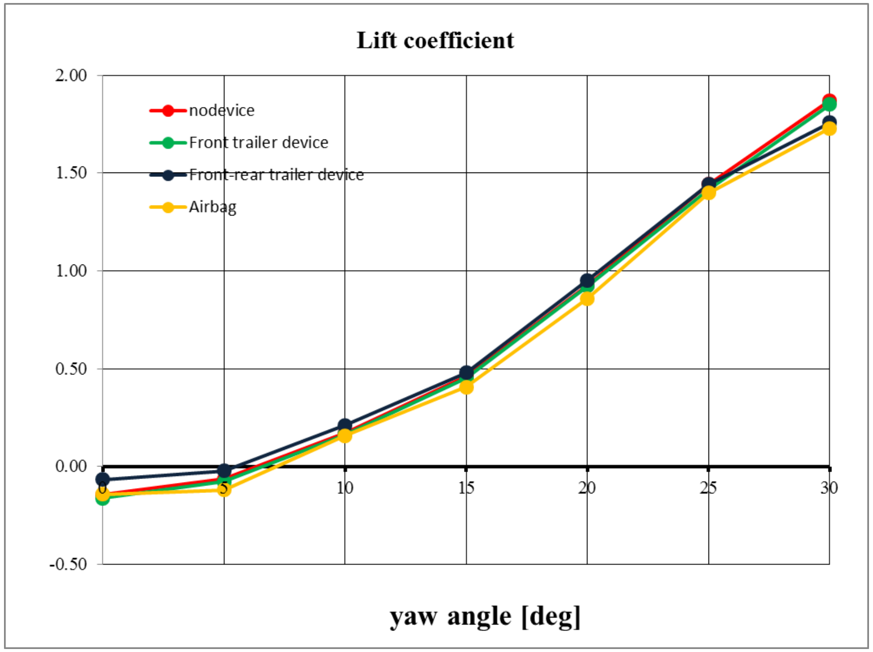
Airbag (L=0,75m)

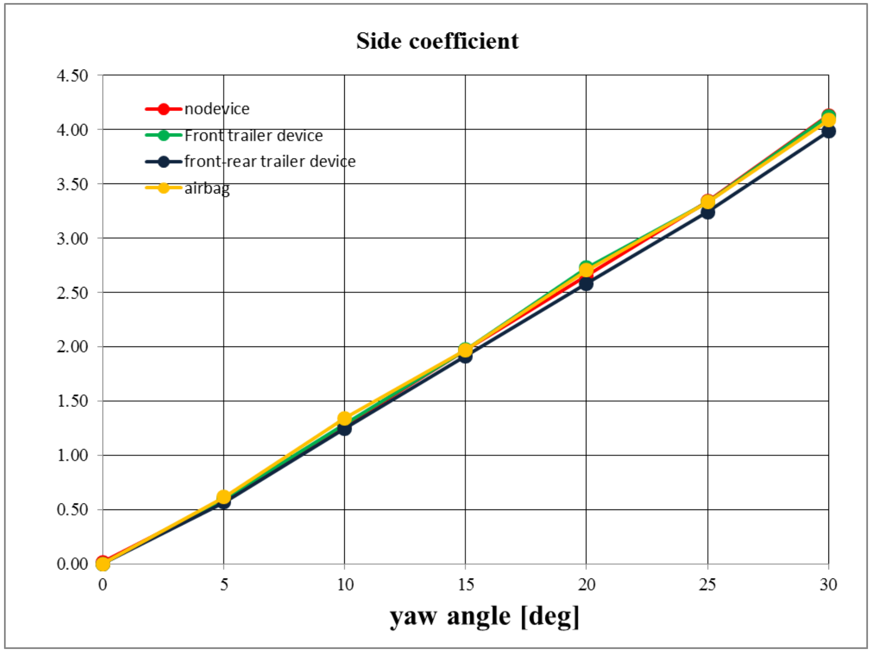
DRAG

yaw angle	Cd	% Cd rid. tot
0	0.566	3.39%
5	0.693	-1.26%
10	0.853	-2.04%
15	1.007	-0.67%
20	1.043	-0.27%
25	1.021	-0.47%
30	1.052	-0.80%



Cross-wind


Lift coefficient
2.00
1.50
1.00
0.50
0.00
-0.50
0
5
10
15
20
25
30
nodevice
Front trailer device
Front-rear trailer device
Airbag
yaw angle [deg]


Side coefficient
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
5
10
15
20
25
30
nodevice
Front trailer device
front-rear trailer device
airbag
yaw angle [deg]

DES results

Target vehicle

DRAG

yaw angle	C_d RANS	C_d DES
0	0,581	0,623
5	0,661	0,679
10	0,824	0,813

SIDE FORCE

yaw angle	C_s RANS	C_s DES
0	0,000	0,000
5	0,594	0,616
10	1,307	1,379

LIFT

yaw angle	C_l RANS	C_l DES
0	-0,155	-0,105
5	-0,058	-0,048
10	0,188	0,183

Front-rear trailer device

DRAG

yaw angle	C_d RANS	% C_d reduction RANS	C_d DES	% C_d reduction DES
0	0,508	12,506%	0,544	12,702%
5	0,585	11,504%	0,600	11,610%
10	0,753	8,606%	0,753	7,454%

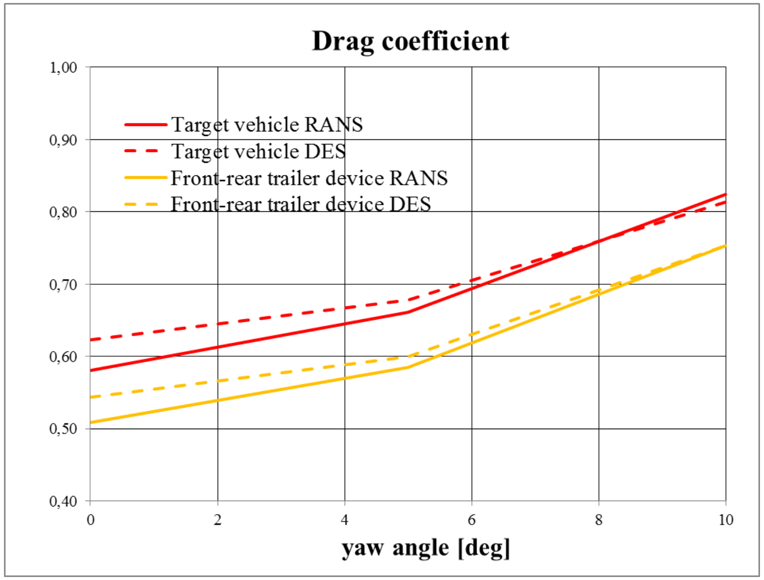
SIDE FORCE

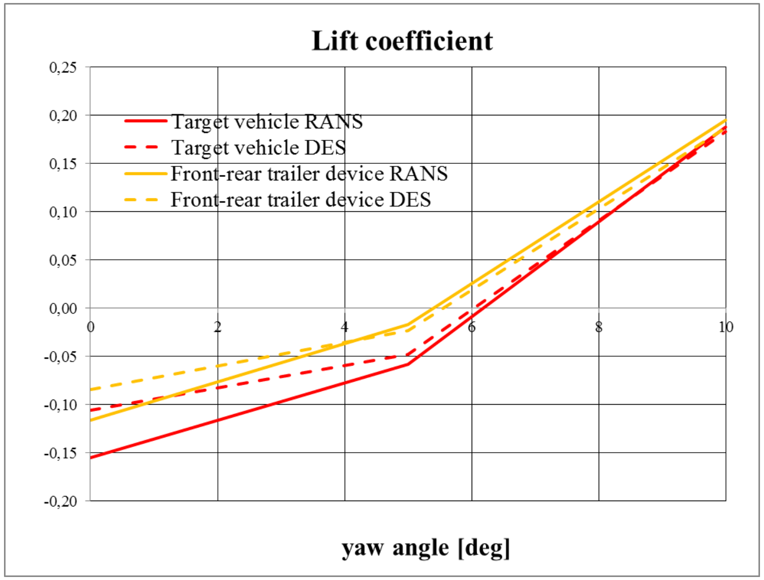
yaw angle	C_s RANS	% C_s reduction RANS	C_s DES	% C_s reduction DES
0	0,000	0,000%	0,000	0,000%
5	0,572	3,716%	0,606	1,603%
10	1,265	3,202%	1,364	1,066%

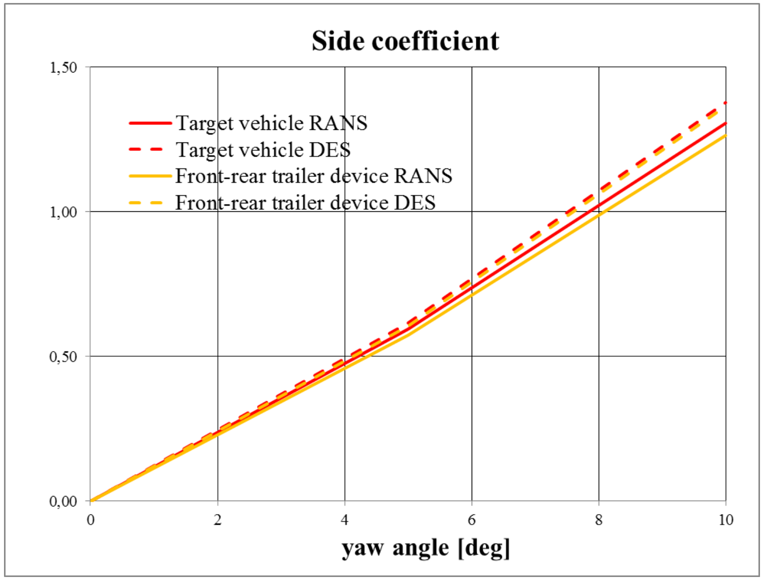
LIFT

yaw angle	C_l RANS	% C_l reduction RANS	C_l DES	% C_l reduction DES
0	-0,116	-8,473%	-0,085	19,628%
5	-0,017	70,650%	-0,023	51,738%
10	0,196	-3,777%	0,187	-2,118%

DES Results


Drag coefficient
Target vehicle RANS
Target vehicle DES
Front-rear trailer device RANS
Front-rear trailer device DES
1,00
0,90
0,80
0,70
0,60
0,50
0,40
0
2
4
6
8
10
yaw angle [deg]

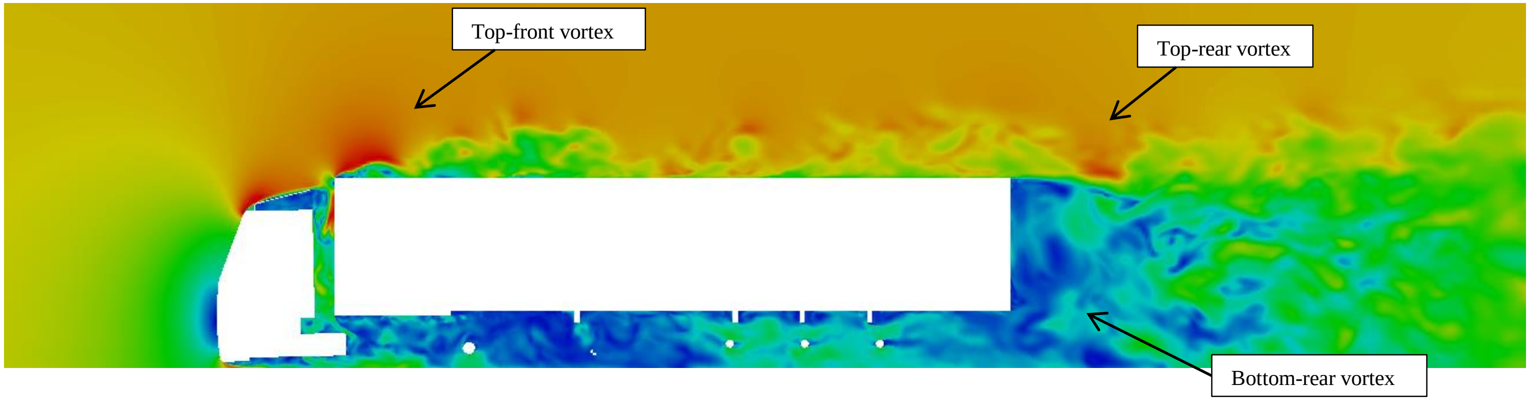

Lift coefficient
Target vehicle RANS
Target vehicle DES
Front-rear trailer device RANS
Front-rear trailer device DES
0,25
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
0
2
4
6
8
10
yaw angle [deg]


Side coefficient
Target vehicle RANS
Target vehicle DES
Front-rear trailer device RANS
Front-rear trailer device DES
1,50
1,00
0,50
0,00
0
2
4
6
8
10
yaw angle [deg]

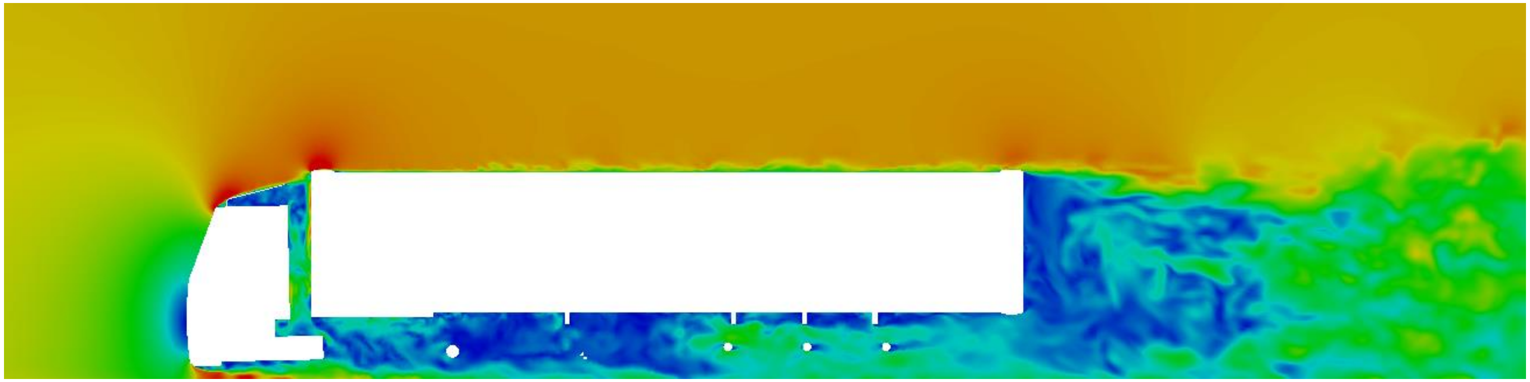
Results DES simulations

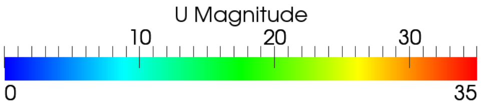
Contourplot y=0 m

No device



Front-rear trailer device



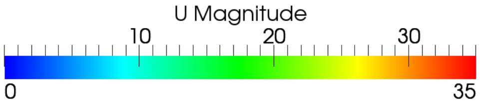


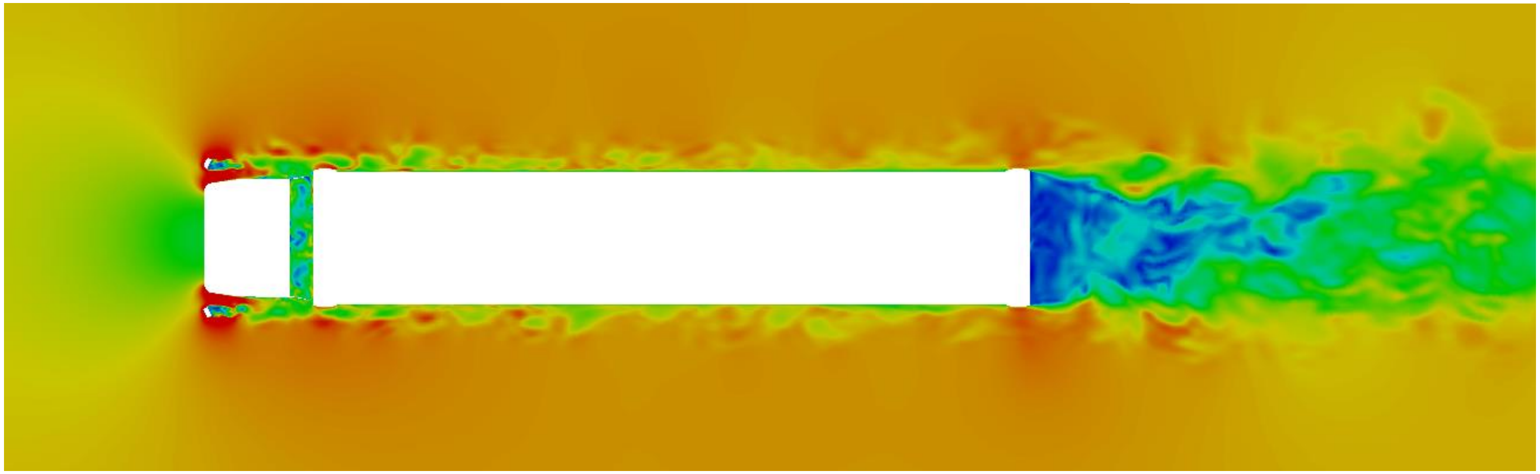
Results DES simulations

Contourplot z=2,6 m

No device

Front-rear trailer device

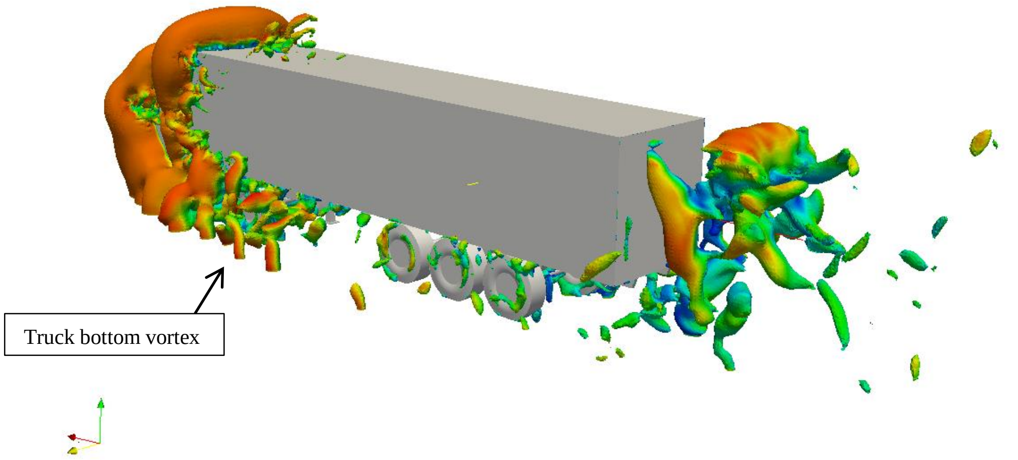


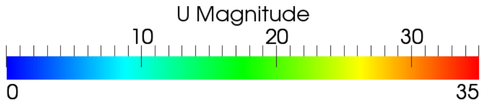


Results DES simulations

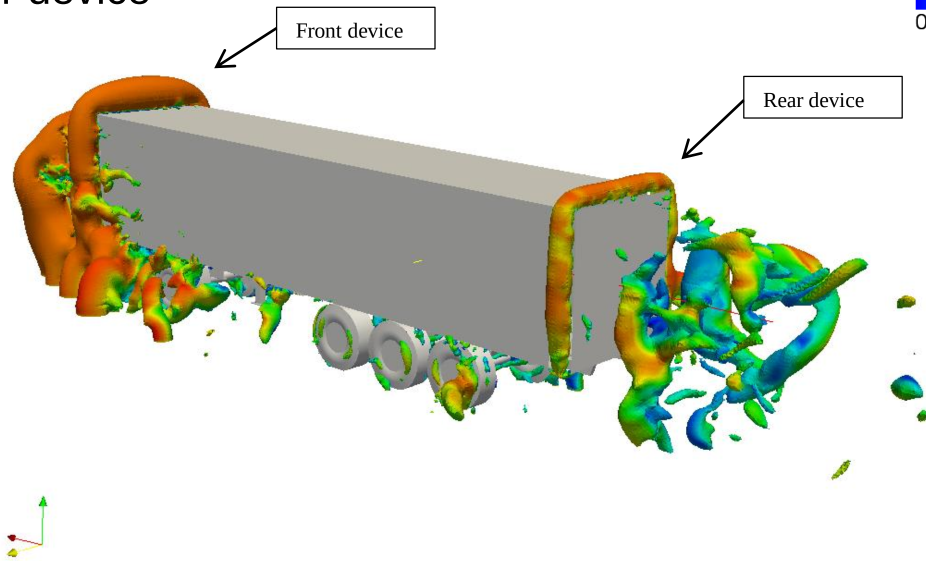
Isovorticity:

No device



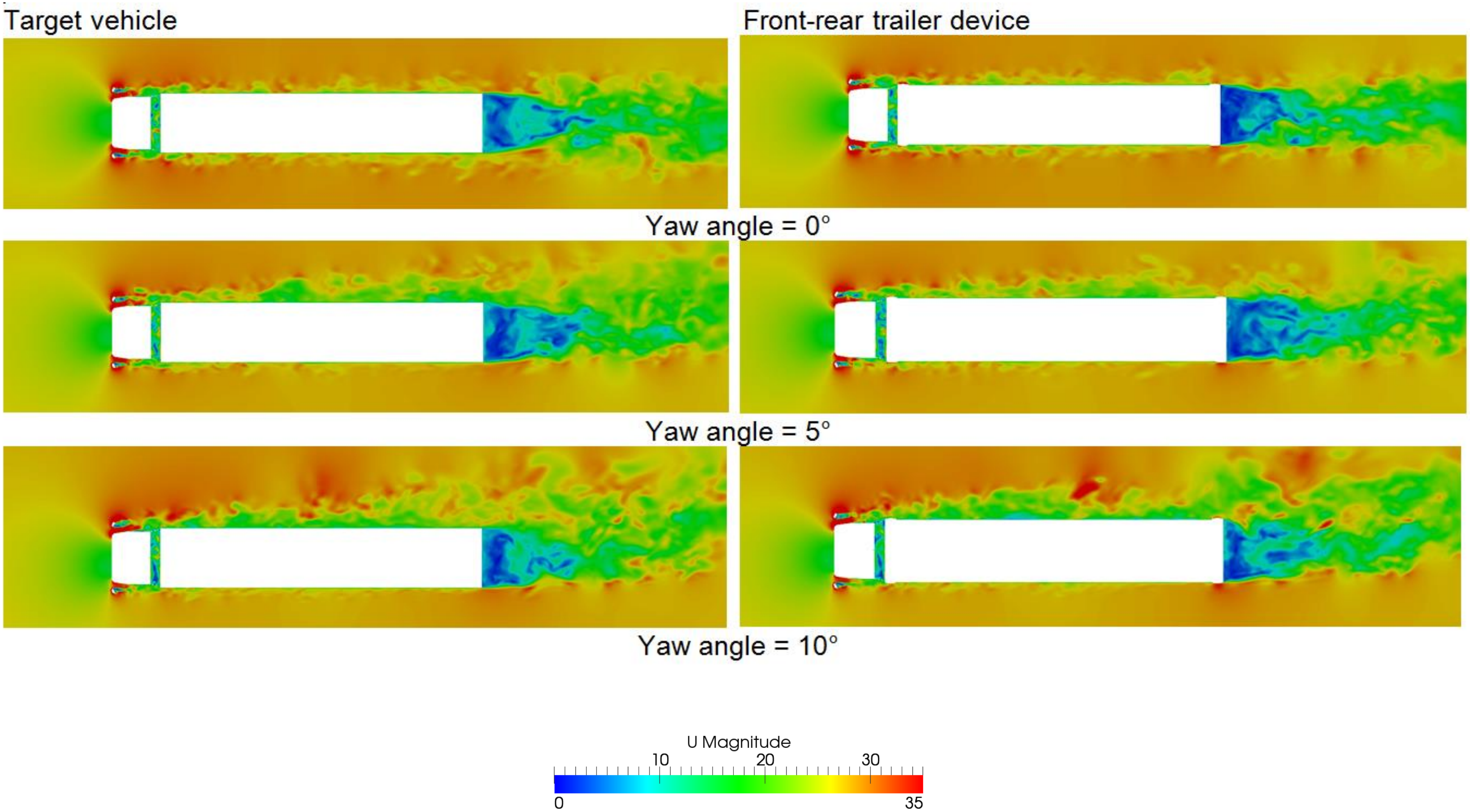


Front-rear trailer device

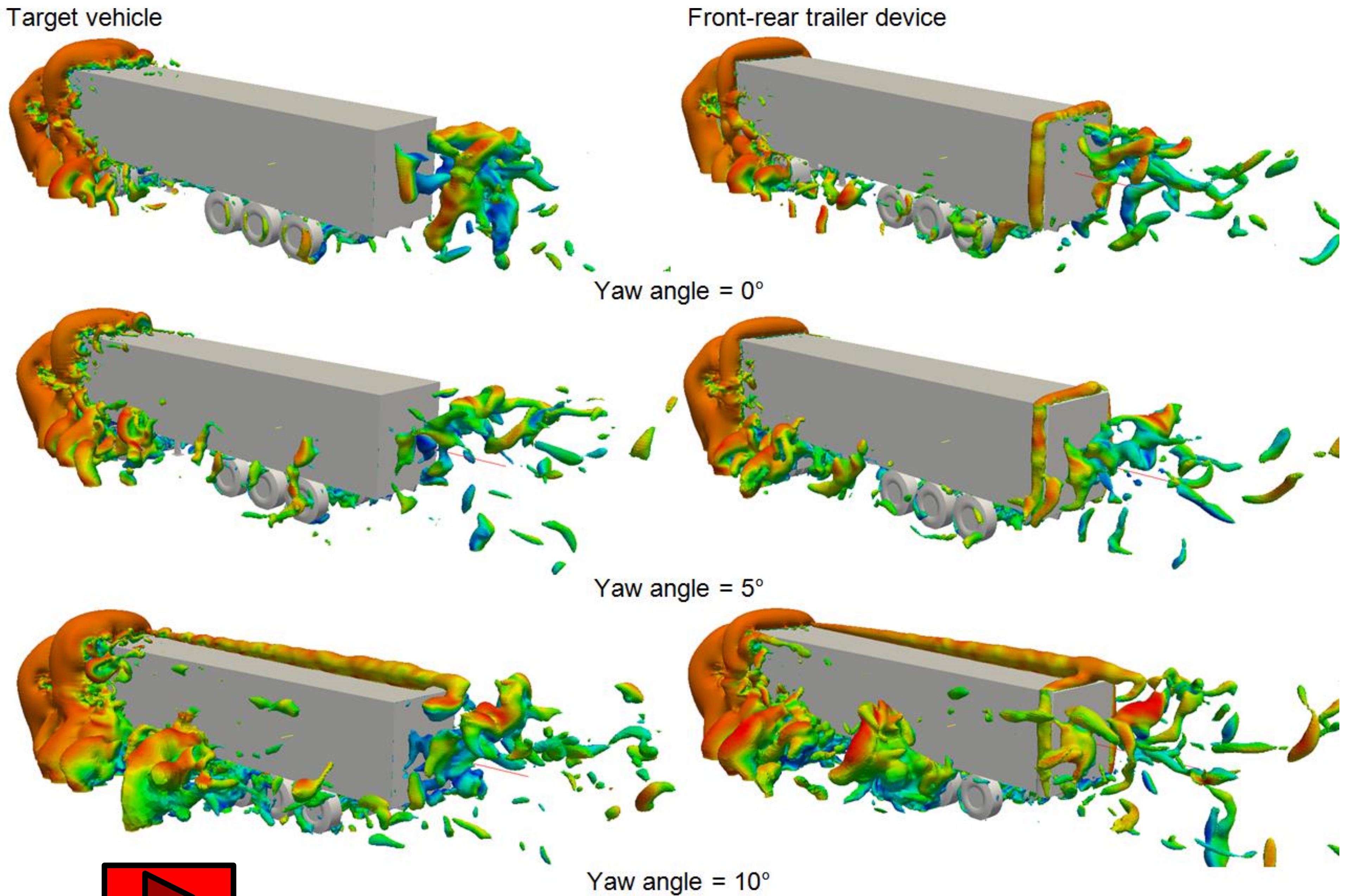


Results DES simulations cross-wind

Contourplot z=2,6 m



Results DES simulations cross-wind



Conclusion

Advantages:

- **15% of drag reduction (around 5 % less in fuel consumption);**
- **No change in the current shape of the truck and trailer;**
- **No impact to the logistic center and to the shipping system (easy install/uninstall on the truck);**
- **Low development costs;**
- **These device can be mounted on every truck (next, current, previous truck generation);**
- **No safety issue.**

THANK YOU FOR YOUR ATTENTION

Paolo Schito – Luigi Salati – Federico Cheli

We acknowledge the CINECA and the Regione Lombardia award under the LISA initiative, for the availability of high performance computing resources and support for Project D4TRUCKS

Italian patent application n. MI2014A002044, entitled “DISPOSITIVO AERODINAMICO PER LA RIDUZIONE DEL DRAG DI VEICOLI TERRESTRI” filed on November 27, 2014

Third Symposium on OpenFOAM® in Wind Energy

Politecnico di Milano

June 15, 2015 – June 17, 2015

MAJOR TOPICS

- + Atmospheric Flows (including flow over complex terrains and sea)
- + HAWT Wind Turbine Aerodynamics and Wakes
- + Vertical Axis Wind turbines
- + Small scale and urban wind energy applications
- + Site Assessment and Wind Plant Aerodynamics
- + Offshore Wind Aerodynamics and Hydrodynamics
- + Other (including meshing, algorithms, post-processing, parallel performance, etc.)

https://www.eko.polimi.it/index.php/sowe2015/SOWE2015