Experimental Methods in Vehicle Aerodynamics

Per Elofsson
Scania CV AB, per.elofsson@scania.com

Outline

- Introduction
- Vehicle aerodynamics for trucks
- Wind tunnels for automotive testing
- Ground simulation
- Testing & analysis

Historical evolution

$C_D \approx 1.2$ (driver dependant)?

$C_D \approx 0.6$

$C_D \approx 0.25$

Scania products

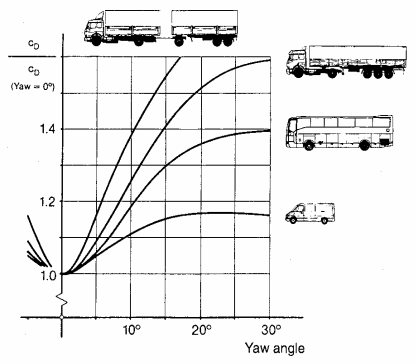
Vehicle aerodynamics for trucks

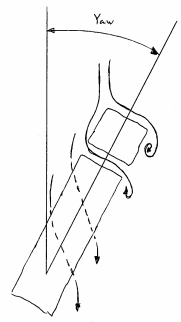
- **Aerodynamic drag**
- Aerodynamic lift is not of great weight
  - ΔC_L=0.05 at 80 kph $\Leftrightarrow$ ΔL=150 N

- Crosswind stability is of low importance for trucks (in general)
- Vehicle soiling is an important field

SCANIA

Wind-averaged drag



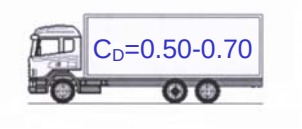


- Necessary to take account of crosswind influence on drag
- Yaw dependance relates to gap between truck & trailer

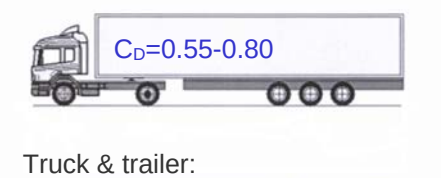
SCANIA

Truck aerodynamics - characteristics

Truck:



Tractor & semitrailer:

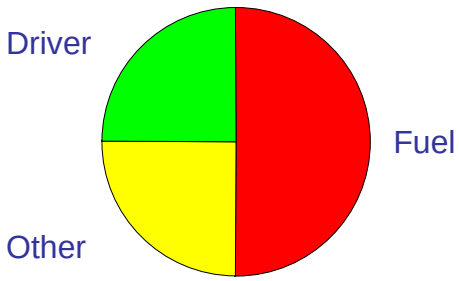


Truck & trailer:

Frontal area: 8 -11.5 m^2

Motivation for improved aerodynamics

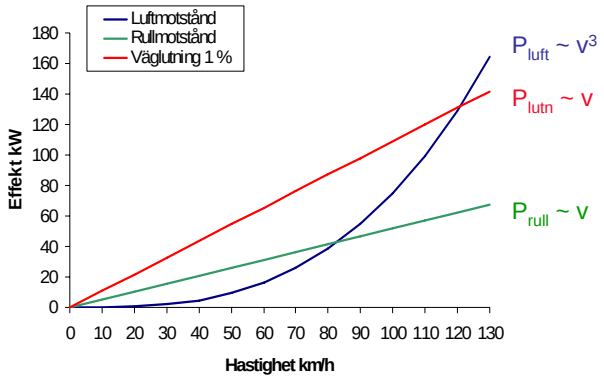
Costs for a truck in long-haulage operation



The fuel cost is almost 50% of the operational cost

Motivation for improved aerodynamics

Driving resistance:



Truck and semitrailer (40t, 80kph) on a flat road:

- ΔC_D= -0,020 ⇔ 1 % Fuel Economy improvement

Experimental aerodynamics at Scania

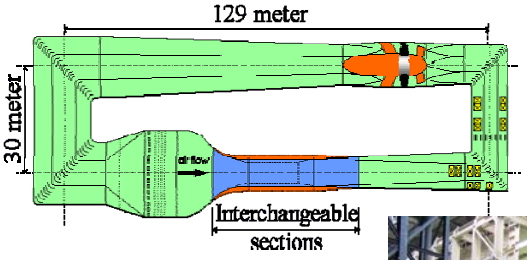
- Full scale testing (aerodynamics & aeroacoustics) at DNW
- 1:6 scale model testing (moving ground) at Lola Cars
- Test track is used for aero-acoustics and soiling tests

Full scale testing

- Balance measurements
- Pressure measurements
- Flow visualization
- Aeroacoustic measurements
- Truck or tractor & semitrailer (non-articulated)

SCANIA

DNW Wind tunnel



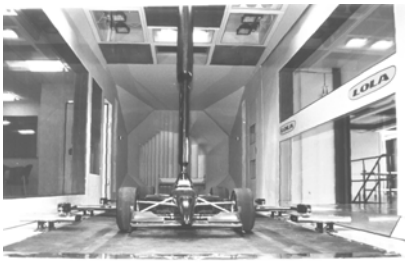
Test vehicle installed in the 9.5 x 9.5 m^2 test section

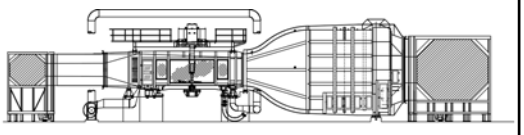
SCANIA

1:6 scale model testing

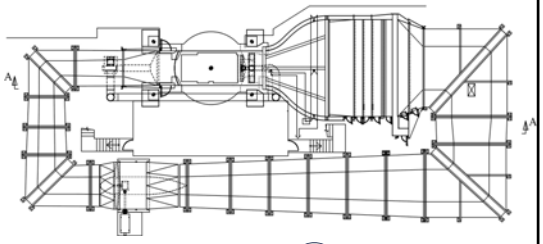
- Moving belt and rotating wheels
- Tractor & semitrailer model with high level of detailing

Lola Cars Wind tunnel





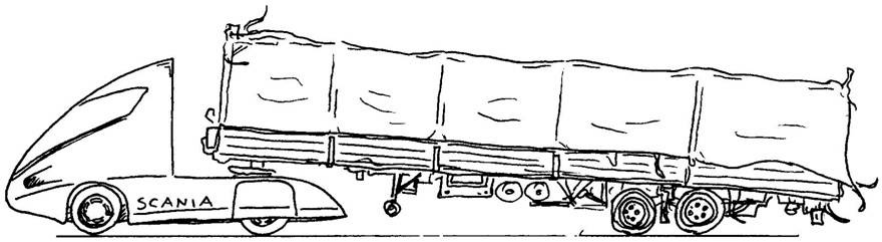
Section A-A



Main development areas

- Cab shape
- Cab details
  - Air deflectors
  - Sun visor, Rear view mirrors
- Chassi details
  - Side skirts
  - Wheel deflectors, floorpanels

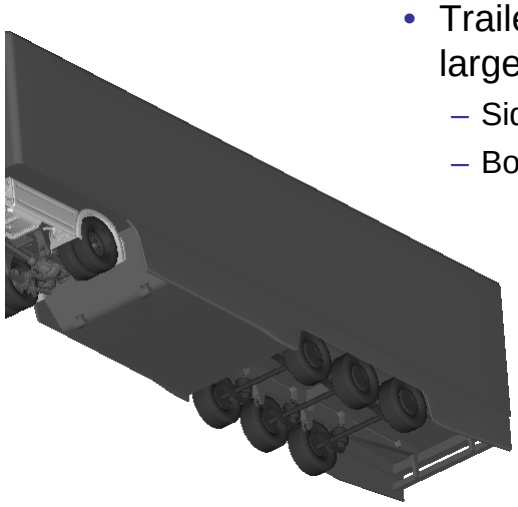
The whole vehicle must be considered

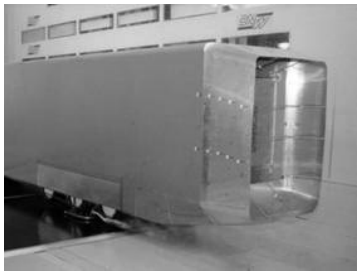


- Trucks and trailers are seldom owned by the same company ⇒ relatively weak interest in aero improvements for trailers

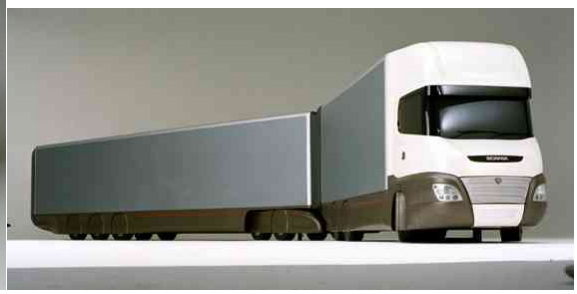
Trailer modifications

- Trailer modifications have large potential ($\Delta C_D \approx 0.25$)
  - Side skirts, chassis covers
  - Boat-tail, rear end diffusor





Example – Concept truck

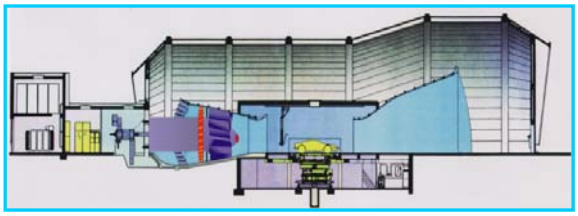


C_D <0.25

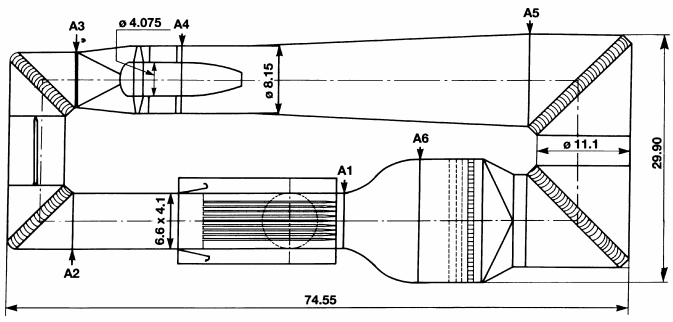
C_D ~0.3

Outline

- Introduction
- Vehicle aerodynamics for trucks
- Wind tunnels for automotive testing
- Ground simulation
- Testing & analysis

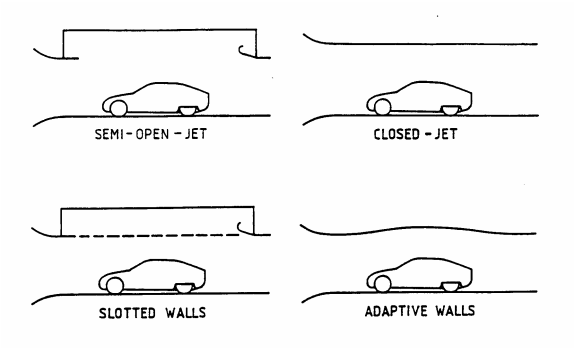


Performance of automotive wind tunnels

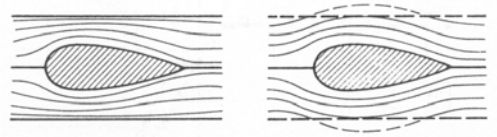


- Maximum wind speed: 140 – 270 km/h
- Test section (area): 10 - 40 m^2
- Fan power: 0.6 - 4 MW

Test section types



Effect of lateral boundaries



Closed TS Open TS

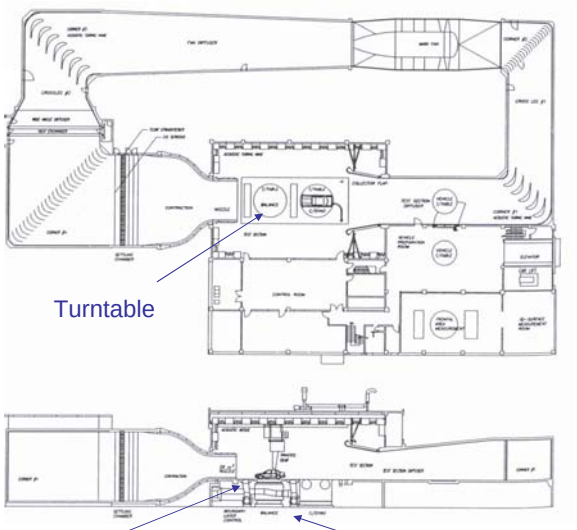
SCANIA

Multi-purpose wind tunnels

- Provides additional test functionality:
  - Soiling (dirt deposition) tests
  - Climate comfort
  - Thermodynamics & cooling performance tests at accurate flow conditions

SCANIA

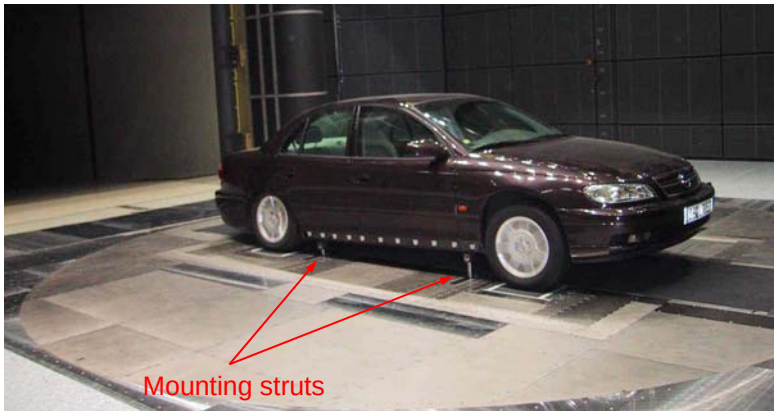
Wind tunnel systems



Force balances

- External balance below the test section floor
  - Wheel pads for stationary ground
  - Struts for moving ground
- External balance on the test section roof
  - Vertical support strut
- Internal balance with support strut

Vehicle installation – moving belt



Picture from FKFS, Stuttgart

Vehicle installation – stationary ground

SAAB 92 -1955

- Wheels are positioned on pads connected to the balance

Ground Simulation – Moving belt

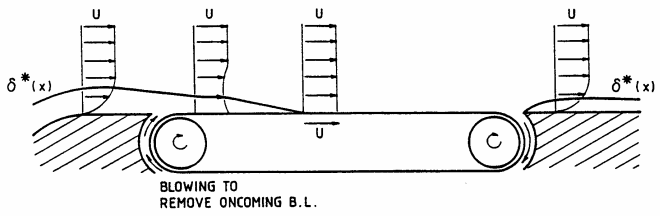
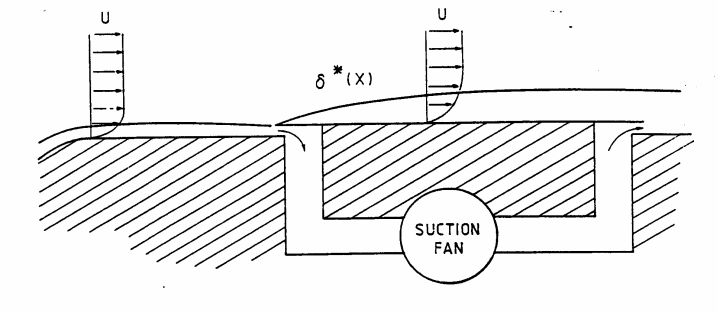
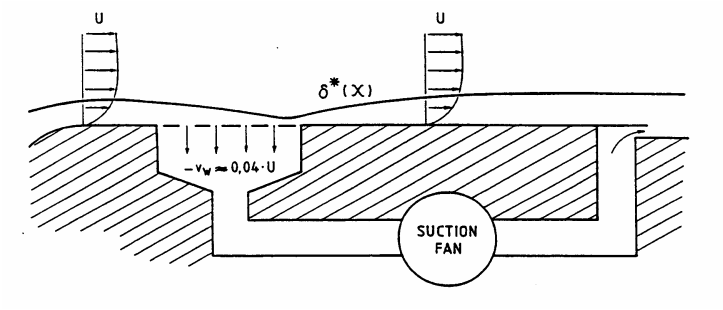


FIGURE 3 - Moving Belt Technique

Ground Simulation – Scoop

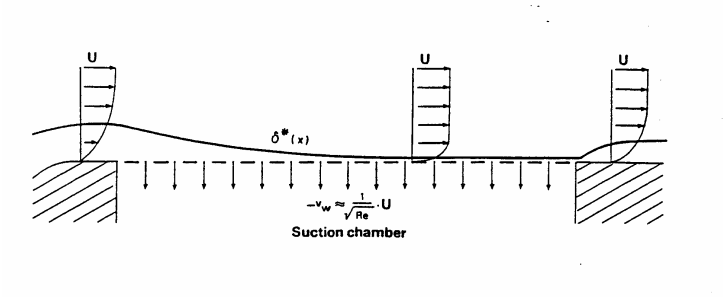


Ground Simulation – Basic suction



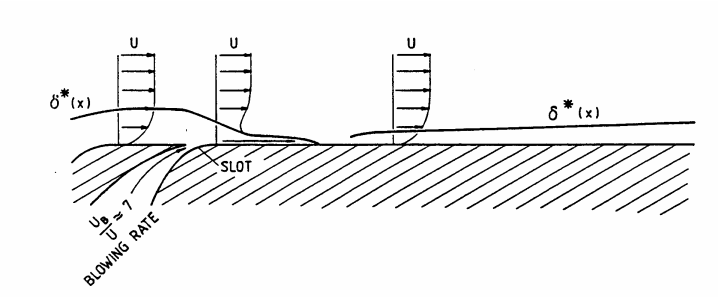
SCANIA

Ground Simulation – Distributed suction



SCANIA

Ground Simulation – Tangential blowing



SCANIA

New ”standard” for MGS

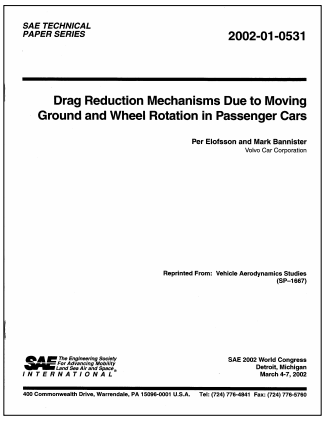
- Best performance is achieved by combining a long Moving Belt with upstream systems
  - MB with presuction & suction/tangential blowing
  - MB with scoop & suction & tangential blowing

• Test section of the new S2A wind tunnel

SCANIA

Why use Moving Ground Simulation?

- Wheel rotation (rear) has a large influence on the aerodynamic performance
- MGS is important for the development of both the exterior and the underfloor



SAE TECHNICAL PAPER SERIES

2002-01-0531

Drag Reduction Mechanisms Due to Moving Ground and Wheel Rotation in Passenger Cars

Per Elofsson and Mark Bannister
Volvo Car Corporation

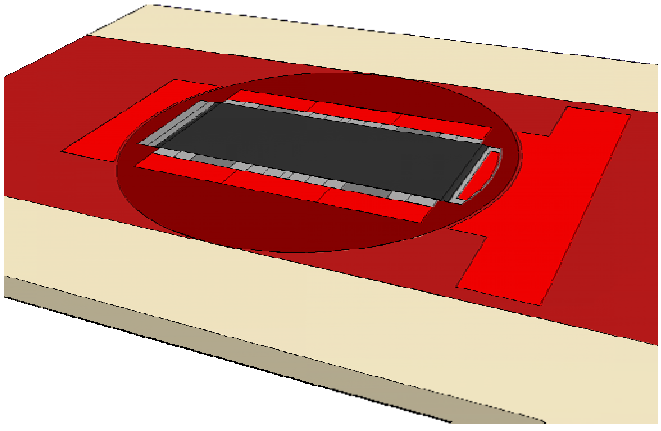
Reprinted From: Vehicle Aerodynamics Studies (SP-1687)

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space INTERNATIONAL

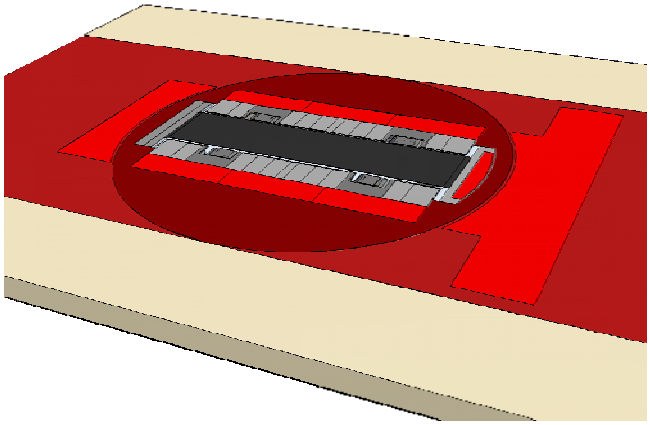
SAE 2002 World Congress
Detroit, Michigan
March 4-7, 2002

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (724) 776-4841 Fax: (724) 776-5760

Single belt moving ground system

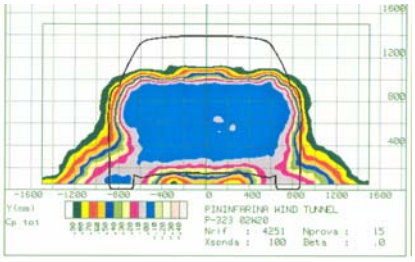


Five belt moving ground system



Outline

- Introduction
- Vehicle aerodynamics for trucks
- Wind tunnels for automotive testing
- Ground simulation
- Testing & analysis

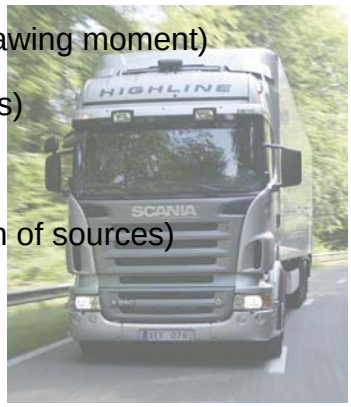


Test objects

- Clay model (model or full-scale)
- Milled model (tooling block)
- Hybrid models
- Mock-up (clay exterior)
- Prototype
- Production vehicle

Vehicle aerodynamic issues

- Drag (fuel consumption, performance)
- High-speed stability (lift)
- Cross-wind stability (side force & yawing moment)
- Passenger comfort (convertible cars)
- Dirt deposition (visibility)
- Aero acoustics (limiting the strength of sources)
- Cooling air-flow



Balance measurements

- Effect of configuration changes on aero coefficients
- Investigate sensitivity to flow angle, vehicle attitude and wind speed

Sensitivity analysis – Vehicle attitude

- Cars with critical rear window slopes (and without roof spoiler) have high sensitivity to changes in attitude
- Small changes in roll or pitch angle can result in large variations in drag and lift coefficients

Flow criticality - Example

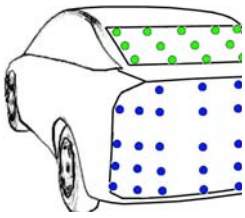
Volvo V50

- The flow over the rear window interacts with the disturbed flow from the rear support of the roof rails $\Rightarrow C_D$ increases
- Difficult to explore with CFD, experiments are needed

SCANIA

Methods to increase the knowledge gained from aerodynamic testing

- Base pressure measurements
- Flow visualization (smoke, tufts & surface paint)
- Wake analysis (seven-hole pressure probe measurements)



SCANIA

Flow visualization - Smoke

Wake analysis

Seven-hole probe rake

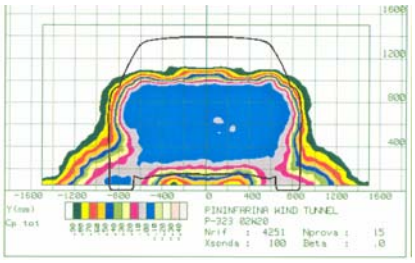
$$D = \iint (P_1 + \rho U_1^2 - P_2 - \rho U_2^2) dydz$$

Floor traverse

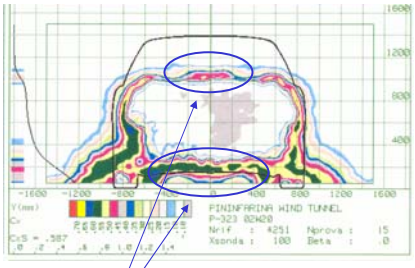
Wake analysis

Wake measured 100 mm downstream of a notchback

Total pressure



Microdrag



Identify regions that can be improved

High speed stability - Example

Volvo S40

- Front and rear spoiler on the T5 version improves the high speed stability even further

Influence of lift on vehicle dynamics

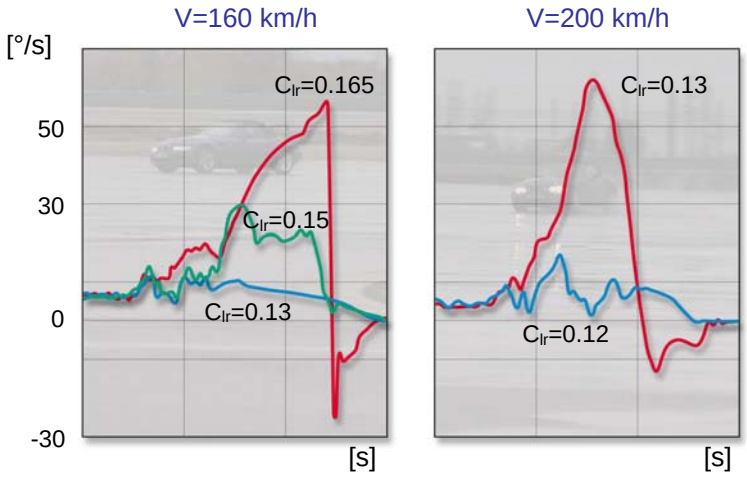
BMW Z4

Example from the MIRA 2002 Conference on Vehicle Aerodynamics

SCANIA

Influence of lift on vehicle dynamics

Dynamic response (yaw velocity)



SCANIA

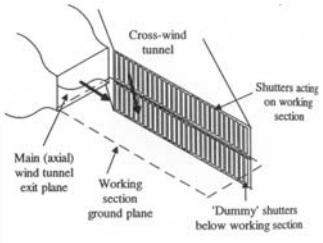
Cross-wind stability

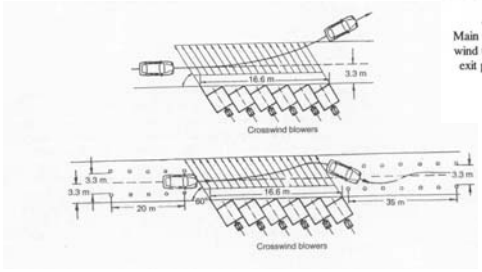
Different test methods:

- Stationary forces & moments from wind tunnel measurements at yaw
- Use of cross wind facilities (at test tracks)
- Studies of cross-wind gusts in special wind tunnels
- Driving behind the sand dunes on a Danish beach on a stormy night..

SCANIA

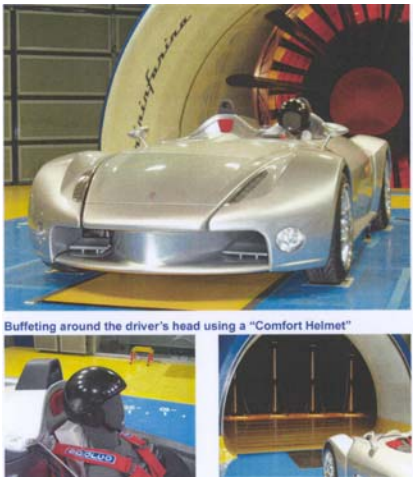
Cross-wind stability





SCANIA

Passenger comfort



Buffeting around the driver's head using a "Comfort Helmet"

- Velocity measurements in the compartment is the standard method (Hot Film, LDV, PIV..)
- Pininfarina ARC has developed the "Comfort Helmet"
- Some companies rely solely on subjective data

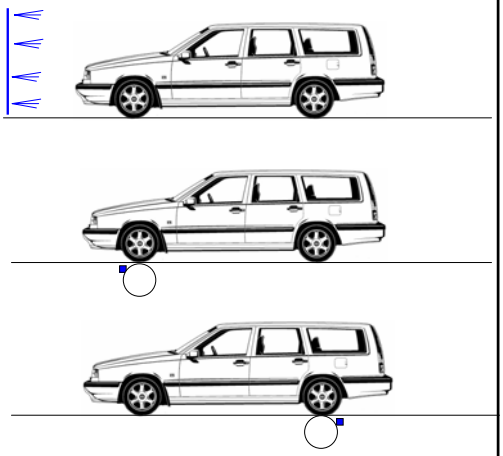
Vehicle soiling - topics

- Foreign soiling
  - visibility through side windows & rear view mirrors
- Self soiling
  - driver comfort, functionality
- Improve conditions for passing vehicles

Methods for studies of vehicle soiling

Example from Volvo Car Corporation (similar methods are used by other car & truck manufacturers)

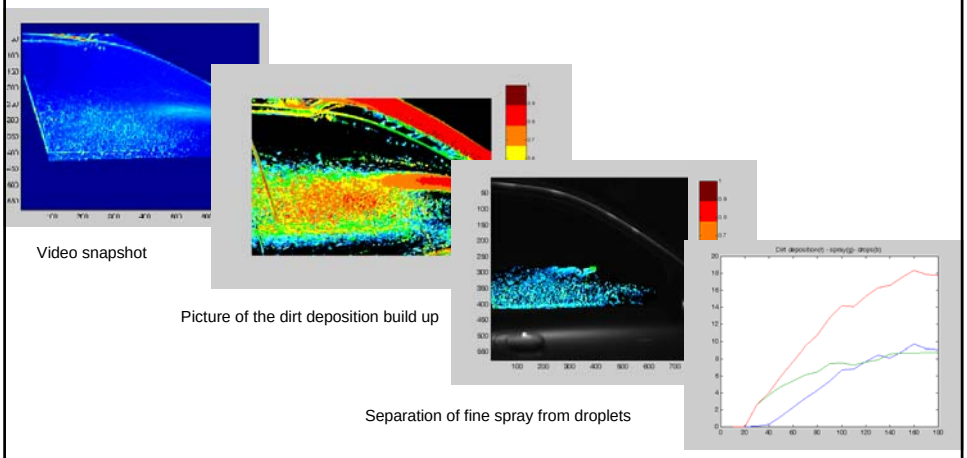
- Detection of emitted light from an UV sensitive chemical dissolved in water
- The signal from a set of UV sensitive cameras are recorded by a frame grabber card in a PC
- Image processing is used to evaluate the dirt deposition



SCANIA

Side window dirt deposition

Image processing sequence



Video snapshot

Picture of the dirt deposition build up

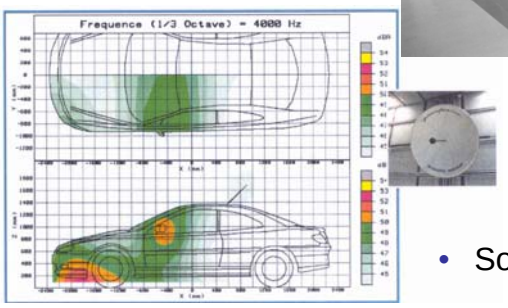
Separation of fine spray from droplets

Quantification of dirt deposition build up

SCANIA

Aero-acoustic measurements

- Measurements with acoustic mirrors in the Pininfarina wind tunnel



- Sound Pressure Level map

SCANIA

Thank you for your attention!

SCANIA