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Heavy commercial vehicles and buses — Test method for yaw stability — Sine with dwell test

Véhicules utilitaires lourds et autobus — Méthodes d’essai pour la stabilité en lacet — Essai de sinus modifié avec pause

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Contents

Page

Foreword

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The committee responsible for this document is ISO/TC 22, *Road vehicles*, Subcommittee SC 33, *Vehicle dynamics and chassis components*.

Introduction

The main purpose of this International Standard is to provide repeatable and discriminatory test results.

The dynamic behaviour of a road vehicle is a very important aspect of active vehicle safety. Any given vehicle, together with its driver and the prevailing environment, constitutes a closed-loop system that is unique. The task of evaluating the dynamic behaviour is, therefore, very difficult since the significant interaction of these driver vehicle-environment elements are each complex in themselves. A complete and accurate description of the behaviour of the road vehicle requires information obtained from a number of different tests.

Since this test method quantifies only one small part of the complete vehicle handling characteristics, the results of these tests can only be considered significant for a correspondingly small part of the overall dynamic behaviour.

Moreover, insufficient knowledge is available concerning the relationship between overall vehicle dynamic properties and accident avoidance. A substantial amount of work is necessary to acquire sufficient and reliable data on the correlation between accident avoidance and vehicle dynamic properties in general and the results of these tests in particular. Consequently, any application of this test method for regulation purposes will require proven correlation between test results and accident statistics.

Heavy commercial vehicles and buses — Test method for yaw stability — Sine with dwell test

1 Scope

This International Standard describes an open-loop test method for determining the yaw stability of a vehicle on a low friction road surface. It applies to heavy vehicles, that is commercial vehicles, commercial vehicle combinations, buses and articulated buses as defined in ISO 3833 (trucks and trailers with maximum weight above 3,5 tonnes and buses and articulated buses with maximum weight above 5 tonnes, according to ECE and EC vehicle classification, categories M3, N2, N3, O3 and O4).

The method is intended for vehicles equipped with electronic yaw-stability control systems.

As the results of this test depend largely on local and temporary changes in road surface friction, this International Standard gives recommendations about keeping the friction level as uniform as possible for good reproducibility of the test results.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 15037-2:2002, *Road vehicles — Vehicle dynamics test methods — Part 2: General conditions for heavy vehicles and buses*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8855, ISO 15037-2 and the following apply.

3.1
beginning of steer input
T_0
time when the steering-wheel angle input is started

3.2
end of steer input
T_1
time when the steering-wheel angle returns to zero at the completion of the sine with dwell steer input

3.3
dwell time
T_d
time interval when the steer input remains constant at absolute maximum amplitude

3.4
steer frequency
f

$$f = \frac{1}{T_1 - T_0 - T_d}$$

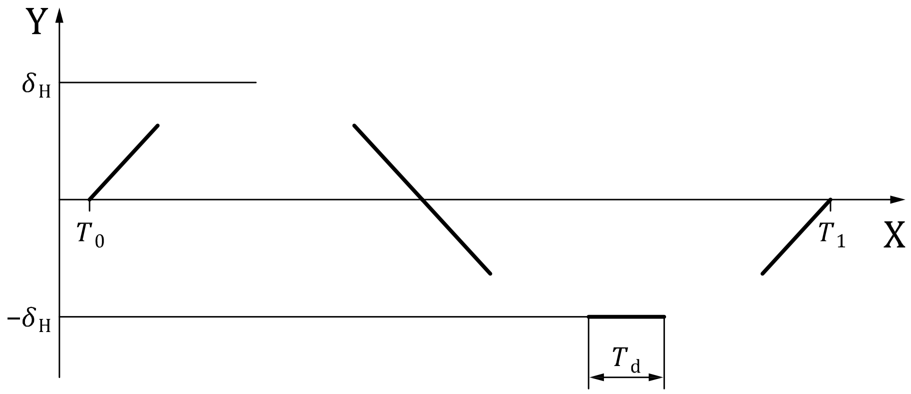
3.5
maximum steady-state lateral acceleration
maximum lateral acceleration that the vehicle can sustain for the selected test surface during steady-state cornering at the selected constant longitudinal velocity without yaw or roll instability when the electronic stability control system is disabled.

3.6
steady-state steering-wheel angle amplitude
δ_{Hss}
smallest steering-wheel angle amplitude at *maximum steady-state lateral acceleration* (3.5)

3.7
time delay
ΔT_i
time difference between the yaw velocity of the *i:th* unit and the yaw velocity of the first unit at their first zero crossing when performing the sine with dwell with steady-state steering-wheel angle amplitude, δ_{Hss}, when $0{,}5 / f + T_0 < t < T_1$

4 Principle

The objective of this test method is to study the yaw-stability control of a vehicle on a low friction surface with a selected initial longitudinal velocity, v_{x0}, which is subjected to a steering-wheel input by a steering machine. The steer input is a sine with dwell of steer frequency, f, and dwell time, T_d, as shown in Figure 1. The steering-wheel angle amplitude, δ_H, is increased in steps until yaw instability occurs. The results are evaluated with respect to responsiveness, yaw stability, and yaw angle after completion of steer.



Key
X time
Y steering wheel angle

Figure 1 — Steering-wheel angle input

5 Measuring equipment

The measuring equipment, transducer installation, and data processing shall be in accordance with ISO 15037-2.

6 Variables

The variables that shall be determined for compliance with this International Standard are the following:

— steering-wheel angle, δ_H;

— longitudinal velocity, v_x;

— lateral acceleration, a_y;

— yaw velocity of each unit, $\dot{\psi}_i$;

— yaw angle of the first unit, ψ_1;

— lateral displacement of the first vehicle unit's first axle, Y_1;

— indication of intervention of the electronic stability control system (e.g. roll and yaw);

— articulation angles between vehicle units, $\Delta\psi_i$;

— indication of the engagement of the anti-jack-knife device.

It is recommended that the following variables also be determined:

— global position of the first vehicle unit;

— lateral velocity, v_y, and/or body side slip angle, β, of the first unit;

— roll angle and roll rate;

— longitudinal acceleration, a_x;

— wheel brake pressures, p_B;

— rotational velocity of wheels, ω_i;

— retarder operation;

— requested engine torque;

— actual engine torque;

— indication of the outriggers touching the ground.

Typical operating ranges of the variables to be determined for this International Standard are shown in Table 1 and in ISO 15037-2.

Table 1 — Variables, typical operating ranges and recommended maximum errors of variables not listed in ISO 15037-2

Variable	Typical operating range	Recommended maximum errors of the combined transducer and recorder system
Brake pressure in air systems	0 kPa to 1 500 kPa	±15 kPa
Brake pressure in hydraulic systems	0 MPa to 30 MPa	±0,3 MPa
Rotational velocity of wheels	0°/s to 4 000°/s	±5°/s
Lateral displacement	±10 m	±0,1 m
Yaw angle	±180°	±1°

7 Test conditions

7.1 General

The test conditions described in ISO 15037-2 along with the following changes and additions shall apply to this International Standard.

7.2 Test track

All standard tests should be carried out on an even test surface with a uniform coefficient of friction. The friction coefficient should not be below 0,1 or exceed 0,3. The standard friction coefficient is 0,2. The friction coefficient shall be estimated before each test series is conducted. It is recommended that the estimation is conducted by full ABS braking. For each test series, the test surface conditions, friction coefficient, and paving material shall be reported. As the results of this test depend largely on local and temporary changes in road surface friction, this International Standard gives recommendations about keeping the friction level as uniform as possible for good reproducibility of the test results.

Frozen lakes are often used to achieve large, open and flat test surfaces. A uniform test surface is required in order to reduce the effects of friction variations on the test results and, consequently, the test surface should be newly prepared with all excess snow removed. Factors affecting the friction coefficient include sunshine, wind, ambient temperature, fresh snow and test surface usage.

NOTE If a frozen lake is to be used as a test surface, then the maximum vehicle load and/or test speed can be limited by the strength of the ice.

7.3 Test vehicle

7.3.1 Safety equipment

An anti-jack-knife device shall be used on vehicle combinations. It shall allow articulation angles large enough not to influence the maximum performance of the electronic stability control system. Outriggers shall be used when there is a risk of rollover. The outriggers should be mounted at a height that corresponds to roll instability.

NOTE There is a risk of rollover when the test surface friction coefficient exceeds 0,3 and/or the vehicle loading configuration results in a high centre of gravity.

7.3.2 Loading conditions

The loading conditions shall be in accordance with ISO 15037-2.

7.3.3 Test equipment

The vehicle shall be equipped with a steering machine including driver emergency override functionality. The machine shall be programmable for the sine with dwell input with different amplitudes and frequencies. The steering machine should fulfil the requirements shown in Table 2.

Table 2 — Performance requirements on the steering machine

Variable	Typical operating range	Recommended maximum errors of the combined transducer and recorder system
Steering-wheel torques	-40 Nm to 40 Nm	±0,2 Nm
Steering-wheel amplitude	-360° to 360°	0,25°

8 Test method

8.1 Initial driving condition

The initial condition for the test shall be driving straight ahead as specified in ISO 15037-2. A nominal initial longitudinal velocity, v_{x0}, is recommended to be selected between 40 km/h to 80 km/h. The standard longitudinal velocity is 50 km/h. It is also recommended to conduct the test at higher velocity if possible.

8.2 Determination of the initial steering-wheel angle amplitude

The vehicle shall be driven at the selected initial longitudinal velocity throughout the test. The steering-wheel angle amplitude is slowly increased until maximum steady state lateral acceleration is reached, which corresponds to the steering-wheel angle amplitude, δ_{Hss}.

NOTE To save time, an estimation of δ_{Hss} based on wheelbase, understeer gradient, steering ratio, friction coefficient, and initial longitudinal velocity can be used to determine the initial steering-wheel angle amplitude.

8.3 Performance of the steering procedure

The steer input shall be as described in Figure 1. After the time, T_1, the steer angle shall be zero until the test run is finished. During the whole manoeuvre, the accelerator pedal shall be kept constant or cruise control shall be used. Either option shall be used for the whole test series. For manual transmissions, a gear position that gives an engine speed as close as possible to the maximum rpm shall be chosen. If the vehicle is equipped with a mechanical differential lock, it shall be disengaged.

To assure oversteering behaviour in the second phase of the manoeuvre, it is recommended that the steer input frequency, f, is between 0,2 Hz and 0,5 Hz and the dwell time ,T_d, is between 0,5 s and 1 s. The standard steer frequency is f = 0,3 Hz with a dwell time of T_d = 0,75 s. Other frequencies and dwell times, within the specified ranges, are also recommended to be evaluated in order to obtain a more comprehensive characterization of the vehicle performance. The initial steering input amplitude shall be just below δ_{Hss} and is incremented in steps not exceeding 5° for subsequent test runs. Each test run shall be repeated at least three times in both the clockwise and counter clockwise turn directions.

The amplitude error compared to the true wave form may not exceed ±0,5 % of the first peak. A test run is finished after reaching steady state or when severe yaw or roll instability occurs.

9 Data evaluation

9.1 General

General data and test conditions shall be presented in the test report in accordance with ISO 15037-2:2002, Annex A. For every change in vehicle loading or configuration, the general data shall be documented.

For every test run, time histories of the variables listed in Clause 6 shall be presented. Apart from their evaluation purposes, the time histories serve to monitor correct test performance and functioning of the transducers.

9.2 Characteristic values

The following characteristic values shall be determined for each individual test run.

responsiveness

d_y

absolute lateral displacement value of the first vehicle unit's first axle at time $0{,}5 / f + T_0$ after start of sine steer input with frequency, f

If there is a deceleration induced by the electronic stability control system during the first part of the manoeuvre, it will affect the travelled distance at time $0{,}5 / f + T_0$. The travelled distance should then be taken into account when comparing responsiveness results.

yaw stability factor

YSF

absolute yaw velocity of each vehicle unit at a specific time t after completion of steer with respect to the absolute peak value of the first unit's yaw velocity, $\dot{\psi}_{1,\text{peak}}$

$\dot{\psi}_{1,\text{peak}}$ is given by:

$$\dot{\psi}_{1,\text{peak}} = \max(|\dot{\psi}_1(0{,}5 / f + T_0 \leq Time \leq T_1)|) \tag{1}$$

The yaw stability factor (YSF) for the first vehicle unit:

$$YSF_1(t + T_1) = \frac{|\dot{\psi}_1(t + T_1)|}{|\dot{\psi}_{1,\text{peak}}|} \tag{2}$$

for the towed vehicle units:

$$YSF_\text{i}(t + T_\text{i}) = \frac{|\dot{\psi}_\text{i}(t + T_\text{i})|}{|\dot{\psi}_{1,\text{peak}}|} \tag{3}$$

for vehicle units with $i > 1$.

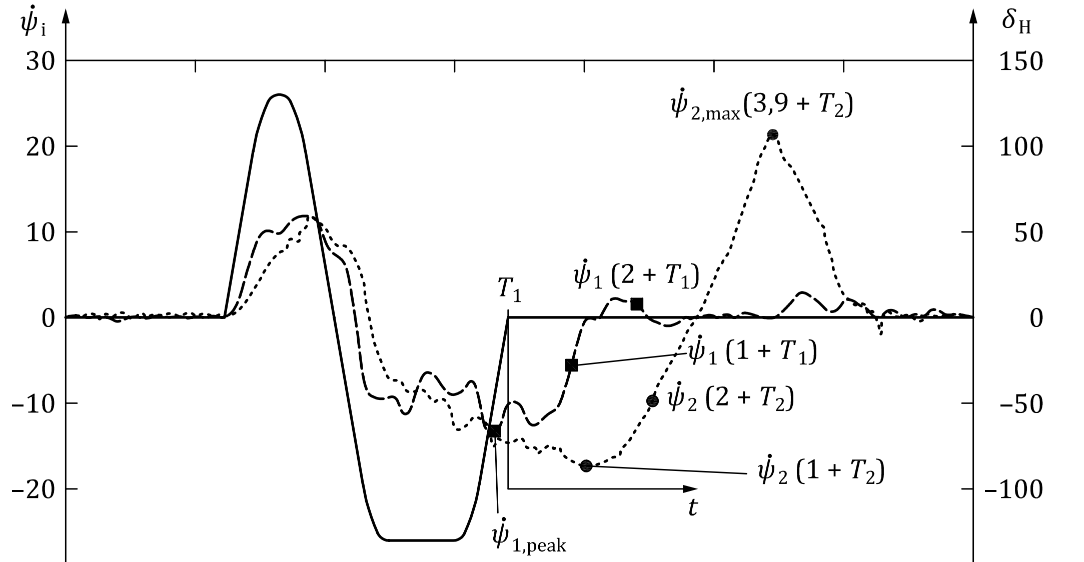
The maximum yaw stability factor:

$$YSF_{\text{i,max}} = \frac{|\dot{\psi}_{\text{i,max}}(t + T_\text{i})|}{|\dot{\psi}_{1,\text{peak}}|} \tag{4}$$

for vehicle units with $i > 1$

where $|\dot{\psi}_{1,\text{peak}}|$ is the absolute value of the second peak, $T_\text{i} = T_1 + \Delta T_\text{i}$, which is including the time delay in yaw velocity between unit 1 and i, $|\dot{\psi}_{\text{i,max}}|$ is the absolute value of the second peak of the following units. Fast convergence to zero of the YSF implies good stability. If the YSF increases with time, it implies instability. These tendencies may be evaluated on a continuous basis or by using a limited number of points in time, not less than two.

Figure 2 shows an example from a test with a tractor semitrailer combination. Figure 2 shows the yaw velocities needed for YSF calculations according to Formulae (2) and (3). The last peak of yaw velocity of the semitrailer occurred due to activation of anti-jack-knife protection.



Key

$\dot{\psi}_i$ yaw velocity (deg/s)

δ_H steering Wheel angle (deg)

t time (s)

NOTE Solid, dashed, and dotted lines correspond to steering wheel angle, yaw velocity tractor, and yaw velocity semitrailer, respectively. Yaw velocities at t = 1 and t = 2 s are marked.

Figure 2 — Tractor semitrailer combination experiencing trailer swing out after completion of steer, equipped with anti-jack-knife protection

final yaw angle

$\psi_{1,final}$

yaw angle of the first unit at the completion of a test run where the vehicle attains a steady state condition

NOTE For an initial counter clockwise steering, a negative value of final yaw angle is expected and positive sign for initial clockwise steering.

maximum yaw angle

maximum yaw angle of the first unit during the test run

The following characteristic values shall be determined for vehicle combinations.

maximum articulation angle

maximum articulation angle between units shall be evaluated

indication of anti-jack-knife protection

by activated anti-jack-knife protection

The following characteristic is optional.

indication of roll instability

by outriggers touching the ground

Annex A
(normative)

Test report — General data and test conditions

A.1 General data

The test report for general data shall be as given in ISO 15037-2:2002, Annex A.

A.2 Test conditions

The test report for test conditions shall be as given in ISO 15037-2:2002, Annex B.

Annex B
(informative)

Example of reporting of sine with dwell tests

Table B.1 — Simulation results for sine with dwell for a 4 × 2 tractor semitrailer combination with connected gross combination weight of 26 metric tonnes

SWA	*ESC off = 0 on = 1*	*Max yaw velocity*	*Resp.*	*Final yaw angle*	*YSF1*		*YSF2*		*Max art. angle*
δ_H [º]		$\lvert\dot{\psi}_{1,\text{peak}}\rvert$ [rad/s]	$d_y\left(\frac{0,5}{f}+T_0\right) > 1,5$ [m]	$\psi_{1\text{final}}(6+T_1) < 0^*$ [rad]	$\frac{\lvert\dot{\psi}_1(1+T_1)\rvert}{\lvert\dot{\psi}_{1,\text{peak}}\rvert} \le 0,7^*$	$\frac{\lvert\dot{\psi}_1(2+T_1)\rvert}{\lvert\dot{\psi}_{1,\text{peak}}\rvert} \le 0,35^*$	$\frac{\lvert\dot{\psi}_2(1+T_2)\rvert}{\lvert\dot{\psi}_{1,\text{peak}}\rvert} \le 0,9^*$	$\frac{\lvert\dot{\psi}_2(2+T_2)\rvert}{\lvert\dot{\psi}_{1,\text{peak}}\rvert} \le 0,45^*$	
60	0	0,17	1,54	-0,15	0,03	0,01	0,06	0,01	5,9
65	0	0,18	1,65	-0,16	0,04	0,00	0,08	0,01	6,6
70	0	0,19	1,75	-0,18	0,05	0,00	0,12	0,01	7,3
75	0	0,21	1,84	-0,19	0,05	0,01	0,17	0,02	8,1
80	0	0,22	1,93	-0,21	0,04	0,02	0,22	0,03	8,9
85	0	0,24	2,02	-0,24	0,03	0,00	0,19	0,07	9,9
90	0	0,25	2,10	-0,29	0,05	0,04	0,06	0,17	10,9
95	0	0,26	2,17	-0,36	0,04	0,05	0,50	0,35	12,2
100	0	0,28	2,23	-0,49	0,50	0,03	0,95	0,17	13,6
105	0	0,29	2,29	-0,70	0,66	0,42	0,81	0,89	15,5
110	0	0,31	2,34	-1,00	0,72	0,59	0,66	0,64	18,7
115	0	0,32	2,39	-2,09	0,77	0,71	0,55	0,50	179,5
120	0	0,33	2,43	-2,75	0,81	0,81	0,48	0,40	179,7
60	1	0,17	1,54	-0,15	0,03	0,01	0,06	0,01	5,9
65	1	0,18	1,65	-0,16	0,04	0,00	0,08	0,01	6,6
70	1	0,19	1,75	-0,18	0,05	0,00	0,12	0,01	7,3
75	1	0,21	1,84	-0,19	0,05	0,01	0,17	0,02	8,1
80	1	0,22	1,93	-0,21	0,04	0,02	0,22	0,03	8,9
85	1	0,24	2,02	-0,24	0,03	0,00	0,19	0,07	9,9
90	1	0,25	2,10	-0,29	0,05	0,04	0,06	0,17	10,9
95	1	0,26	2,17	-0,34	0,05	0,07	0,38	0,34	12,2
100	1	0,28	2,23	-0,40	0,17	0,01	0,71	0,26	13,6
105	1	0,29	2,29	-0,43	0,24	0,01	0,83	0,07	15,4
110	1	0,31	2,34	-0,46	0,27	0,05	0,82	0,10	17,4

NOTE 1 Software in the loop version of Electronic Stability Control is both disabled and enabled.

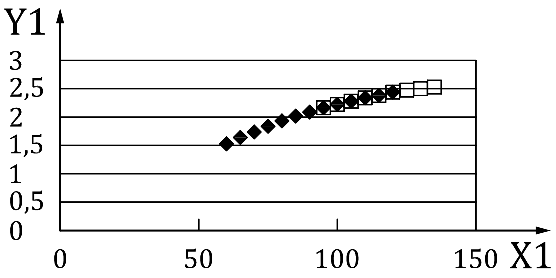
NOTE 2 The values are just examples of what could be expected for good responsiveness and stability for a tractor semitrailer.

Table B.1 *(continued)*

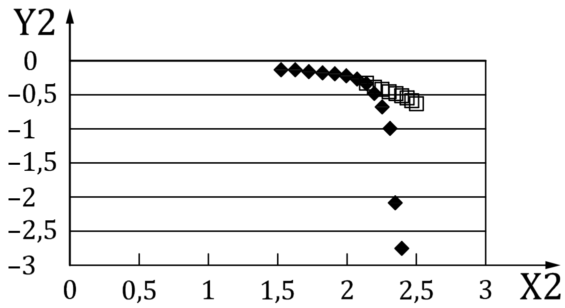
SWA	*ESC* *off = 0 on = 1*	*Max yaw velocity*	*Resp.*	*Final yaw angle*	*YSF1*		*YSF2*		*Max art. angle*
δ_H [º]		$\lvert\dot{\psi}_{1,\text{peak}}\rvert$ [rad/s]	$d_y\left(\frac{0,5}{f}+T_0\right) > 1,5$ [m]	$\psi_{1\,\text{final}}(6+T_1) < 0^*$ [rad]	$\frac{\lvert\dot{\psi}_1(1+T_1)\rvert}{\lvert\dot{\psi}_{1,\text{peak}}\rvert} \leq 0,7^*$	$\frac{\lvert\dot{\psi}_1(2+T_1)\rvert}{\lvert\dot{\psi}_{1,\text{peak}}\rvert} \leq 0,35^*$	$\frac{\lvert\dot{\psi}_2(1+T_2)\rvert}{\lvert\dot{\psi}_{1,\text{peak}}\rvert} \leq 0,9^*$	$\frac{\lvert\dot{\psi}_2(2+T_2)\rvert}{\lvert\dot{\psi}_{1,\text{peak}}\rvert} \leq 0,45^*$	
115	1	0,32	2,39	-0,49	0,28	0,12	0,72	0,25	19,5
120	1	0,33	2,43	-0,52	0,29	0,10	0,63	0,44	21,5
125	1	0,34	2,47	-0,55	0,28	0,03	0,55	0,61	23,4
130	1	0,35	2,50	-0,59	0,27	0,04	0,49	0,63	25,3
135	1	0,36	2,53	-0,64	0,32	0,10	0,45	0,55	27,0

NOTE 1 Software in the loop version of Electronic Stability Control is both disabled and enabled.

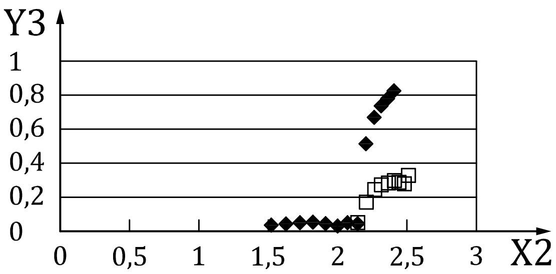
NOTE 2 The values are just examples of what could be expected for good responsiveness and stability for a tractor semitrailer.



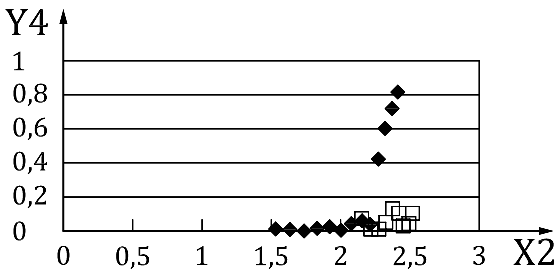
a) **Responsiveness**



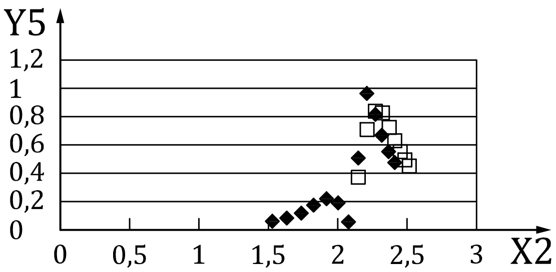
b) **Final Yaw angle**



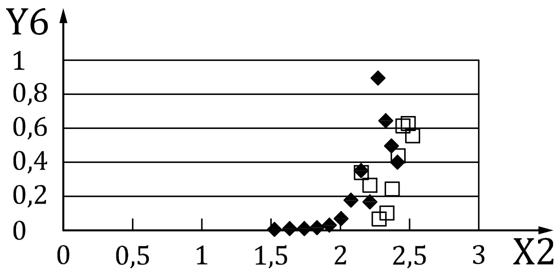
c) **Yaw stability factor of first unit at 1 + T1**



d) **Yaw stability factor of first unit at 2 + T2**



e) **Yaw stability factor of second unit at 1 + T1**



f) **Yaw stability factor of second unit at 2 + T2**

Key

X1 steering wheel angle [deg]

X2 responsiveness [m]

Y1 ypos [m]

Y2 yaw angle [rad]

Y3 YSF1 < 0,7

Y4 YSF1 < 0,35

Y5 YSF2 < 0,9

Y6 YSF2 < 0,45

NOTE Illustrated plots c-f where characteristic values are shown as function of responsiveness. ESC disabled and enabled represented by diamonds and squares, respectively.

Figure B.1 — Simulated results from Table B.1, illustrated plots a,b show steering wheel angle as a function of ypos and responsiveness as a function of yaw angle

Bibliography

[1] ISO 3833, *Road vehicles — Types — Terms and definitions*

[2] ISO 8855, *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*

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