Basics of Vehicle Dynamics

Module H5

Evaluation Criteria of Handling and Steering Systems

- Testing manoeuvres
- Quality indexes

Testing Manoeuvres

SYNTHESIS CRITERIA AND EXPERIMENTAL EVALUATION OF HANDLING AND STEERING SYSTEMS

EXPERIMENTAL MEASUREMENTS IN STANDARD MANOEUVRES

Steering-pad with constant radius
Step steering input
Steering wheel release in curve
ISO lane change
Tip IN / Tip OUT
Sinusoidal steer input at 0,2 Hz
Complete steer cycles
Sweep sine manoeuvre

CAR HANDLING EVALUATION QUESTIONARY

OBJECTIVE PARAMETERS IDENTIFICATION

STATISTICAL ANALYSIS ON SUBJECTIVE EVALUATION

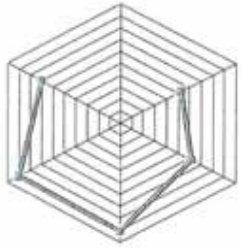
OBJECTIVE PARAMETERS CORRELATION vs. SUBJECTIVE EVALUATIONS

BASICS OF VEHICLE DYNAMICS
Module H5
Evaluation Criteria of Handling and Steering Systems

EXPERIMENTAL METHODOLOGY APPLICATION

EXPERIMENTAL TESTS ON INSTRUMENTED CAR

CARS PERFORMANCE INDEX



CAR CLUSTER DATA BASE

Comparison

BEHAVIOUR CRITICISM FINDING

INSTRUMENTED VEHICLE FOR STANDARD CHARACTERIZATION

BASICS OF VEHICLE DYNAMICS
Module H5
Evaluation Criteria of Handling and Steering Systems

EXPERIMENTAL CHARACTERIZATION

CARRIED OUT MANOUEVRES

STEERING-PAD ISO 4138 R=40 m
STEERING-PAD ISO 4138 R=100 m

STEP STEERING INPUT ISO 7401 V=100 km/h
STEERING WHEEL RELEASE V=100 km/h

ISO LANE CHANGE TR 3888 V=90 km/h

TIP IN R=100 m, AY=0.4 g
TIP OUT ISO 9816 R=100 m, AY=85% AYlim.

SINUSOID ISO 7401 F=0.2 HZ, AY=0.25 g, V=60 km/h
SINUSOID ISO 7401 F=0.2 HZ, AY=0.25 g, V=120 km/h

STEERING WHEEL CYCLES V=5 km/h
STEERING WHEEL CYCLES WITH STOPPED CAR

SWEEP SINE MANOEUVRE

MEASURED SIGNALS

MEASURED SIGNALS AND MEASUREMENT/FILTERING PROCEDURES COMPLY TO ISO DIS 15037

MEASURED VARIABLES ARE:
STEERING WHEEL ANGLE
LATERAL ACCELERATION
YAW SPEED
SIDE SLIP ANGLE
STEERING WHEEL TORQUE
ROLL RATE
THROTTLE
CAR SPEED
PHOTOELECTRIC CELL REFERENCE

SYNTHESIS PARAMETERS IDENTIFICATION PROCEDURE

1) IDENTIFICATION OF MANY POTENTIAL PARAMETERS

2) POTENTIAL PARAMETERS CALCULATION IN EXPERIMENTAL ROAD TEST

3) NOT RELIABLE PARAMETERS ELIMINATION

4) NOT SIGNIFICANT PARAMETERS ELIMINATION

} SPREAD ANALYSIS

5) CORRELATION ANALYSIS AMONG RESIDUAL PARAMETERS

↓

OBJECTIVE PARAMETERS

BASICS OF VEHICLE DYNAMICS
Module H5
Evaluation Criteria of Handling and Steering Systems

STEERING-PAD MANOEUVRE (ISO 4138)

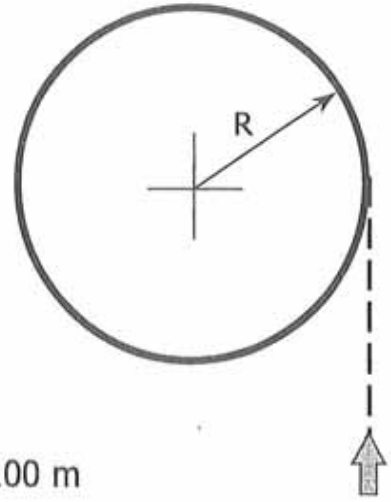
GOAL :

CAR STEADY STATE BEHAVIOUR CHARACTERIZATION, EVALUATING:

- UNDERSTEER CURVE
- SIDE SLIP ANGLE CURVE
- STEERING WHEEL TORQUE

STEERING -PAD MANOEUVRE
STANDARD PROCEDURE
(ISO 4138)

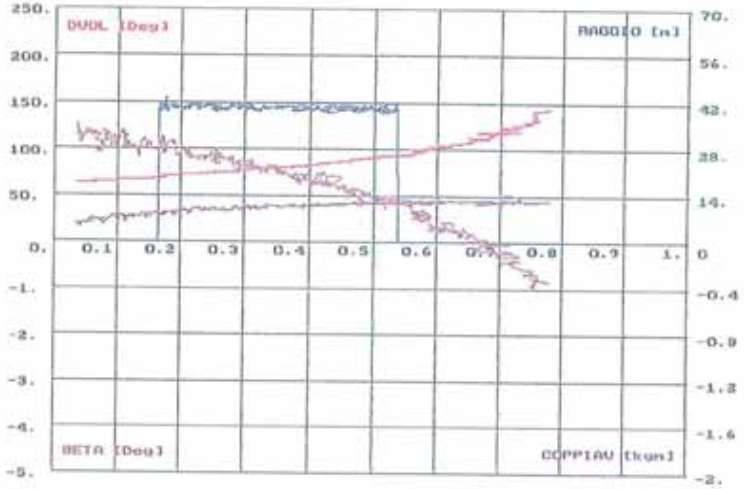
- THE VEHICLE RUNS IN A STRAIGHT LINE AT THE MINIMAL SUPPORTING SPEED (OFFSET).
- THE DRIVER STARTS CIRCULAR PATH AND DESCRIBES A WHOLE TURN.
- SPEED INCREASES, WITH LONGITUDINAL ACCELERATION LESS THAN 0.05 g, UNTIL THE CAR ADHESION LIMIT.
- THE MANOEUVRE IS PERFORMED AT LEAST 3 TIMES FOR BOTH LEFT AND RIGHT TURNS.

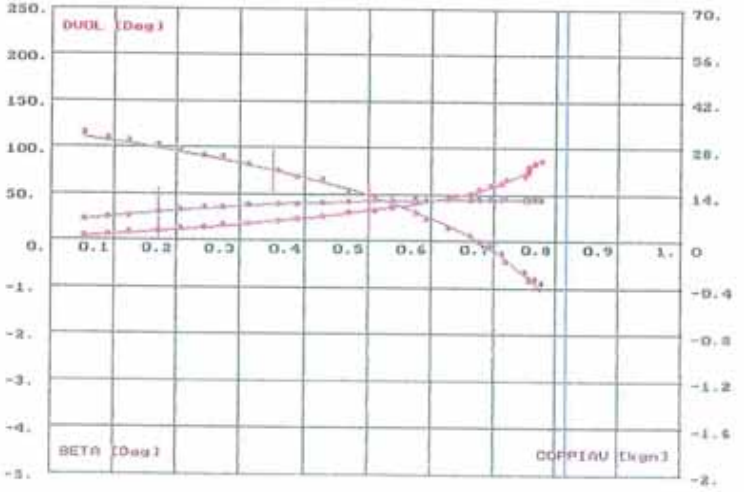


R=40/100 m

BASICS OF VEHICLE DYNAMICS
Module H5
Evaluation Criteria of Handling and Steering Systems

CONSTANT RADIUS STEERING-PAD MANOEUVRE
DATA ANALYSIS





STEP STEERING INPUT MANOEUVRE (ISO 7401)

GOAL :

TO DETERMINE TRANSIENT RESPONSE BEHAVIOUR, EVALUATING:

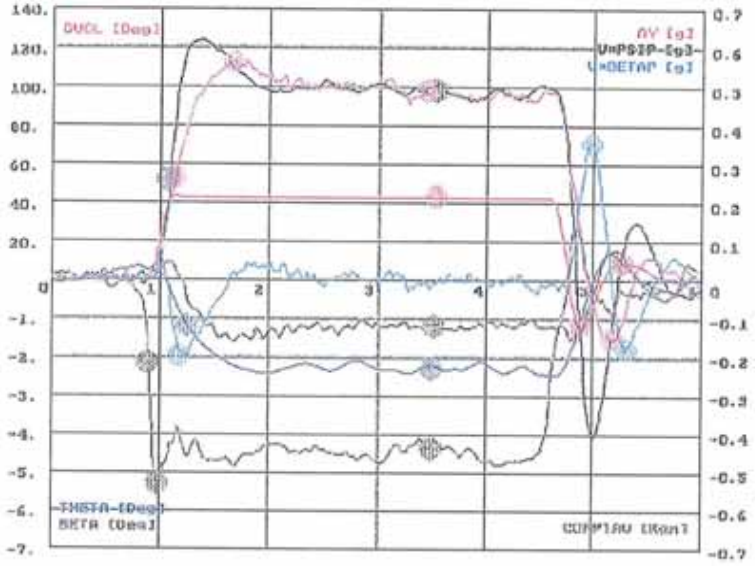
- SATISFACTORY CONTROL RESPONSE CHARACTERISTICS
- STABILITY
- BODY MOTION
- STEERING WHEEL RE-ALIGNEMENT QUALITY

BASICS OF VEHICLE DYNAMICS
Module H5
Evaluation Criteria of Handling and Steering Systems

STEP STEERING INPUT PROCEDURE (ISO 7401)

- THE CAR IS DRIVEN AT 100 km/h IN IV GEAR IN A STRAIGHT LINE
- AFTER 3 s, A STEERING INPUT SHALL BE APPLIED AS RAPIDLY AS POSSIBLE TO A PRESELECTED VALUE
- MAINTAIN THE STEERING INPUT AT THAT VALUE FOR ABOUT 3 s.
- RELEASE THE STEERING WHEEL AND LET THE CAR FREE TO RE-ALIGN
- THE STEERING WHEEL ANGLE AMPLITUDES ARE APPLIED FROM 10°, UNTIL THE LIMIT OF THE CAN BY 5° STEPS, FOR BOTH RIGHT AND LEFT SIDES
- NO CHANGE IN THROTTLE POSITION SHALL BE MADE

STEP STEERING INPUT
MANOEUVRE ELABORATION



CALCULATED PARAMETERS:

Transient response
- Times lags
- Overshoot values

Steady state response
- Average variables values

Steering wheel oscillations
- Measured variables first and second peaks
- Peaks response time

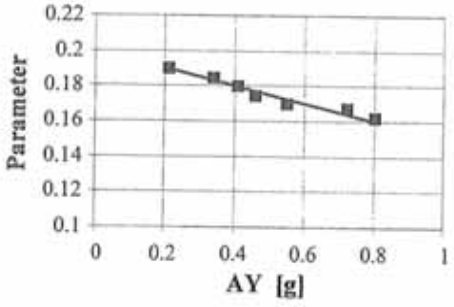
STEP STEERING INPUT:
- **PROCEDURE FOR THE OBJECTIVE PARAMETERS IDENTIFICATION**

SINGLE MANOEUVRES ELABORATION AND PARAMETERS CALCULATION

→

SYNTHESIS OF MANOEUVRES
parameter = f(AY)

understeer, sideslip angle and steering wheel torque curves at constant speed

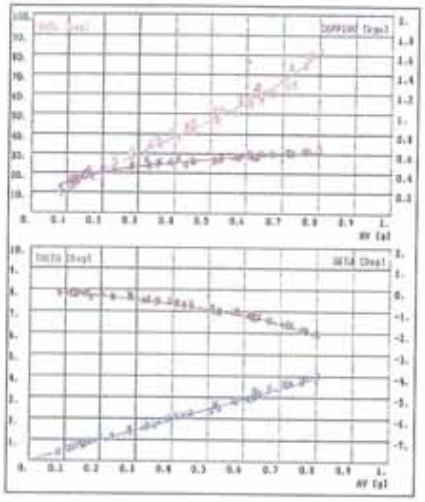


Calculation of parameters similar to constant radius steering pad parameters

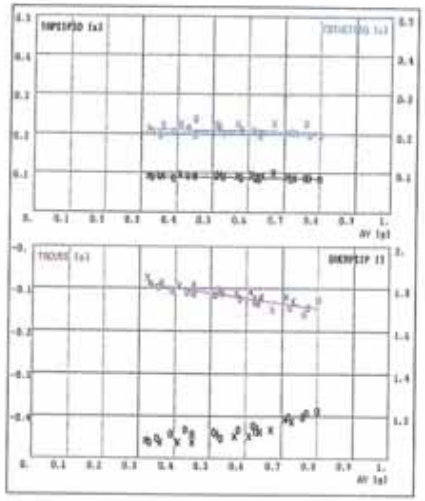
Calculation of:
- shape
- parameter values at 0.4 g
- Interpolation discrepancy

STEP STEERING INPUT MANOEUVRE SYNTHESIS

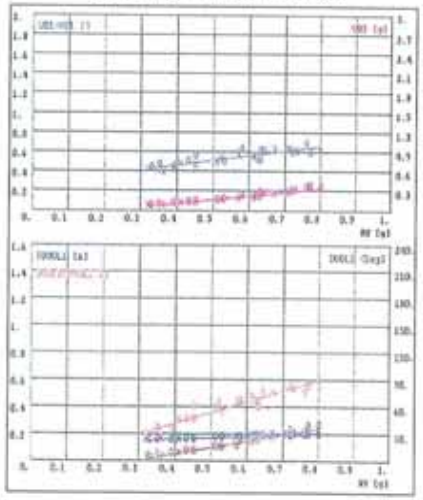
Steady state behaviour



Transient behaviour



Steering wheel release



ISO LANE CHANGE MANOEUVRE (ISO 3888)

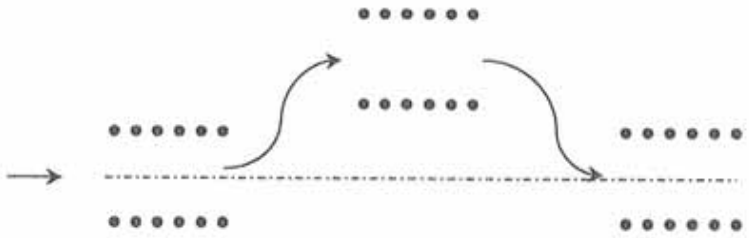
GOAL :

CAR BEHAVIOUR CHARACTERIZATION IN OBSTACLE AVOIDANCE MANOEUVRES, EVALUATING:

- CAR RESPONSE CHARACTERISTICS
- STABILITY
- BODY MOTIONS

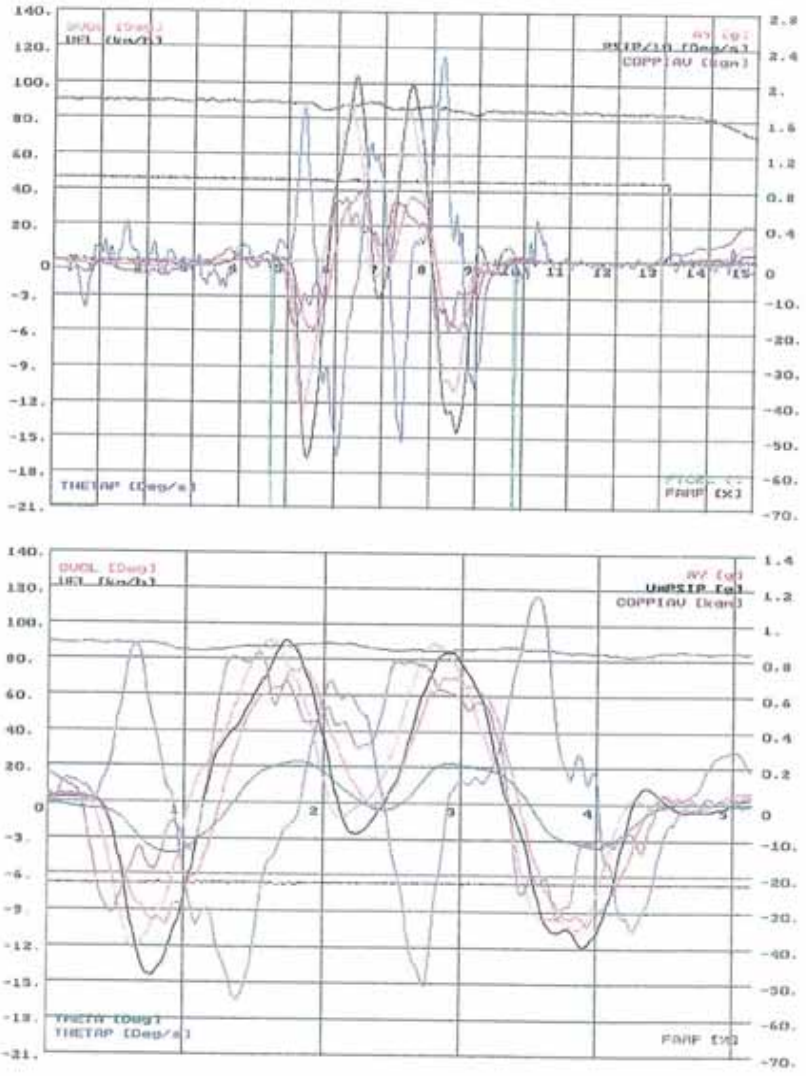
ISO LANE CHANGE MANOEUVRE PROCEDURE (ISO/TR 3888)

- THE CAR IS DRIVEN IN A STRAIGHT LINE AT CONSTANT SPEED 90 Km/h IN IV GEAR (OFFSET)
- THE CAR HAS TO PASS THE LANE CHANGE TRACK, THAT IS MARKED WITH CONES
- THE THROTTLE POSITION SHALL BE HOLD AS STEADY AS POSSIBLE
- AFTER THE EXIT, THE CAR SHALL BE DRIVEN IN A STRAIGHT LINE (WITH CONSTANT THROTTLE POSITION) FOR AT LEAST 1 s
- 10 RUNS



BASICS OF VEHICLE DYNAMICS
Module H5
Evaluation Criteria of Handling and Steering Systems

ISO LANE CHANGE MANOEUVRE DATA ANALYSIS

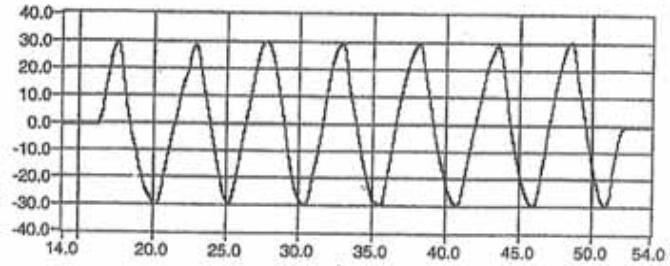


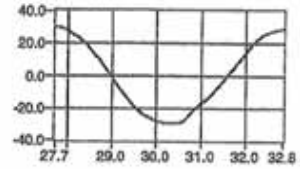
SINUSOIDAL STEER INPUT PROCEDURE (ISO/WD 13674-1)

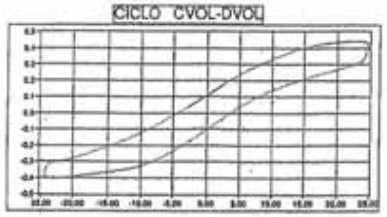
- THE MANOEUVRE IS PERFORMED AT TWO DIFFERENT SPEEDS, 60 AND 120 km/h
- THE CAR IS DRIVEN IN A STRAIGHT LINE AT THE NOMINAL SPEED
- A SINUSOIDAL STEERING WHEEL INPUT IS APPLIED WITH A FREQUENCY OF 0.2 Hz AND AMPLITUDE SUITABLE TO OBTAIN THE LATERAL ACCELERATION PEAK BETWEEN 0,2 AND 0,25 g
- THE RUNS SHALL BE REPEATED IN ORDER TO OBTAIN AT LEAST 15 COMPLETE CYCLES FOR EACH SPEED.

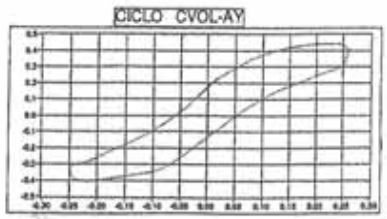
BASICS OF VEHICLE DYNAMICS
Module H5
Evaluation Criteria of Handling and Steering Systems

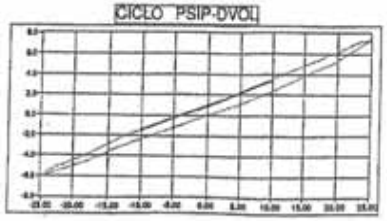
SINUSOIDAL STEER INPUT DATA ANALYSIS

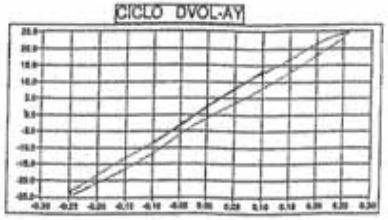












ISO LANE CHANGE MANOEUVRE DATA ANALYSIS METHOD (ISO/TR 3888)

Objective parameters description

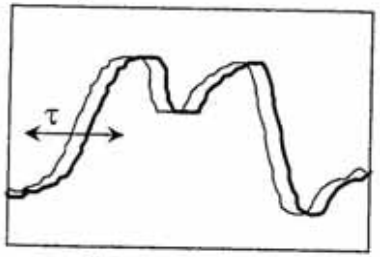
Dynamic gains

Signal RMS ratios:

RMS=sqrt((Σx^2)/n)
x = signal t.h.
n = t.h. number points

Significant signals:
Yaw rate/steering wheel angle
Roll angle/lateral acceleration

Time lags by cross correlation



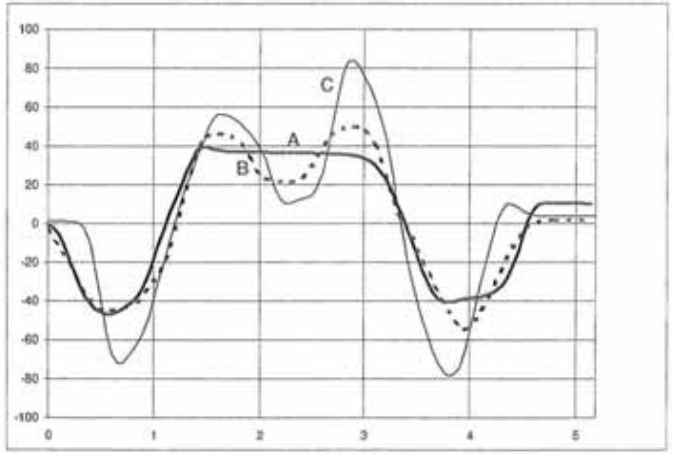
Significant signals :
Lateral acceleration/steering wheel angle
Yaw rate/steering wheel angle
Steering wheel torque/steering wheel angle
Yaw rate/lateral acceleration
Roll angle/lateral acceleration

Synthesis

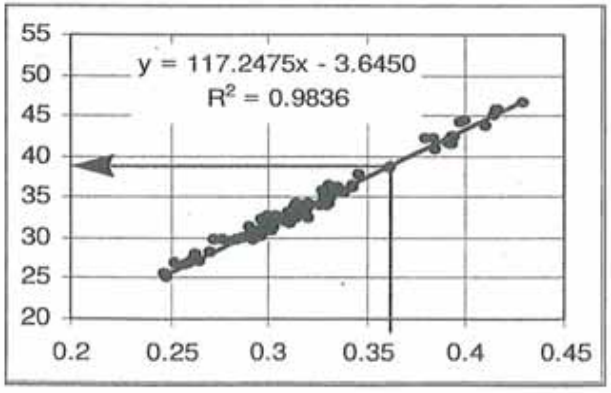
Recorded manoeuvres objective parameters average values calculation, indicating the scattering based on standard parameter deviations

ISO LANE CHANGE MANOEUVRE: EXECUTION / ELABORATION WAY UPDATING

Perform 15/20 runs with different execution ways



Linear regression to obtain parameters values at a reference rmsAY



TIP IN / TIP OUT
(ISO 9816)

GOAL :

DETERMINING CAR BEHAVIOUR DURING AN ENGINE TORQUE TRANSIENT CONDITIONS, EVALUATING:

- CAR STABILITY
- DEVIATION FROM ASSIGNED LINE

BASICS OF VEHICLE DYNAMICS
Module H5
Evaluation Criteria of Handling and Steering Systems

TIP IN / TIP OUT PROCEDURE

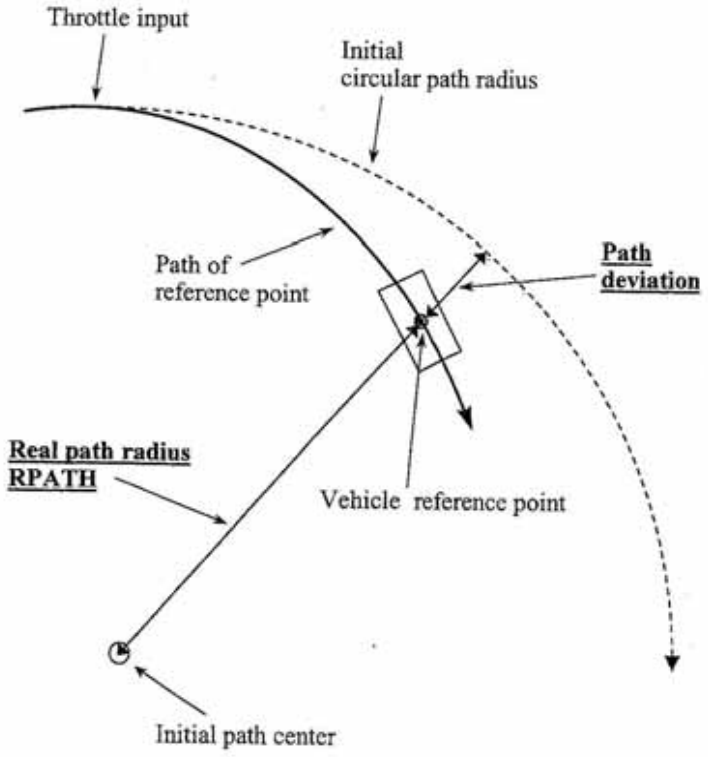
(ISO 9816)

- THE CAR IS DRIVEN IN A STEADY STATE CIRCULAR PATH (R=100 m OFFSET)
- THE ACCELERATOR PEDAL SHALL BE PUSH / RELASED AS QUICKLY AS POSSIBLE.
  THE STEERING WHEEL SHALL BE HELD STEADY
- THE VEHICLE SHALL BE FREE FOR AT LEAST 3s
- DETERMINATION OF LATERAL ACCELERATION STARTING VALUE:
  - TIP IN AY= 0.4 g
  - TIP OUT AY= 0.85 AY max STR
- THE TEST SHALL BE PERFORMED AT LEAST THREE TIMES FOR BOTH LEFT AND RIGHT TURNS.

TIP IN / TIP OUT MANOEUVRE : OBJECTIVE PARAMETERS

1) Transient parameter :
VEL, PSIP, BETA, RCURV, RPATH Variations in the first second after throttle input

2) Trend parameters :
VEL, RCURV, RPATH variations between first and third second after throttle input



SINUSOIDAL STEER INPUT MANOEUVRE

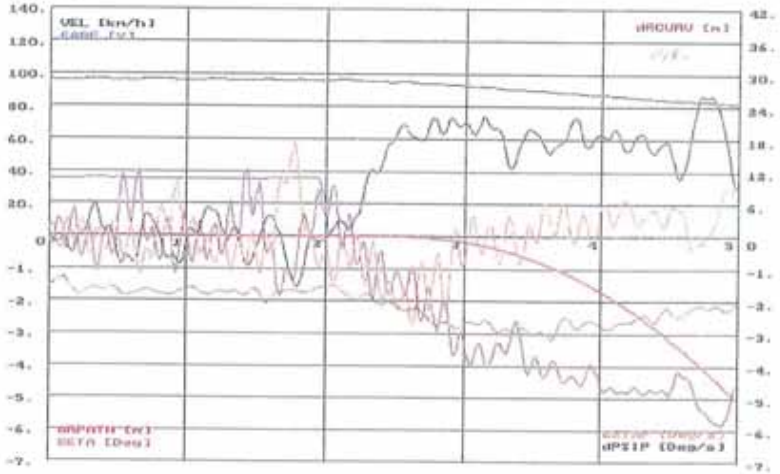
GOAL :

STEERING SYSTEM BEHAVIOUR CHARACTERIZATION ON STRAIGHTS AND IN TURN IN CURVE, EVALUATING:

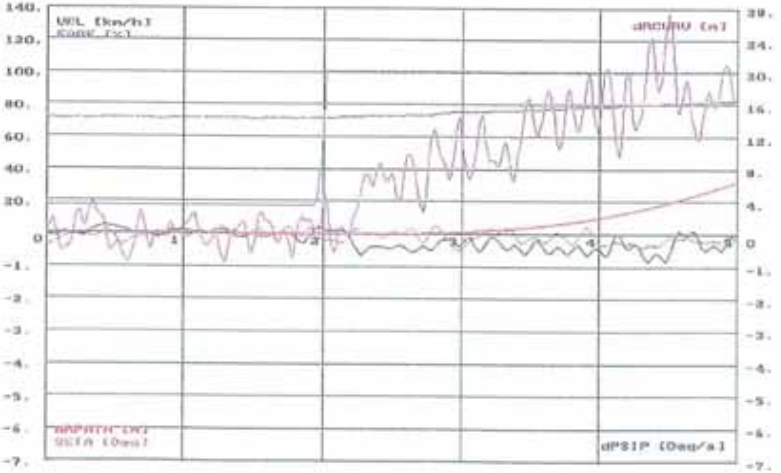
- RESPONSE ACCURACY TO THE STEERING INPUT
- STEERING WHEEL FORCE FEED-BACK

TIP IN / TIP OUT DATA ANALYSIS

TIP OUT



TIP IN



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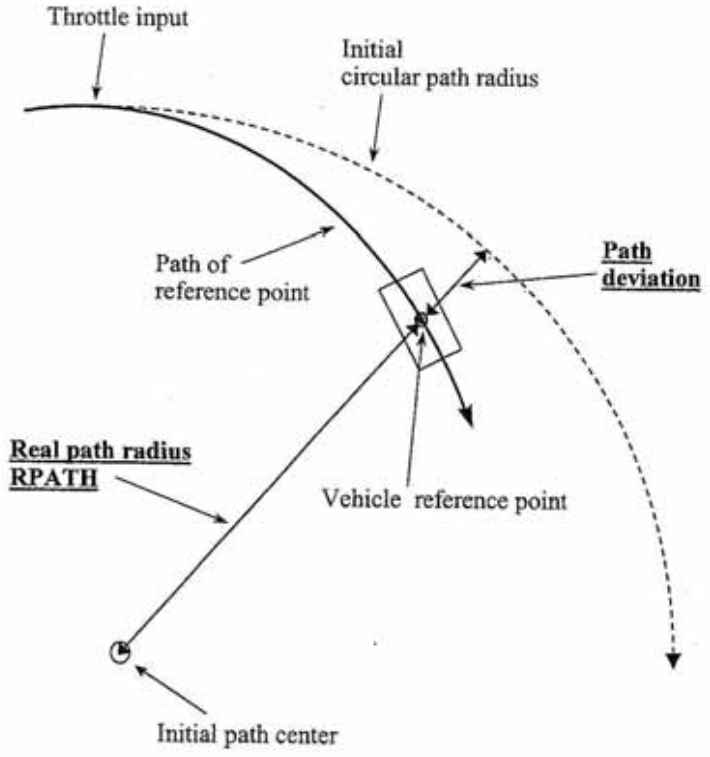

SINUSOIDAL STEER INPUT MANOEUVRE

GOAL :

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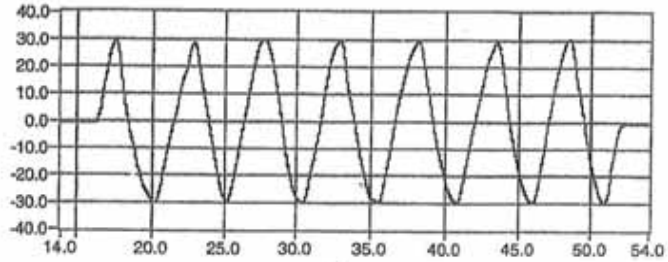
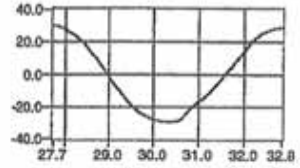
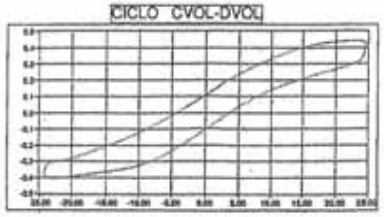
SINUSOIDAL STEER INPUT PROCEDURE (ISO/WD 13674-1)

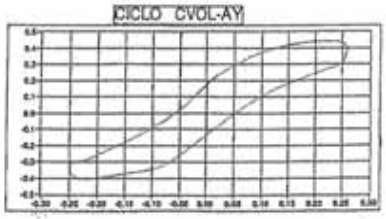
- THE MANOEUVRE IS PERFORMED AT TWO DIFFERENT SPEEDS, 60 AND 120 km/h
- THE CAR IS DRIVEN IN A STRAIGHT LINE AT THE NOMINAL SPEED
- A SINUSOIDAL STEERING WHEEL INPUT IS APPLIED WITH A FREQUENCY OF 0.2 Hz AND AMPLITUDE SUITABLE TO OBTAIN THE LATERAL ACCELERATION PEAK BETWEEN 0,2 AND 0,25 g
- THE RUNS SHALL BE REPEATED IN ORDER TO OBTAIN AT LEAST 15 COMPLETE CYCLES FOR EACH SPEED.

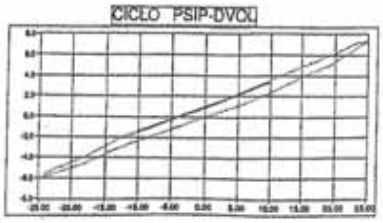
SINUSOIDAL STEER INPUT DATA ANALYSIS

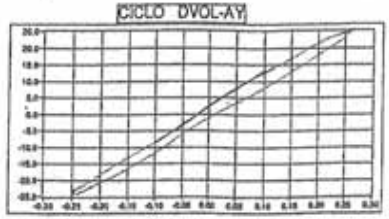




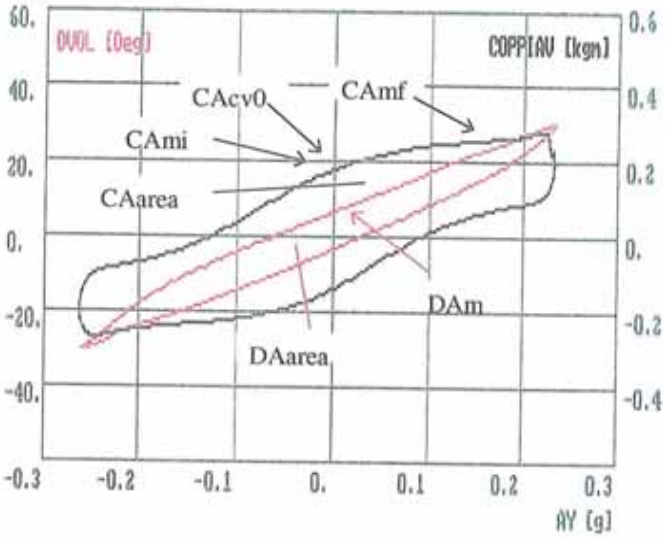


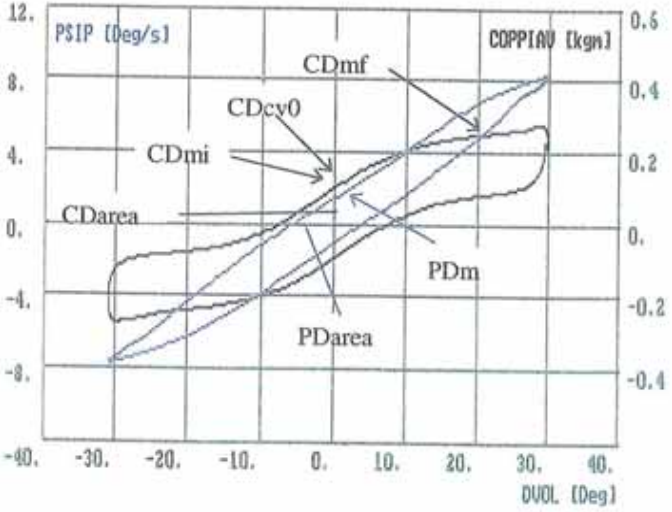






SINUSOIDAL STEER INPUT DATA ANALYSIS





COMPLETE STEER CYCLES MANOEUVRE

GOAL :

STEERING SYSTEM BEHAVIOUR CHARACTERIZATION DURING PARKING MANOEUVRE, EVALUATING:

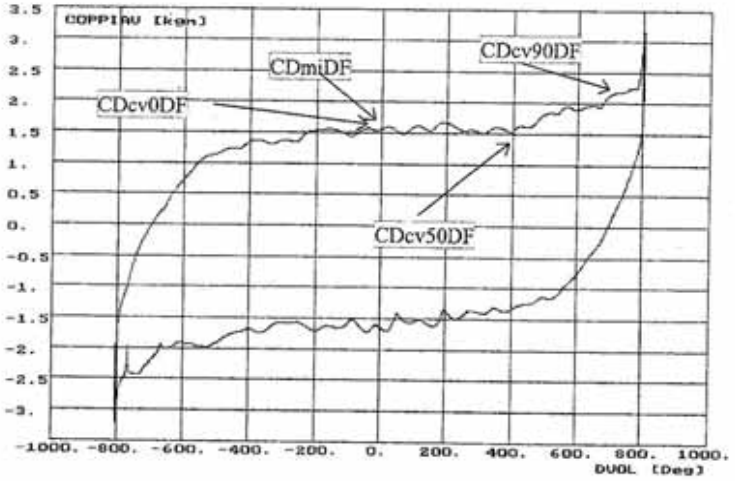
- SYSTEM MANEUVERABILITY
- STEERING TORQUE IN PARKING

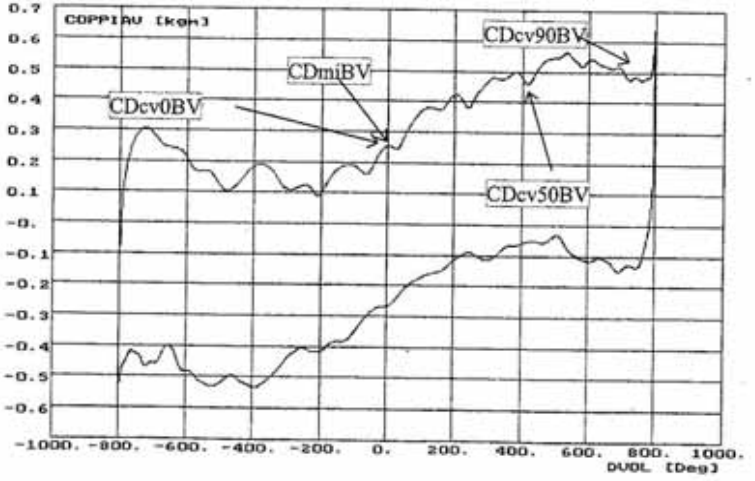
BASICS OF VEHICLE DYNAMICS
Module H5
Evaluation Criteria of Handling and Steering Systems

COMPLETE STEER CYCLES PROCEDURE

- TEST IS PERFORMED WITH STANDING VEHICLE (ENGINE RUNNING) AND AT A MINIMUM SUSTAINING SPEED (ABOUT 5 km/h)
- THE DRIVER TURNS THE STEERING WHEEL COMPLETELY IN BOTH DIRECTION, WITH NOT ANY INTERRUPTION IN THE ROTATION, PERFORMING AT LEAST TWO COMPLETE CYCLES.
- ACCEPTED AVERAGE VALUES OF STEERING WHEEL ANGULAR SPEED ARE BETWEEN 100 and 150 deg/s
- THREE REPETITIONS ARE EXECUTED

COMPLETE STEER CYCLES DATA ANALYSIS





SWEEP SINE MANOEUVRE (ISO 7401, ISO/TR 8726)

GOAL :

CAR BEHAVIOUR EVALUATION IN TERMS OF GAIN AND PHASE, IN PARTICULAR:

INPUT: STEERING WHEEL ANGLE OUTPUT: LATERAL ACCELER.

INPUT: STEERING WHEEL ANGLE OUTPUT: YAW RATE

INPUT: LATERAL ACCELER. OUTPUT: ROLL ANGLE

INPUT: STEER. WHEEL TORQUE OUTPUT: STEERING WHEEL ANGLE

IDENTIFY A SIMPLIFIED EQUIVALENT CAR MODEL

DEVELOP QUICK, RELIABLE AND RELEVANT OBJECTIVE TEST PROCEDURE IN ORDER TO REDUCE TIME AND CONSEQUENTLY COST OF TESTING PROCESS OF CARS

SWEEP SINE MANOEUVRE ELABORATION: LATERAL DYNAMICS

ELABORATION METHODS:

NUMERICAL METHOD

- CROSS-SPECTRUM AND AUTO-SPECTRUM OF REGISTERED SIGNALS USING FFT ALGORITHMS (HANNING WINDOWS OF 512 POINTS WITH AN 80% OVERLAP ARE USED)

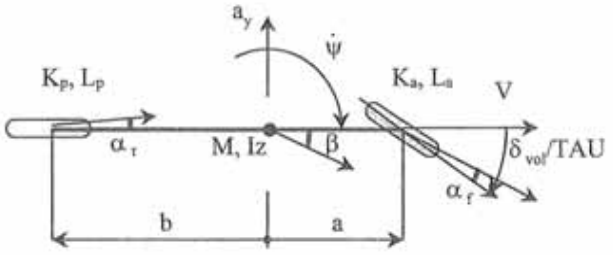
ANALYTICAL METHOD

- VEHICLE MODEL AND MODEL PARAMETERS IDENTIFICATION BY MEASURED SIGNALS AND CALCULATED ONES MATCHING

BASICS OF VEHICLE DYNAMICS
Module H5
Evaluation Criteria of Handling and Steering Systems

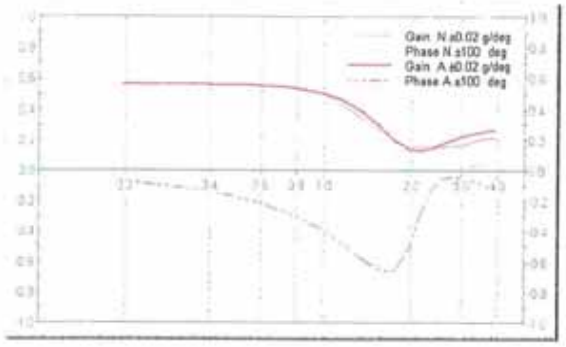
MATHEMATICAL MODEL FOR ANALYTICAL ELABORATION

"Single track", linear constant parameters model; parameter shall be easily measured or identified by road tests



- Easily measured parameters :
  - wheelbase
  - front weight
  - rear weight
  - steering ratio
- Identified parameters :
  - moment of inertia about z axis
  - cornering stiffness for front and rear axles
  - equipment relaxation length for front and rear axles

SWEEP SINE MANOEUVRE: DATA ANALYSIS

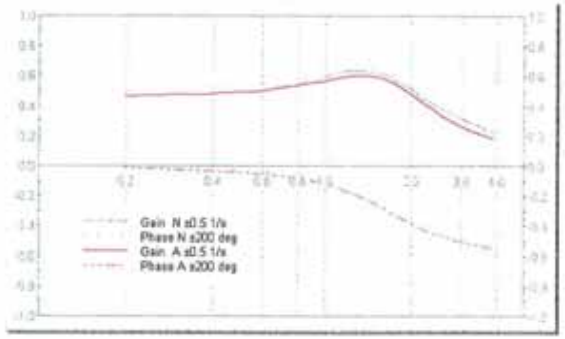


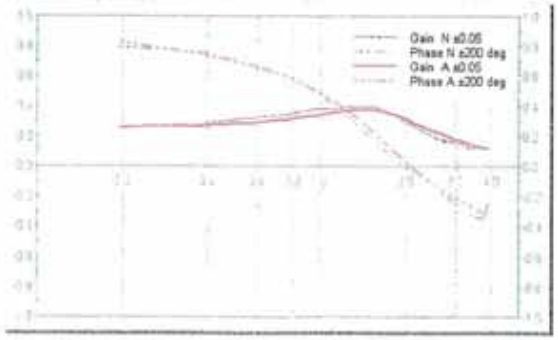
Input : Steering wheel angle

Output : Lateral Acceleration

Input : Steering wheel angle

Output : Yaw rate





Input : Steering wheel angle

Output : Sideslip angle

FREQUENCY RESPONSE CHARACTERISTIC PARAMETERS

The parameters, obtained by numerical transfer functions, are:

❖ lateral acceleration response function:

• minimum gain frequency	f(Gmin)
• maximum phase lag frequency	f(Phmin)
• min. phase frequency	f(Phmax)
• pass band at 90%	f(G90)
• gain and time delay at 0.5 Hz	G(0.5), tr(0.5)
• gain and time delay at 1.0 Hz	G(1.0), tr(1.0)
• gain and time delay at 2.0 Hz	G(2.0), tr(2.0)
• gain and time delay at 3.0 Hz	G(3.0), tr(3.0)

❖ yaw rate function response:

• maximum gain frequency	f(Gmax)
• amplification rate	Gmax/G0
• pass band at 90%	f(G90)
• gain and time delay at 0.5 Hz	G(0.5), tr(0.5)
• gain and time delay at 1.0 Hz	G(1.0), tr(1.0)
• gain and time delay at 2.0 Hz	G(2.0), tr(2.0)
• gain and time delay at 3.0 Hz	G(3.0), tr(3.0)

Time delay is obtained from phase log as follow:

$$tr(freq) = Ph(freq) / (freq*360)$$

Quality Indexes

SUBJECTIVE EVALUATIONS: FINDING MODE AND STATISTICAL ANALYSIS

SUBJECTIVE EVALUATIONS FINDING MODE

- Evaluation questionnaire
- Jury
- Car sample
- Tests execution

STATISTICAL ANALYSIS

- Questionnaire collection
- Scattering analysis
- Mean car evaluation for each question
- Partial ratings and pre-synthesis/synthesis ratings correlation

QUALITY INDEXES IDENTIFICATION PROCEDURE