WLTP-08-23e

WT+CD Validation Program
State of Progress

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WLTP Annex 4, November 18th 2014

Contents

- Objectives
- Test program
- Test procedure
- Results
  - Bias and dispersion of the methods
  - Influence of ambiant conditions
  - Comparison of the methods
- Status

Objectives

- RLD determination with “Wind-tunnel + chassis dyno” vs “coast-down”, to enable the introduction of the WT+CD method in GTR15
  - Comparison of both methods
  - Comparison of reproducibility for both methods
- Comparison of the running resistance measured with WT+CD with the ISO method (stabilized speeds) and by deceleration

Test Program

- Initial Tests
  - 3 Tracks
  - 2 Chassis dynos
  - 1 Wind tunnel

  N.B. : Dyno tests = 2 methods
  =ISO method (stabilized speed) + deceleration

- Supplemental tests : Car manufacturer vehicle exchange
  - Vehicles 1 & 3
    Track 4 + WT 2 + flat belt
  - Vehicle 6 : medium M1
    Track 3 + chassis dyno 2

Test Program

- Test Vehicles

	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5
Category	Light M1	Medium M1	High M1	Medium M1	N1
Gearbox	Manual	Manual	Automatic	Manual	Manual
Test mass (kg)	1104	1490	1808	1536	2110
Wheeldrive	4x2	4x2	4x2	4x4	4x2
Tire size	175/65 R14	195/65 R15	235/45 R18	215/65 R16	215/60R16
RRC [kg/t] *ISO*	7.9 *18164*	7.9 *8767*	8.5 / 8.8 *18164/28580*	8.3 *28580*	7.4 / 7.7 *18164/28580*
Cd.A*	0.673	0.748	0.610	1.006	1.150

* Measurements were carried out in this test program

Test Program

- Schedule
  - Track tests : finished
  - Wind tunnel measures : finished
  - Dyno tests : finished
  - Supplemental tests : on going (to be done by end of November)

Test Procedure

- Track tests
  - Step 1 : braking test
  - Step 2 : warming up during 20min at 118km/h (90% WLTC max speed)
  - Step 3 : 1min at 130km/h and 20s at 140km/h
  - Step 4 : coast down

- Dyno tests
  - Step 1 : id test track
  - Step 2 : id test track
  - Step 3 : id test track
  - Step 4 : 3 measurements

Results

- Number of measurements available

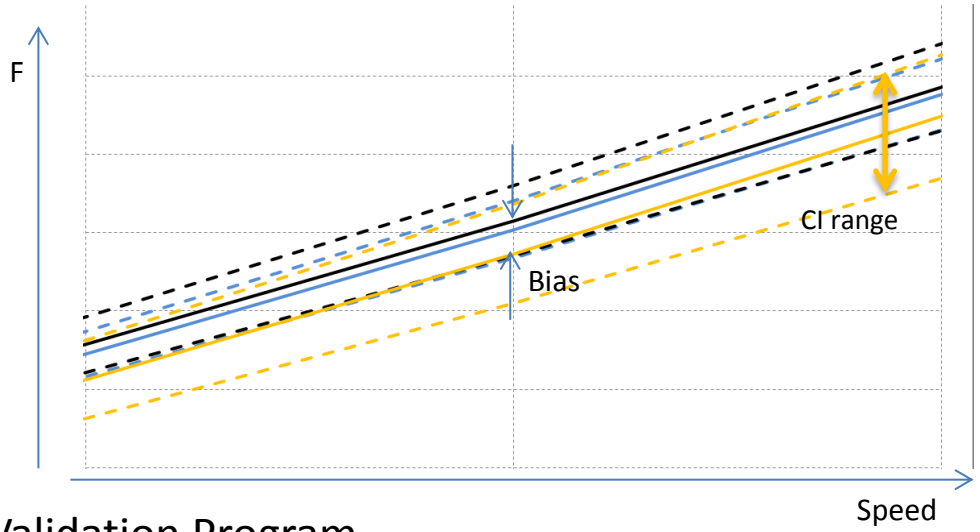
  Minimum of 3 consecutive pairs of measurements which satisfies 3% statistical accuracy

  Annex 4 4.3.1.4.2

	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5
Track 1	3 (5)	3 (5)	2 (4)	3 (5)	2 (2)
Track 2	2 (2)	2 (2)	-	1 (2)	2 (3)
Track 3	1 (1)	1 (2)	1 (1)	2 (2)	1 (1)
Dyno 1 - Deceleration	3	3	3	3	3
Dyno 1 - Stabilized	3	3	3	3	3
Dyno 2 - Deceleration	2	1	2	2	2
Dyno 2 - Stabilized	3	1	2	2	2

Bias & dispersion

- Each method is assessed with the calculation at each speed of:
  - The range between the averages of measurements done at each test facility (~bias of the method)
  - The dispersion estimated by a CI range (confidence interval)



Statistic tests

<u>Objective</u> = determine the dispersion of the measurements

- Dispersion: F-test (equality of two variances)

  Applicable where there is more than 1 test

  As dispersion appears to be similar for each track for a specific vehicle, the following assumption is made:

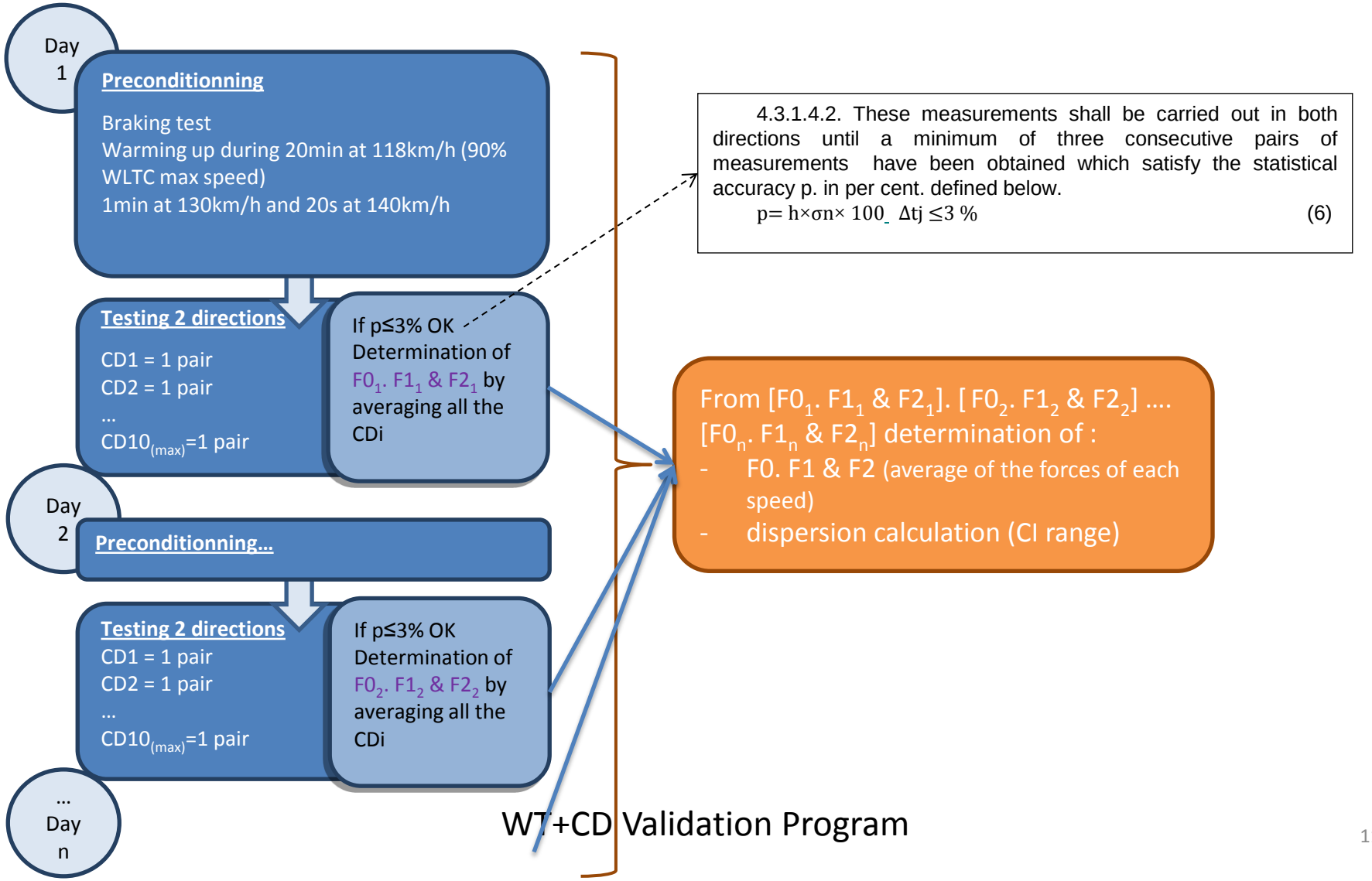
  ⇒ A common σ_{track} is taken for each vehicle, calculated using all the tests from all the tracks *(Obj= to limit the CI range width of the track tests due to a limited number of repetitions, hence a very high h factor)*

  ⇒ $\mathbf{CI} = \frac{\mathbf{h}.\boldsymbol{\sigma}_{\mathbf{track}}}{\sqrt{\mathbf{n}}}$ (h as defined in GTR15 Annex4 4.3.1.4.2, n number of tests)

  The same is done for chassis dyno results

- Vehicles with no possible statistic analysis
  - Vehicle 2 : no repeatability on chassis dyno 2
  - Vehicle 3 : no tests on track 2 & no repeatability on track 3

Track test Force determination



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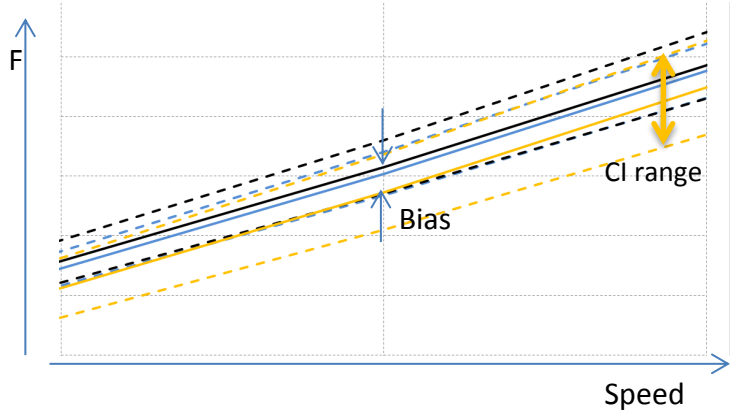
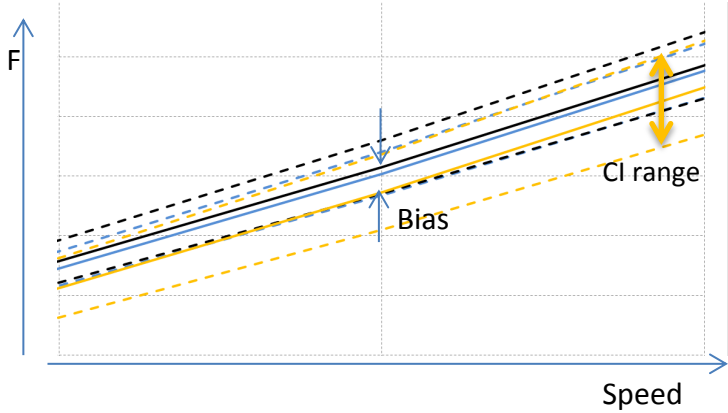
Range between the averages of measurements done at each test facility (~bias of the methods)



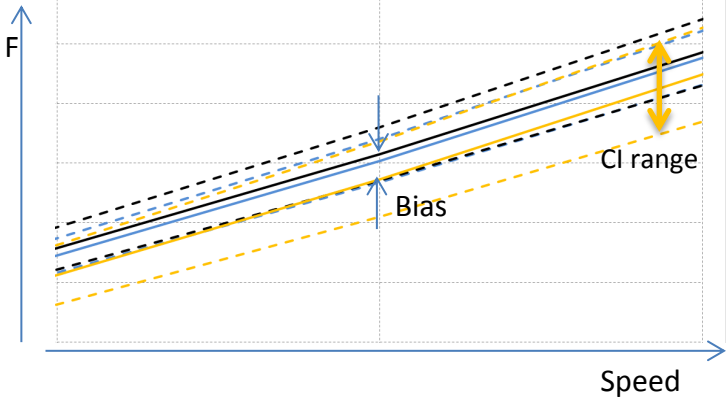
Method	Bias [N]	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5
Tracks	Mean	17.8/5.5%	19.0/6.0%	12.4/3.6%	12.5/2.6%	29.1/5.1%
	Min	3.7/3.2%	9.8/2.1%	**2.0/0.5%**	2.7/1.3%	17.2/4.4%
	Max	25.8/7.4%	23.0/**8.9%**	27.7/7.9%	17.5/3.4%	**51.9**/7.4%
Dynos Stab	Mean	4.8/2.2%	7.3/2.6%	7.5/2.1%	10.2/2.7%	4.7/0.9%
	Min	**4.0**/0.9%	4.1/**0.5%**	6.5/1.0%	9.5/1.1%	3.6/0.6%
	Max	6.3/6.0%	8.6/5.0%	8.0/3.0%	**11.7/6.3%**	7.4/2.0%
Dynos Decel	Mean	3.5/2.0%	3.1/2.2%	4.4/1.4%	4.4/0.8%	6.2/1.2%
	Min	**0.2/0.0%**	**0.2/0.0%**	**0.2/0.0%**	0.5/0.2%	3.6/0.7%
	Max	7.3/**6.8%**	5.5/3.9%	8.0/3.7%	**9.7**/1.9%	8.5/1.6%

Dispersion of the methods: CI range



Method	CI range [N]	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5
Tracks	Mean	32.6/9.7%	24.2/5.3%	-	15.3/4.1%	62.6/9.1%
	Min	**1.7**/1.6%	2.3/1.7%	-	9.6/**1.0%**	6.3/2.4%
	Max	55.9/14.8%	68.3/8.8%	-	35.2/**17.1%**	**125.8**/11.6%
Dynos Stab	Mean	2.7/1.2%	4.5/1.6%	17.9/6.3%	9.6/3.7%	22.3/3.7%
	Min	**1.5/0.5%**	3.6/0.6%	10.4/1.6%	6.7/0.7%	15.6/1.5%
	Max	5.2/3.9%	7.6/2.7%	27.3/11.8%	12.6/7.2%	**31.1/14.0%**
Dynos Decel	Mean	2.1/1.1%	4.5/1.6%	25.5/7.0%	16.6/4.1%	16.3/4.2%
	Min	**1.1/0.3%**	3.8/0.9%	4.6/2.1%	9.9/1.7%	10.6/1.0%
	Max	4.9/4.6%	7.6/2.8%	33.4/15.4%	15.4/9.1%	**38.1/17.0%**

Bias & dispersion of each method



- **Bias**
  - The range between the tracks results go from:
    - **2N to 52N**
    - 0.5% to 8.9%
  - The range for the 2 WT+CD are all **under or close to 10N**; but reflect only the bias due to chassis dyno measurements as the tests were not repeated in the WT (only 1 Cd.A measurement carried out for each vehicle)

    => the WT+CD offer a better « reproducibility between the test facilities »

- **Dispersion**
  - The CI range for tracks go from:
    - **1.5N to 125.8N**
    - 1.0% to 17.1%
  - The CI range for the WT+CD stab go from:
    - **1.5N to 31.1**N
    - 1.7% to 17% (% are equivalent to tracks because dispersion is mainly at low speeds due to no WT repetitions)

    => the WT+CD offer a better « repeatability » (done w/o WT repetitions, but still at lower speeds where aero has less influence the dispersion is higher with track measurements)

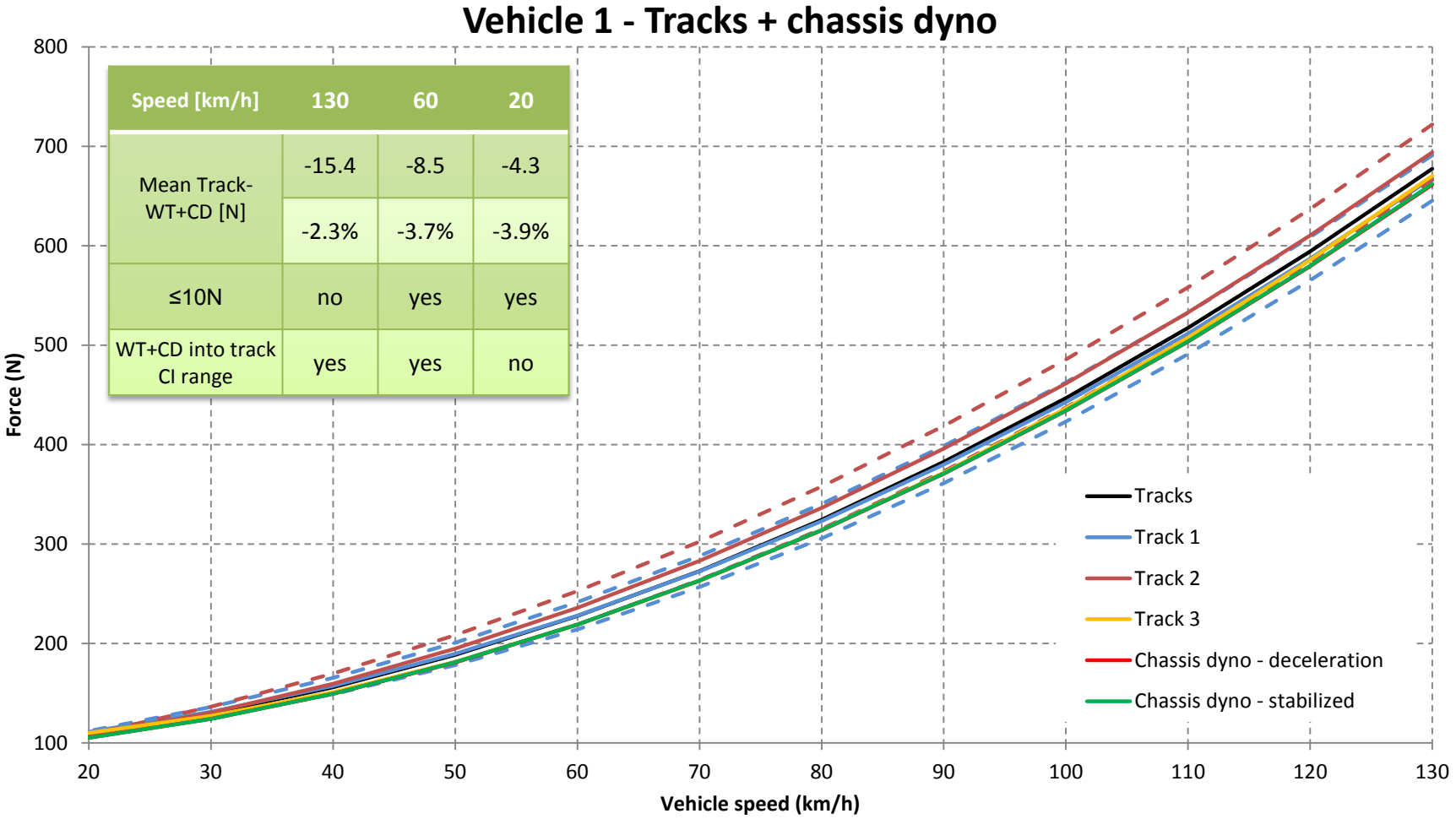
Comparison of the methods

Because the WT+CD methods have smaller bias and dispersion, in order to ease the reading of the graphs, only the mean value of all the measurements is shown

The calculation are done with the WT+CD stabilized method

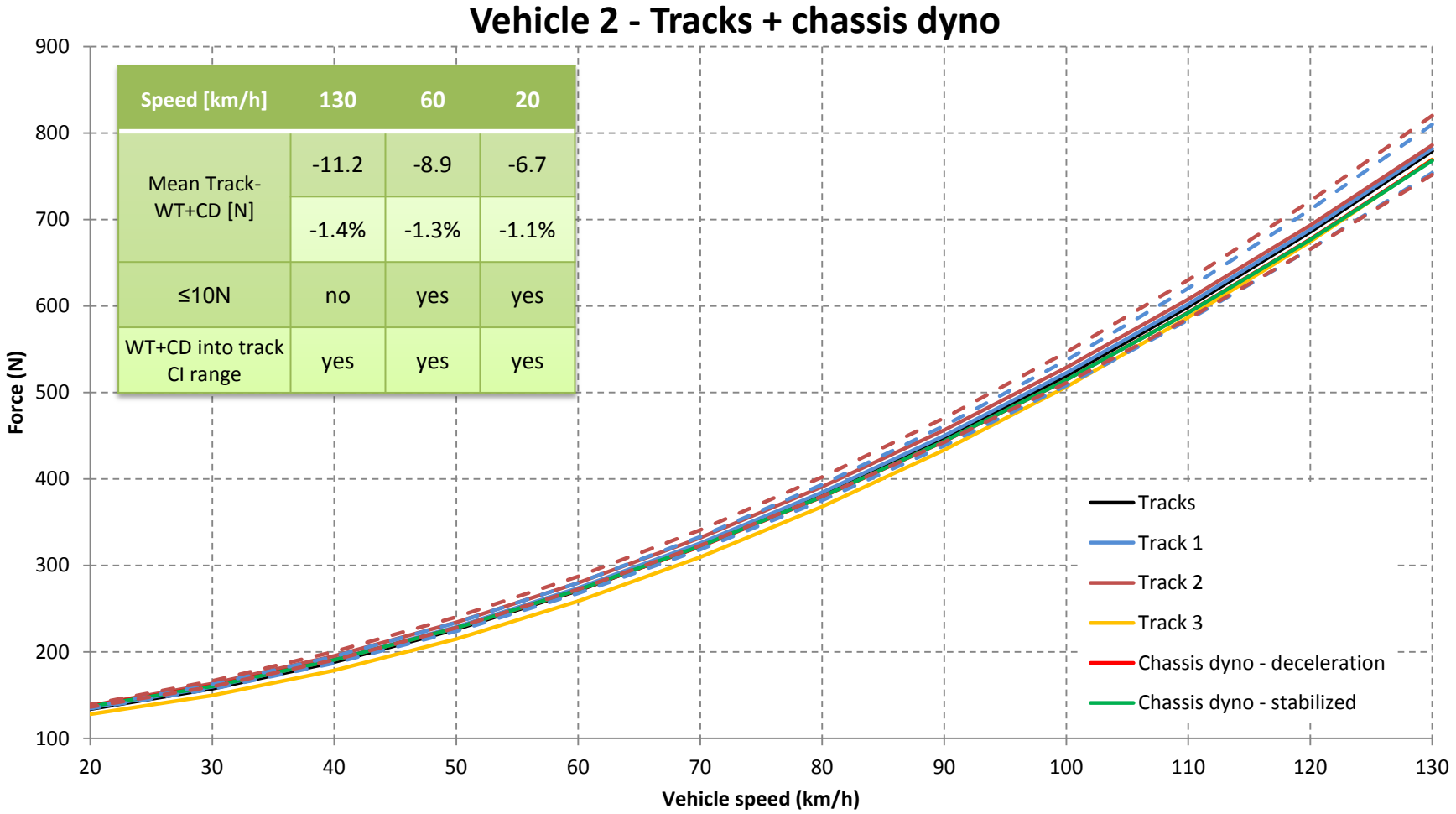
Mean Track and WT+CD results

Speed [km/h]	130	60	20
Mean Track-WT+CD [N]	-15.4	-8.5	-4.3
	-2.3%	-3.7%	-3.9%
≤10N	no	yes	yes
WT+CD into track CI range	yes	yes	no



Mean Track and WT+CD results

Speed [km/h]	130	60	20
Mean Track-WT+CD [N]	-11.2	-8.9	-6.7
	-1.4%	-1.3%	-1.1%
≤10N	no	yes	yes
WT+CD into track CI range	yes	yes	yes



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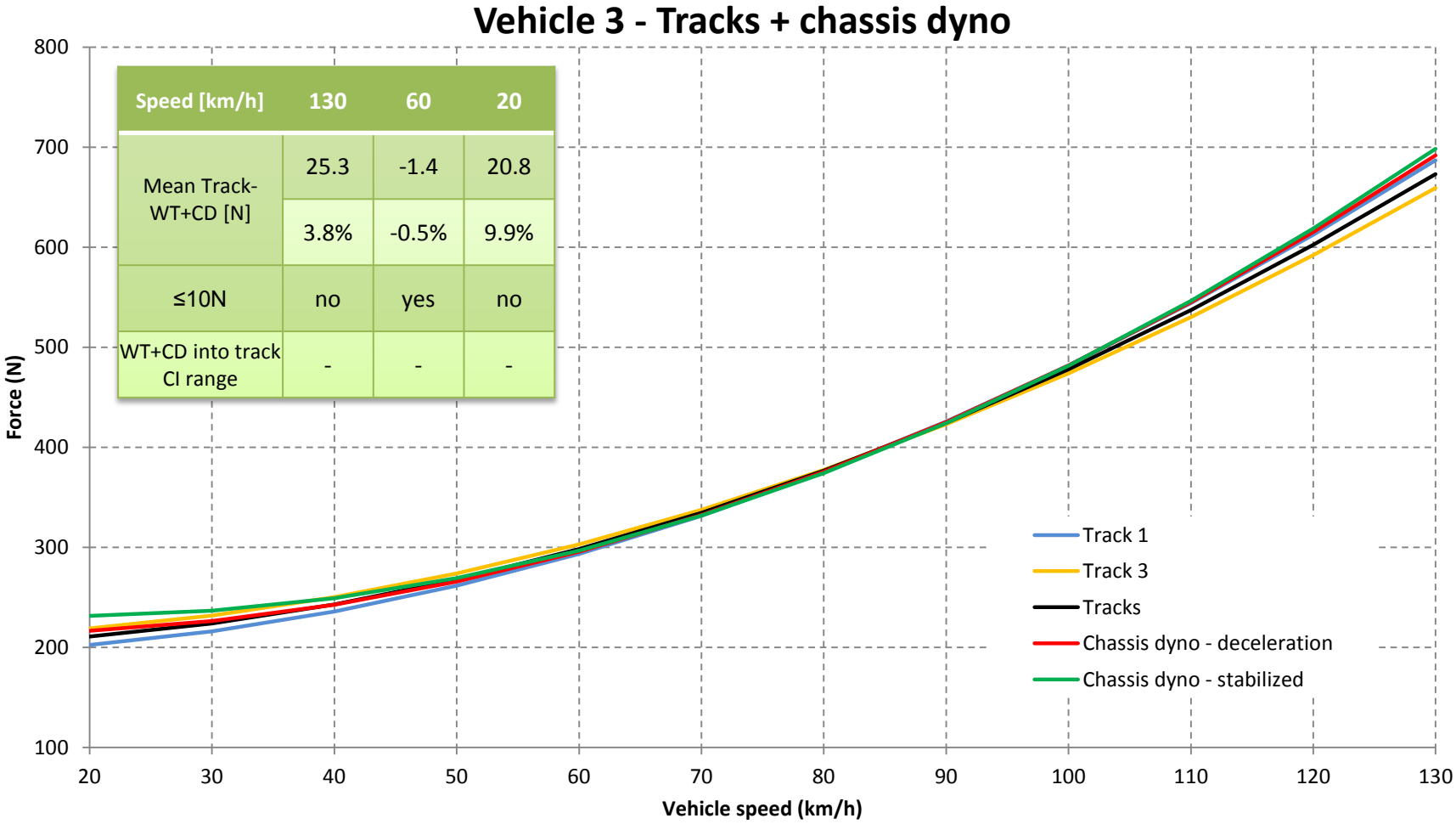
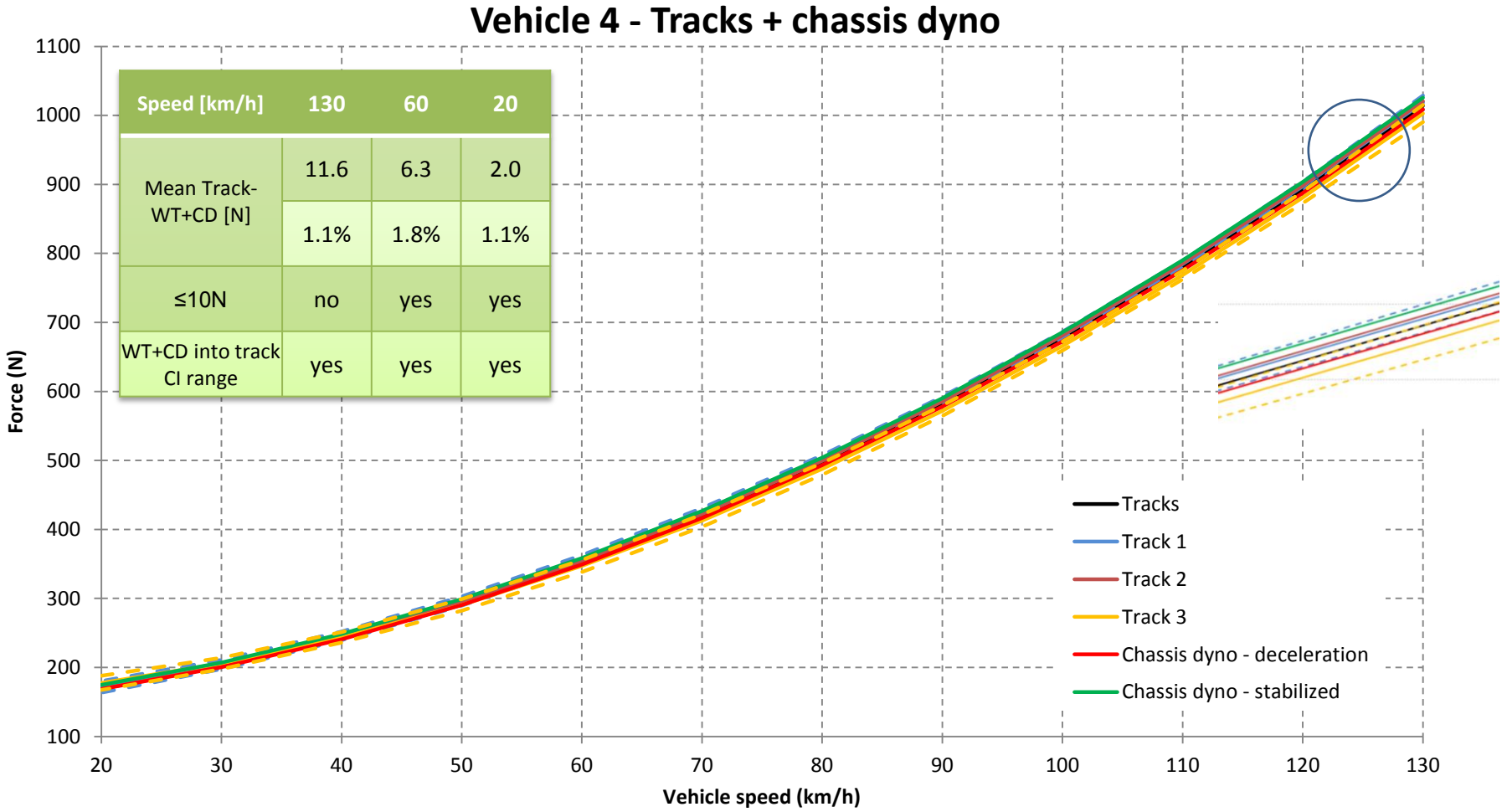
Mean Track and WT+CD results

Speed [km/h]	130	60	20
Mean Track-WT+CD [N]	25.3	-1.4	20.8
	3.8%	-0.5%	9.9%
≤10N	no	yes	no
WT+CD into track CI range	-	-	-



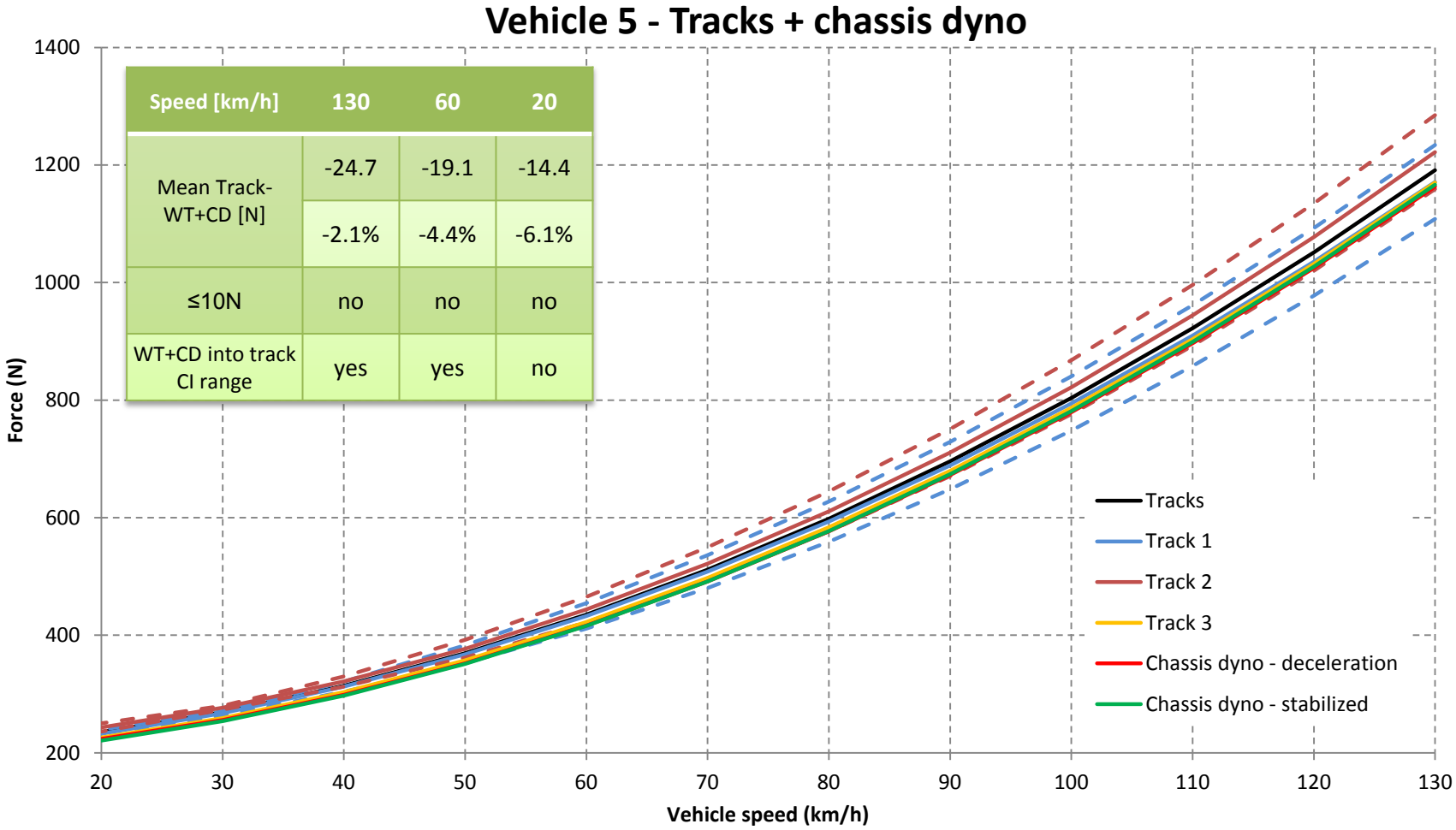
Mean Track and WT+CD results

Speed [km/h]	130	60	20
Mean Track-WT+CD [N]	11.6	6.3	2.0
	1.1%	1.8%	1.1%
≤10N	no	yes	yes
WT+CD into track CI range	yes	yes	yes



Mean Track and WT+CD results

Speed [km/h]	130	60	20
Mean Track-WT+CD [N]	-24.7	-19.1	-14.4
	-2.1%	-4.4%	-6.1%
≤10N	no	no	no
WT+CD into track CI range	yes	yes	no



Comparison between the methods

- The WT+CD method gives results that differ from
  - are usually <10N (apart from N1 vehicle)
  - -6.1% to +1.8% (+9.9% including V3) from the track

  ⇒Difference between WT+CD and track average results are in the order of magnitude of the bias and the dispersion of the tracks

Influence of correction factors

- The tests on the tracks were carried out in very stable conditions
  => Corrections factors are low
  => Difficult to study ambient conditions influence

$$F^* = \left((f_0 - w_1 - K_1) + f_1 v\right) \times \left(1 + K_0(T - 293\_K)\right) + K_2 f_2 v^2$$

Maximum abs values		V1	V2	V3	V4	V5
Mass	**K_1 [N]**	**0.5**	**0.9**	**0.3**	**2.1**	**1.0**
Wind (all tests done <3m/s)	Speed [m/s]	1.0	1.0	0.9	1.0	1.6
	w_1 [N]	**0.2**	**0.2**	**0.2**	**0.2**	**0.7**
Temp (all tests done >20°C)	Mean T° [°C]	23.8	25.9	25.7	27.4	26.6
	T° gradient [K]	3.0	5.2	3.0	4.7	5.4
	K_0' factor	**1.061**	**1.051**	**1.049**	**1.064**	**1.057**
	K_2 factor	**1.031**	**1.031**	**1.037**	**1.031**	**1.046**

Influence of correction factors

N	V1					
	T1	T1	T1	T2	T2	T3
130	-0.6	9.0	9.4	18.9	3.5	18.0
120	-0.2	8.4	8.7	17.2	3.3	15.5
110	0.1	7.9	8.1	15.5	3.1	13.2
100	0.4	7.4	7.5	14.0	3.0	11.0
90	0.7	6.9	7.0	12.6	2.8	9.1
80	0.9	6.4	6.5	11.3	2.6	7.4
70	1.1	5.9	6.0	10.0	2.4	5.9
60	1.3	5.5	5.7	8.9	2.2	4.6
50	1.4	5.1	5.3	7.9	2.1	3.5
40	1.5	4.7	5.0	7.0	1.9	2.6
30	1.6	4.3	4.8	6.2	1.8	1.9
20	1.6	3.9	4.6	5.5	1.6	1.3

N	V2					
	T1	T1	T1	T2	T2	T3
130	6.5	11.0	13.1	6.8	7.5	20.6
120	6.3	10.3	12.1	6.4	7.0	17.8
110	6.1	9.7	11.3	5.9	6.6	15.1
100	5.9	9.1	10.4	5.5	6.1	12.8
90	5.7	8.6	9.7	5.1	5.7	10.6
80	5.5	8.0	8.9	4.7	5.3	8.7
70	5.3	7.5	8.3	4.3	4.9	7.0
60	5.1	7.0	7.7	4.0	4.5	5.5
50	4.8	6.5	7.1	3.7	4.2	4.2
40	4.6	6.1	6.6	3.4	3.9	3.2
30	4.4	5.6	6.2	3.1	3.6	2.3
20	4.1	5.2	5.8	2.8	3.3	1.7

N	V3		
	T1	T1	T3
130	11.0	2.5	22.7
120	10.6	2.7	20.3
110	10.3	2.9	18.1
100	10.1	3.0	16.0
90	9.8	3.2	14.2
80	9.6	3.4	12.5
70	9.4	3.5	11.1
60	9.2	3.7	9.8
50	9.1	3.8	8.8
40	9.0	3.9	7.9
30	8.9	4.0	7.3
20	8.8	4.1	6.8

N	V4					
	T1	T1	T1	T2	T3	T3
130	8.6	23.7	1.0	31.3	26.6	12.6
120	8.2	21.8	1.3	28.2	23.0	10.3
110	7.8	20.1	1.6	25.3	19.6	8.2
100	7.5	18.4	1.8	22.6	16.5	6.2
90	7.1	16.9	2.0	20.1	13.8	4.5
80	6.7	15.5	2.2	17.9	11.3	2.9
70	6.3	14.2	2.3	15.8	9.1	1.6
60	5.9	13.1	2.4	13.9	7.1	0.4
50	5.6	12.0	2.4	12.3	5.5	-0.6
40	5.2	11.1	2.4	10.8	4.2	-1.4
30	4.8	10.3	2.3	9.5	3.1	-1.9
20	4.3	9.6	2.3	8.5	2.3	-2.3

N	V5				
	T1	T1	T2	T2	T3
130	25.2	9.0	25.0	20.7	54.5
120	23.6	8.7	22.7	18.8	48.3
110	22.0	8.5	20.4	17.1	42.6
100	20.5	8.2	18.4	15.4	37.3
90	19.1	8.0	16.5	13.9	32.5
80	17.7	7.8	14.8	12.6	28.2
70	16.5	7.5	13.3	11.4	24.3
60	15.3	7.3	12.0	10.3	20.9
50	14.2	7.1	10.8	9.3	17.9
40	13.2	6.8	9.8	8.5	15.4
30	12.2	6.6	8.9	7.9	13.4
20	11.3	6.4	8.3	7.3	11.9

=> Corrections factors are less than 5%

Status

- Despite some tests w/o repeatability, there is a sufficient database to work on
- Stable test conditions on the tracks make it difficult to have a clear study on the influence of ambient conditions parameters (it was not the initial aim of this program)
- WT+CD offer a better repeatability & reproducibility than the track method
- WT+CD results are close to track results (usually <10N)

- <u>Upcoming</u>
  - Supplementary tests results
  - Chassis dyno curve correction factor approach