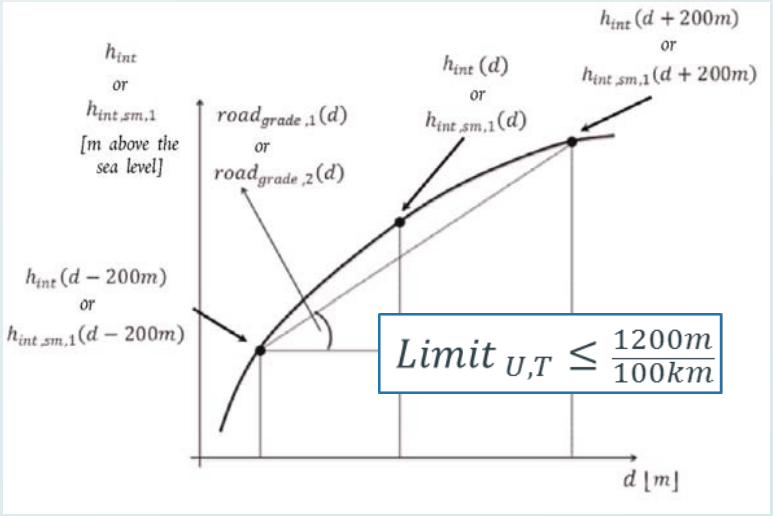
RDE Boundary Conditions
Cumulative Positive Altitude Gain

4th RDE IWG meeting, Tokyo 1-2 April 2019

RDE Boundary Conditions
Cumulative Positive Altitude Gain

REGULATION EU 2018/1832, App. 7b
Procedure to determine the cumulative positive elevation gain of a trip.



- What is the procedure for cumulative positive altitude gain applied for?
- How does it help to detect a biased trip composition based on the Limit (urban & total) of 1200m/100km?

RDE Boundary Conditions
Cumulative Positive Altitude Gain

- The trip requirements for the cumulative positive altitude gain, limited to 1200m/100km (for urban and total), prevent a bias due to trip composition with excessive energy demand driving uphill and excessive energy dissipation driving downhill (i.e. due to excessive braking).
- Even when the elevation difference between the start and the end point is within the limits (±100m) the trip composition in-between should be checked to protect against extremes.

RDE Boundary Conditions
Cumulative Positive Altitude Gain

cpAG=cumulative positive altitude gain

Moderate road gradients

Start

cpAG=500 *m*/100 *km*

End

± 100 m

Occasionally high gradients

Start

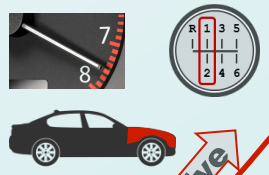
cpAG=1000 *m*/100 *km*

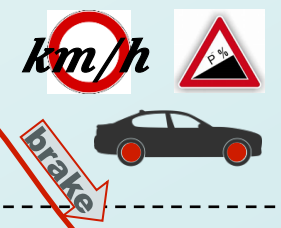
End

± 100 m

pot. energy gain → energy dissipation → *NTE Limit [mg or #/ km]*

Repeated high gradients





Start

cpAG=1500 *m*/100 *km*

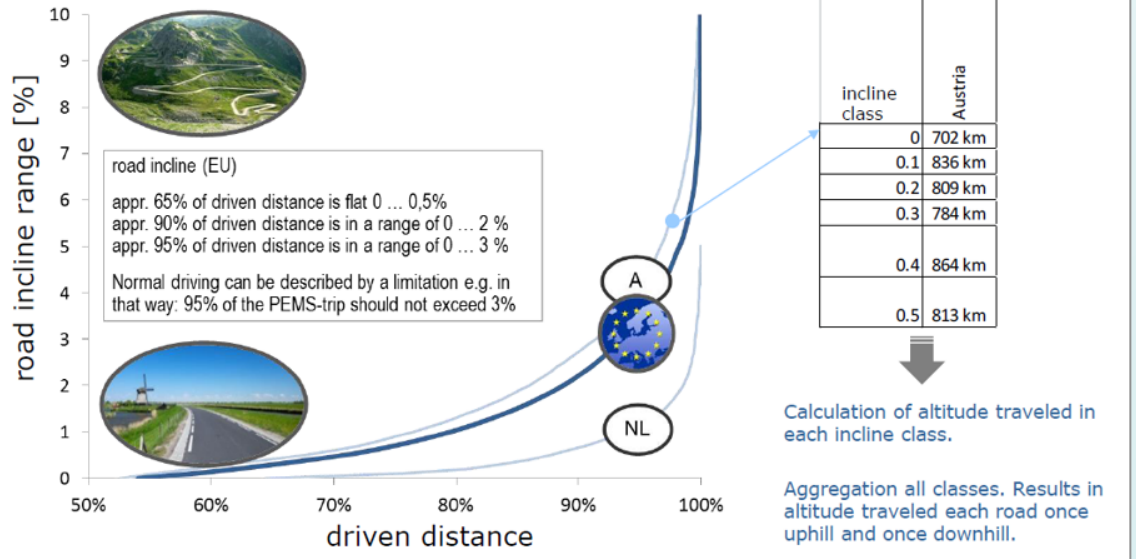
End

± 100 m

RDE Boundary Conditions
Cumulative Positive Altitude Gain

Note: Vehicle km by altitude data was provided by Emisia in 2012 and resulted in cumulative positive altitude gain being added in the second RDE package, Regulation (EU) 2016/646.

Statistical Analysis of European Map Data (Navtech)



incline class	Austria
0	702 km
0.1	836 km
0.2	809 km
0.3	784 km
0.4	864 km
0.5	813 km

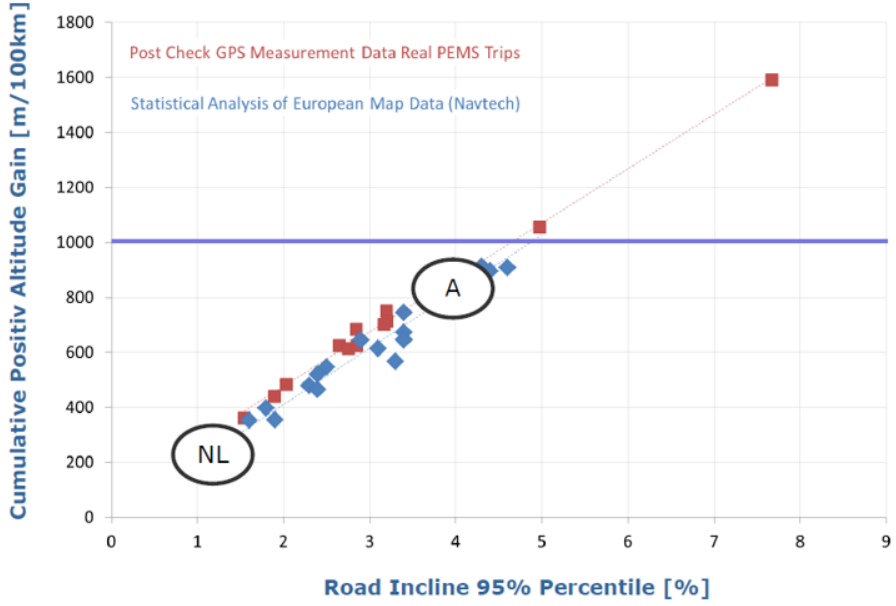
Calculation of altitude traveled in each incline class.

Aggregation all classes. Results in altitude traveled each road once uphill and once downhill.

Divided by two results in cumulated positive altitude traveled each road once which is in data base

19.03.2015 1

Analysis of road incline vs. cumulative positive altitude gain



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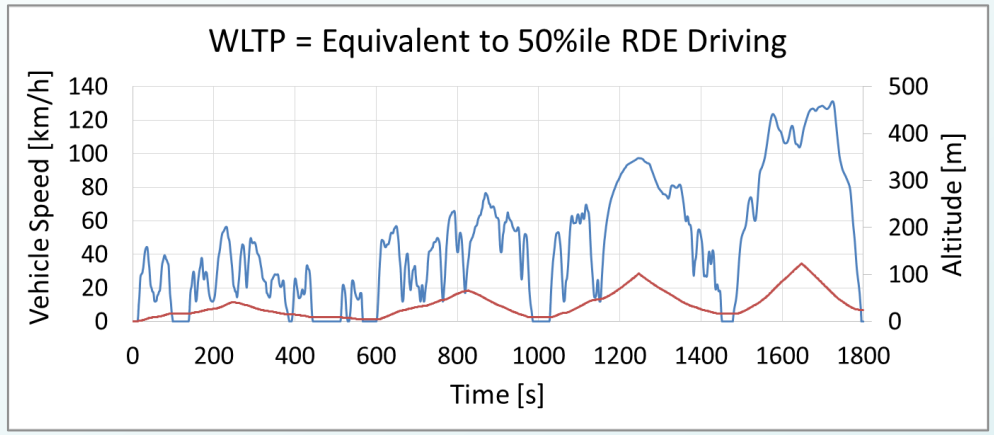
Limit derivation for the cumulative positive altitude gain.

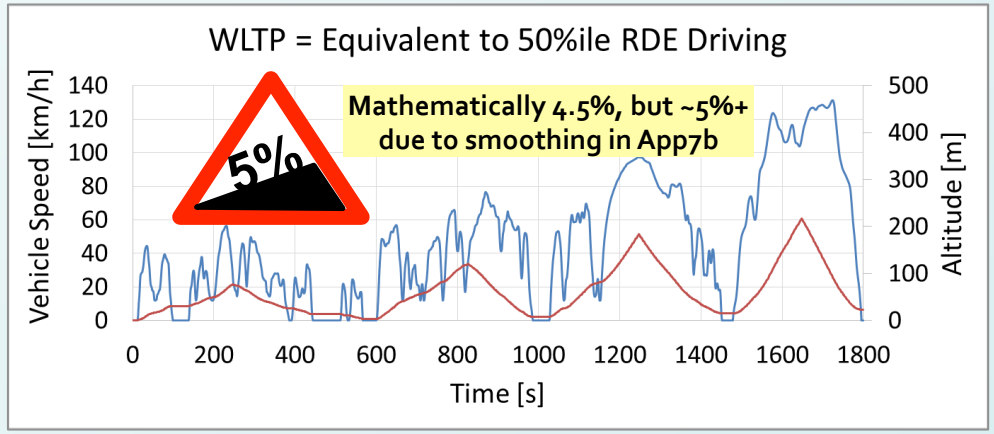
RDE Boundary Conditions
Cumulative Positive Altitude Gain

Positive Altitude Gain & Delta Elevation effect on "50%ile" driving:



1200m/100km. Plus 100m delta over typical RDE distance, therefore +25m over WLTP distance, results in:

- 9% increase in Cycle Energy.
- Equivalent to driving 9% further on a level road.



Removing the Positive Altitude gain limit and therefore experiencing RDE tests with, for example, 2255m/100km plus 100m delta over typical RDE distance results in:

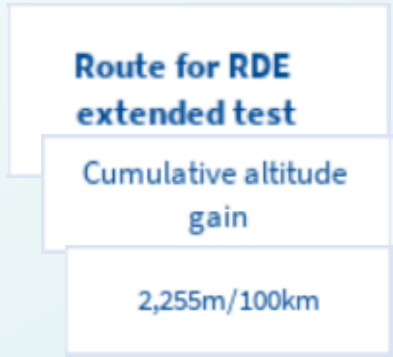
- 24% increase in Cycle Energy.
- Equivalent to driving 24% further on a level road.

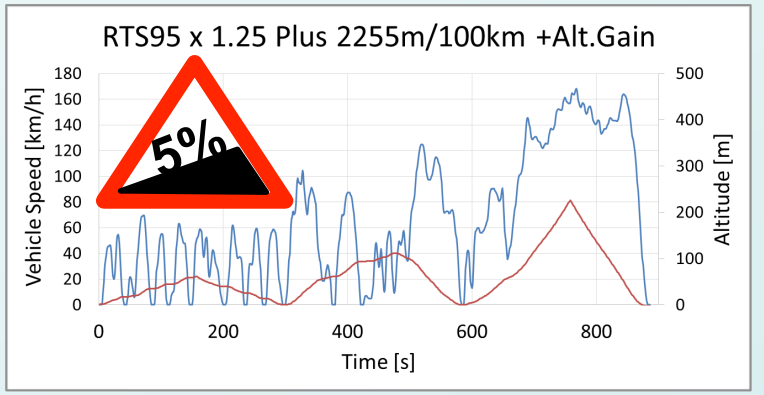
Removing the limit would introduce the potential for an unquantifiable increase in trip severity.

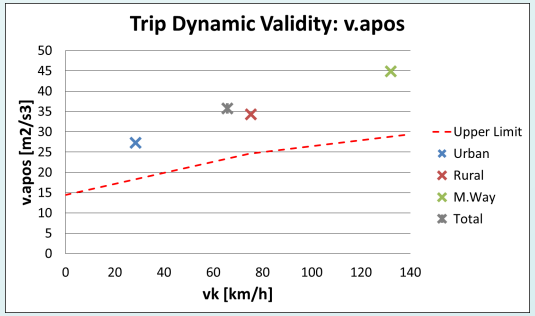
Overall RDE Cycle Energy (KJ/km) results from a combination of all of the test conditions experienced, with capability required in the face of the maximum levels of ***all*** conditions combined.

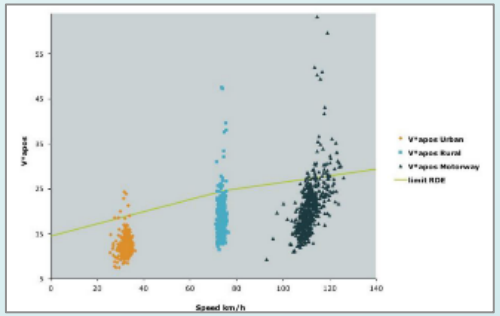
As discussed at RDE-LDV in 2017: a Euro6d RDE compliant combination of Payload, Dynamic Driving and Positive Altitude Gain can easily result in Cycle Energy > 150% of the WLTP reference cycle against which the emissions standards are set.

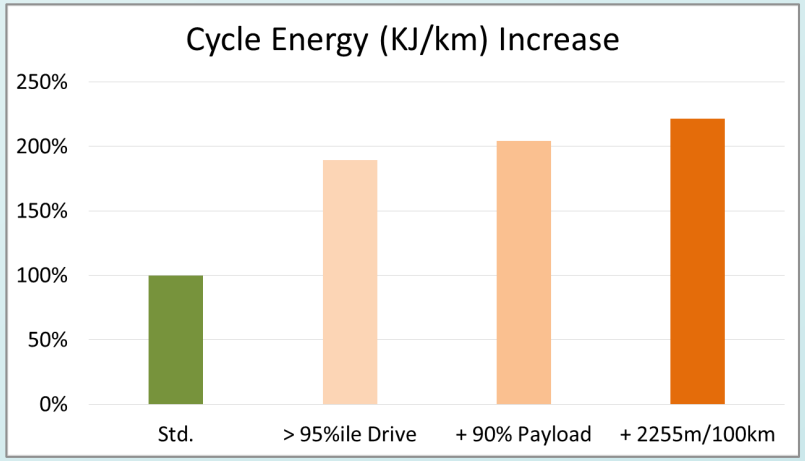
Extending this further, for example to the levels of Dynamic Driving and Positive Altitude gain that we have seen being called for (*T&E "Cars with engines: can they ever be clean?" September 2018*) would push this to > 200% of the WLTP reference Cycle Energy.











If no limit to worst case combinations, then it is reasonable to apply bounds to each individual condition.

RDE Boundary Conditions
Cumulative Positive Altitude Gain

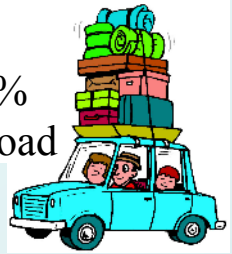
Compliance with RDE limits "*for all possible RDE tests*" is a significant challenge, requiring engineering sign-off testing under extreme combinations of conditions, e.g.

Cold Start / Ambient
3 > -2 > -7°C

Altitude 700>1300m
+ve Altitude Gain
1200m/100km

"None Shall Fail"

95%ile Driving Dynamics



90% Payload

Hot Ambient
30 > 35°C

An RDE test protocol that does not include limits on Boundary Conditions is not meaningful. No amount of testing would enable Type Approval to be anything other than a gamble against unknown combinations of conditions that may be used during ISC.

Without a limit on Positive Altitude Gain…

- *All testing on the most extreme gradients that can be found in Europe?*

- *Implications for a Global Test Requirement?*

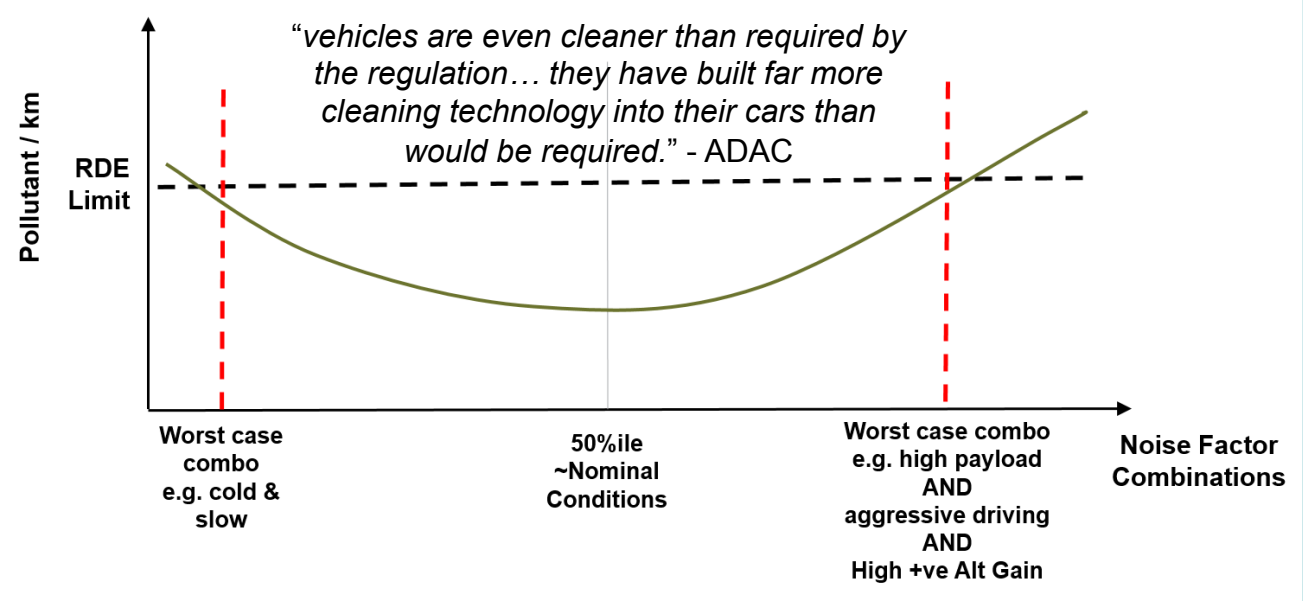
RDE test protocols should focus on conditions of relevance to real world air quality.

RDE Boundary Conditions
Cumulative Positive Altitude Gain

The challenge of meeting RDE limits against worst case combinations of conditions is resulting in the demonstration of an increasing number of examples, from Type Approval RDE tests and 'typical' real world driving (ADAC, etc.), of extremely low emissions results:

RDE, with limits applied to individual boundary conditions, is making a very significant difference for real world air quality… under the greatest majority of real world operating conditions.

vs. energy efficiency implications of extreme engineering solutions required to deliver emissions capability for conditions rarely experienced, except during intentionally focussed testing.



RDE needs to be balanced within the wider scope of sustainable mobility's environmental impact.

Therefore our proposal is that the limit on Cumulative Positive Altitude Gain must be kept in the RDE GTR Working Document.

Thank you.

Back-up Information

Interaction of CPAG / other Boundary Conditions with Appendix 6 Results Evaluation.

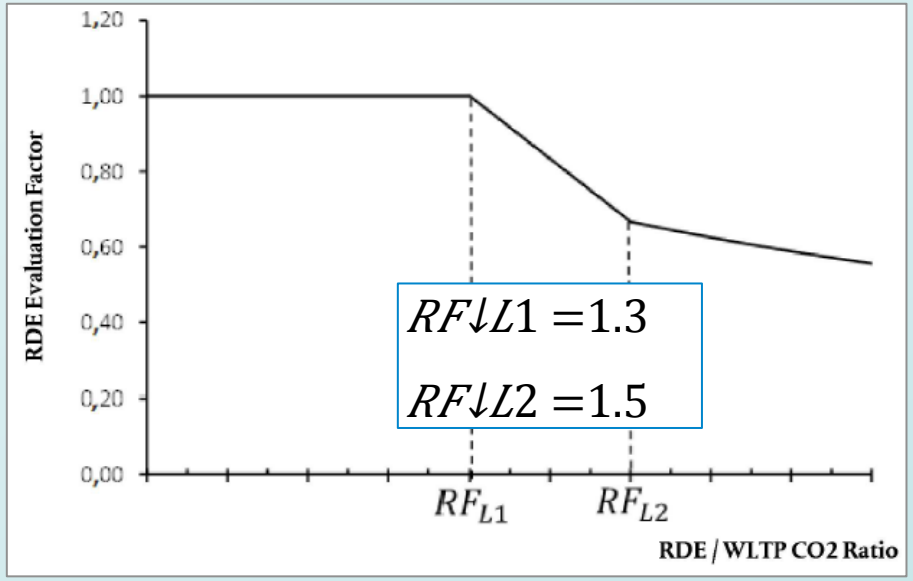
RDE Boundary Conditions
Cumulative Positive Altitude Gain

The application of Appendix 6 (Calculation of the Final RDE emissions results) is intended for valid trips only. Therefore if a biased trip is not recognized the CO2 normalization will apply with the following impact:

- A noticeable result evaluation factor (RF_k) starts only @150% (i.e. with a ratio between the CO2 emissions measured during the RDE test and the WLTP test of $r_k \geq RF_{L2} = 1{,}50$).
- The ratio r_k is derived using the distance-specific mass of CO2, emitted over the RDE trip (or the Urban part) as a "overall value" i.e. without consideration of locally occurring extreme values due to a biased trip composition. (which is ok for valid trips).

$$M\downarrow RDE,k = m\downarrow RDE,k \cdot RF\downarrow k$$

$$r\downarrow k = M\downarrow CO\downarrow 2,RDE,k / M\downarrow CO\downarrow 2,WL$$



RDE Boundary Conditions
Cumulative Positive Altitude Gain

As a result:

- It is already being seen that the outcome of App. 6 is not fully normalizing the emissions, due to the physics involved in emissions control systems.
- Necessarily resulting in Euro6d-RDE delivering great performance in driving conditions experienced by the majority of consumers, most of the time.
- Delivering real world air quality benefits.

Pushing further at the edges of the vehicle operational envelope will truly break the link with the real goal here, leading to the requirement for extreme engineering solutions – to deliver emissions capability for very unusual combinations of conditions… rarely experienced except during intentionally *focused* RDE testing.