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INSTITUTE FOR INTERNAL COMBUSTION ENGINES AND THERMODYNAMICS

Constant Speed Evaluation Tool
VECTO-CSE V2.0.4

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Updates compared to versions 2.0.3 marked in GREEN

User Manual

By order of

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DG CLIMA

Inffeldgasse 19, A-8010 Graz, Austria

Tel.: +43 (316) 873-30001 • Fax: +43 (316) 873-30002

http://ivt.tugraz.at

Constant Speed Evaluation Tool

VECTO-CSE V2.0.x

Technical Documentation

Written by:	Martin Rexeis, TUG (Methodology) Martin Dippold, TUG (Software) Konstantinos Anagnostopoulos, JRC (Software)	2014/06/25 AppVer: v2.0.1-pre3

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Content

1. Introduction

A first version of a tool for evaluation of constant speed tests has already been developed in 2012 by TUG in a project sponsored by DG JRC. This software was named "VECTO Constant Speed Evaluation tool" Version 1.0 or short "CSE 1.0" and was distributed to all members of the HDV CO_2 advisory group. CSE V1.0 was applied during the Proof of Concept phase of the LOT3 project in 2012 and 2013.

Caused by the further development of the aerodynamic drag test procedure a major update of the evaluation tool was required. This update is released with VECTO-CSE V2.0.x. This software tool is compatible with the latest version of the technical annex.

The main changes of VECTO-CSE 2.0.x compared to VECTO-CSE 1.0 are:

- All kinds of test track layouts with any configuration of measurement sections[1] and driving directions are supported.
- It supports the following methods for identifying the position of the vehicle in relation to Track's *measurement sections*:
    - a combination of opto-electronic triggers with a GPS device or
    - a high precision DGPS system
- The foreseen calibration procedures for signals from the mobile anemometer and for vehicle speed are performed by the tool automatically.
- The algorithms are adapted to automatically evaluate the combination a "high speed test" and two "low speed tests" (one before and one after the high speed test) for each combination of measurement section and driving direction.
- All validity checks as specified in the technical annex which have to be passed to get approved results (e.g. for ambient conditions, stability criteria during constant speed phases) are considered in the test evaluation.

The tool as released in June 2014 is designed as an "engineering version", where still some parameters or settings used in the evaluation can be modified by the user. This software shall be used in the ongoing process of elaborating the final details of the constant speed test procedure in 2014. Once all details of the official test procedure have been defined, a VECTO-CSE "declaration version" shall be generated, where all evaluation parameters are fixed to the exactly as specified in the regulations.

[1] Measurement sections (abbrev.: MS) define the part of the test track where the recorded signals are analysed in the evaluations.

2. Structure of the software

The CSE-Tool is written in VB.Net and delivered as executable file and Visual Studio 2010 project with commented source code. The CSE-Tool is a portable application, i.e. it is not necessary to run a setup procedure for installation. The executable file can be run from any place on a computer or in a network. More details on how to operate VECTO-CSE can be found in section 6.

3. Input data and file structures

This section gives a detailed description of the input data and the file structure required for VECTO-CSE.

3.1. Input/Output files conventions

The files read and written by VECTO-CSE are either JSON or CSV files. In the **CSV**s are the following separator's allowed as list- and decimal separator which can be defined under Tools/preferences:

- Dot "**.**"
- Comma "**,**"
- Double point "**:**"
- Semicolon "**;**"

Lines starting with `#` are interpreted as comment-lines and ignored by the input routines, but are not preserved through read/written cycles. Such comments can be placed at any line of a CSV file.

JSON files do not support comments, but help can be provided by their accompanying json-schemas (see below). They are split in two sections,

- The `Header`, which contains administrational fields and fields related to the actual parsing of the file. This section accepts arbitrary content which is preserved when read/written, so it can be used instead of comments.
- The `Body`, which contains the actual content of the file, and has a rather strict format, according to each file type (see below).

Here is an extract from a typical JSON-file:


```
{
  "Header": {
    "Title":            "vecto-cse JOB",
    "FileVersion":      "1.0.0",
    "AppVersion":       "2.0.1-pre2",
    "ModifiedDate":     "2014/06/04 17:42:29 +02:00",
    "CreatedBy":        "JRC(lic: 04c137c0-24df-4d90-a3e2-b02fe3dba8ea)",
    "StrictBody":       null,
    "BodySchema":       null
  },
```


Of interest are the following two header properties:

- `/Header/StrictBody`: Controls whether the application will accept any unknown body-properties while reading the file. Set it to `true` to debug malformed input-files, i.e. to detect accidentally renamed properties.
- `/Header/BodySchema`: The JSON-schema of the body will be placed HERE on the next save. When `true`, it is always replaced by the Body's schema on the next save. When `false`, it overrides application's choice and is not replaced ever.

The software uses different extensions for certain file-types. This approach allows for quick browsing for specific data. However, any kinds of extensions can be used for input files as long as they are correctly specified in the Job file.

3.2. Overview of Input files

Table 1 gives an overview on all input files handled by VECTO-CSE.

Table 1: Overview input files

File type	Default extension	Explanation
vehicle	*.csveh	contains relevant information on the tested vehicle configuration (e.g. vehicle test mass, anemometer height)
ambient conditions	*.csamb	contains ambient conditions as measured by the stationary weather station
configuration file for measurement sections (“ms config”)	*.csms	contains the configuration of the measurement sections (coordinates, driving directions etc.) on the test track. The measurement sections can be configured for the calibration run and the measurement runs separately.
measurement data	*.csdat	contains the measurement data recorded at the vehicle consolidated in 100Hz. Separate input files are required by CSE for: i.) the calibration run (during warm up of the vehicle) ii.) the first low speed run iii.) the high speed run iv.) the second low speed run Similar file formats are used for i.) to iv.)

File type	Default extension	Explanation
altitude profile (optional)	*.csalt	contains the altitude profile on the measurement sections. This data is used for the correction of traction force for gradient influence in the evaluation if the related feature is activated in the VECTO-CSE GUI
criteria (optional)	*.cscrt	an be used to save or import a set of evaluation parameters (e.g. for validity or correction functions)
job	*.csjob	contains all information for a test evaluation (evaluation settings, paths to input data). The job file is automatically created if VECTO-CSE is operated via the user interface but can also be generated or edited e.g. by means of a text editor. After a successful calculation VECTO-CSE also writes the main evaluation results into the job-file.
criteria (optional)	*.cscrt	can be used to save or import a set of evaluation parameters (e.g. validity criteria or settings for correction functions). For reasons of traceability for each calculation the used parameters are in any case also stored in the Job-file.

3.3. Vehicle file (*.csveh)

The vehicle file contains the relevant information on the vehicle configuration. The file follows the JSON format. Figure 1 shows the structure of the vehicle file.

```
{
  "Header": {
    "Title": "vecto-cse VEHICLE",
    "FileVersion": "1.0.0",
    "AppVersion": "2.0.1-pre1",
    "ModifiedDate": "2014/05/28 00:33:50 +02:00",
    "Strict": true,
    "BodySchema": null,
  },
  "Body": {
        "classCode":         4,
        "configuration":    "rigid",
        "vehWidth":         2.45,
        "vehHeight":        3.5,
        "anemometerHeight":  4.55,
        "testMass":         25000.0,
        "wheelsInertia":    90.0,
        "gearRatio_low":    2.5,
        "gearRatio_high":   1,
        "axleRatio":        3.6,
        "gearBox_type":     "MT_AMT",
   }
}
```

Figure 1: Structure of the vehicle file

The data relevant for the calculations have to be specified in the "body" according to the following conventions:

- `"classCode"`: Vehicle class code according to the HDV CO_2 segmentation matrix (1-17 for trucks and 21-23 for busses); (**no unit**)
- `"configuration"`: If the vehicle was measured without trailer (input "rigid") or with trailer i.e. as a truck/trailer or tractor semitrailer combination (input "tractor") (**no unit**)

The combination the abovementioned parameter is the criteria for allocation of generic data for C_dxA dependency on beta.

- `"testMass"`: Vehicle test mass during measurements (**unit: [kg]**). Please fill in the average value valid for the test sequence from low speed run 1, high speed run and low speed run 2. In VECTO-CSE the vehicle mass is used for correction of traction forces from road gradient and from acceleration (if these features are activated) and for determination of the vehicle average RRC (rolling resistance coefficient).
- `"wheelsInertia"`: Rotational inertia of all wheels (**unit: [kgm²]**). Please determine this value based on the tire dimensions with the help of VECTO (the CO_2 simulation tool) or use the tables from the ACEA White book. In VECTO-CSE this inertia is used for correction of traction forces for acceleration (if this feature is activated)
- `"axleRatio"`: Axle transmission ratio (**no unit**)
- `"gearRatio_high"`: Transmission ratio of the gear engaged during the high speed tests (**no unit**)
- `"gearRatio_low"`: Transmission ratio of the gear engaged during the low speed tests (**no unit**)
- `"anemometerHeight"`: Height of the measuring point of the anemometer installed at the vehicle (**unit: [m]**).
- `"vehHeight"`: Maximum vehicle height (**unit: [m]**). This value is applied in CSE for boundary layer correction of the air speed measured with the anemometer.
- `"vehWidth"`: Vehicle width (**unit: [m]**). Value without side mirror. (Remark: this value is not used in CSE so far, a potential use is to calculate the frontal area).
- "gearbox_type": Vehicle gearbox type. Vehicles with manual or automated transmission (without torque converter) are specified by the input "MT_AMT", vehicles with automatic transmission with torque converter are specified by "AT" (**no unit**).

3.4. File with ambient conditions measured by the stationary weather station (*.csamb)

Figure 2 shows an example for the structure of the file containing the ambient conditions measured by the stationary weather station. The file follows the CSV-Format.

# VECTO-CSE file with data from stationary weather station			
<t>	<t_amb_stat>	<p_amb_stat>	<rh_stat>
# [s] since daystart	[°C]	[mbar]	[%]
25200	18.1	1015.8	69.2
25210	18.0	1015.8	69.3
25220	18.1	1015.8	69.3
25230	18.0	1015.8	69
25240	18.0	1015.8	68.9
25250	18.0	1015.8	68.9
25260	18.1	1015.8	68.9
open number of rows ...			

Figure 2: Structure of the ambient conditions file

In the first row the column identifiers have to be specified. In the *.csamb file the order of columns is arbitrary. Row 2 and the following contain the measured values. Table 2 gives the specifications of the data signals to be provided in the ambient conditions file.

Table 2: Signal specifications for the ambient conditions file

signal	**column identi-fier**	**unit**	**remarks**
time	<t>	[s] since day start	The time signal is used for consolidation with data measured at the vehicle; any frequency can be specified, minimum requirement from the tech-nical annex is 1 signal per 5 minutes
ambient tem-perature	<t_amb_stat>	[°C]	
ambient pres-sure	<p_amb_stat>	[mbar]	
relative air hu-midity	<rh_stat>	[%]	e.g. 50% humidity is specified in the file by a val-ue of "50"

3.5. Files with configuration of measurement sections (*.csms)

The measurement section files contain the configuration to allocate the recorded data to cer-tain combinations of measurement sections (MS) and driving directions. In VECTO-CSE the MS have to be configured separately for the calibration test and for the measurement runs. Figure 3 shows the structure of a measurement section file.

trigger used (1=yes; 0=no)

0								
meas. section ID	direction ID	lenght	heading	lat start	long start	lat end	long end	optional: path and/or filename altitude file
# [id]	[id]	[m]	[°]	[mm.mm]	[mm.mm]	[mm.mm]	[mm.mm]	[-]
1	1	250	236	..P1..	..P1..	..P2..	..P2..	*TrackDemo_1_1.csalt*
2	1	250	236	..P2..	..P2..	..P3..	..P3..	*TrackDemo_2_1.csalt*
3	1	250	56	..P4..	..P4..	..P5..	..P5..	*TrackDemo_3_1.csalt*
4	1	250	56	..P5..	..P5..	..P6..	..P6..	*TrackDemo_4_1.csalt*
open nr. of rows ...								

Figure 3: Structure of the measurement section file

The data to be specified is explained below:

Row 1, column 1: specification whether a trigger signal is used to identify the exact moment when the vehicle enters a measurement section ("1" = trigger signal used; "0" = no trigger signal is used). The methods how CSE evaluates the measurement data for these two options are described in section 4.2.

From row 2 on: Specification of the measurement sections according to Table 3. The order of columns in the measurement section file is fixed. The header name definition is needed (as shown in Figure 3) and have to be labelled as non-comment line. The unit definition can be used but always have to be labelled as comment line. The number of measurement sections to be used in the VECTO-CSE evaluations is free.

Table 3 gives the specifications for the data to be provided in the measurement section files. For further explanation on the following pages two examples for test track layout and related configuration in the *.csms-file are given.

Table 3: Data specifications for the measurement section files

column number	data	column identifier	unit	remarks
1	measurement section ID	Pos. fixed	[-]	user defined identification number
2	driving direction ID	Pos. fixed	[-]	user defined identification number If on a circular test track only a single sense of rotation is driven, the MS on both straights can be labelled with driving direction "1" (VECTO-CSE internally validates the criteria for driving directions based on the heading signal). Measurement sections evaluated for the calibration run have to be configured in two driving directions.
3	heading	Pos. fixed	[°]	heading of the measurement section
4	length of the measurement section	Pos. fixed	[m]	to be determined by distance measuring wheel (or by DPGS). Distance is used for: • calibration run: calibration of vehicle speed

column number	data	column identifier	unit	remarks
				• measurement runs: verification of valid distance driven inside the measurement sections see also footnote [2]
5	latitude start point of section	See Table 4	[mm.mm] [dd.dd] [ss.ss]	The coordinates also have to be provided in case a trigger signal is used for identification of MS (for the purpose of plausibility checks). For standard GPS devices please provide minimum 4 digits after the decimal separator (refers to an accuracy of better than 1.8 meter). For the DGPS option please provide minimum 5 digits after the decimal separator (refers to an accuracy of better than 0.18 meter)
6	longitude start point of section	See Table 4		
7	latitude end point of section	See Table 4		
8	longitude end point of section	See Table 4		
5	path and/or filename of altitude file	Pos. fixed	[-]	only required for the constant speed tests (not the calibration test) and if the altitude correction is enabled. If only the filename is specified here, VECTO-CSE searches in the folder of the *.csms-file.

The coordinates can be defined in three different units. For the selection which coordinate unit is used an additional specification is needed:

Table 4: Coordinate definition (header options)

Coordinate	unit	Additional specification
Decimal minutes	[mm.mm]	**Standard choice**. No addition needed
Decimal grad	[dd.dd]	Additional **"(D)"** needed in the header name
Decimal seconds	[ss.ss]	Additional **"(S)"** needed in the header name

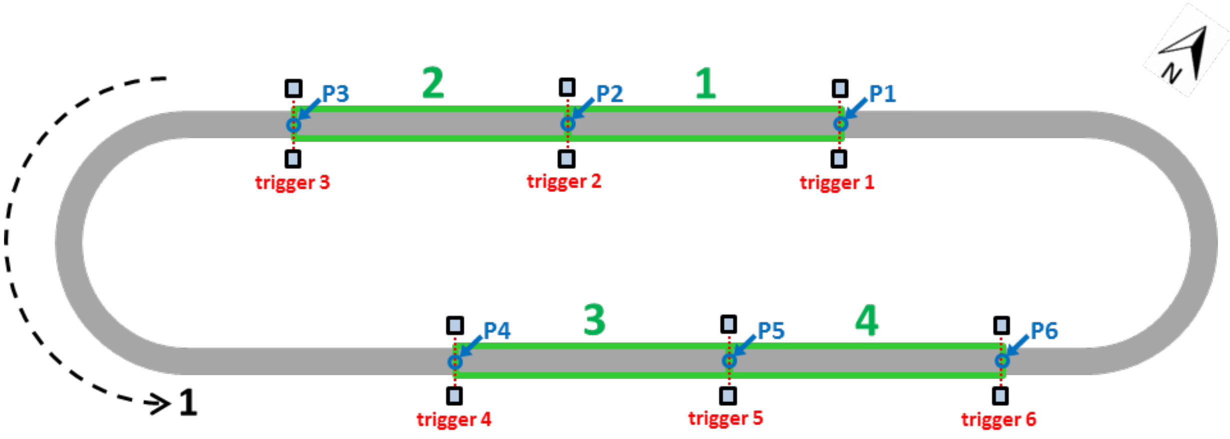
---

[2] VECTO-CSE the length of a measurement section is also calculated internally from the coordinates of start and endpoint. This value is compared with the distance as specified by the user and – if the difference is greater than the parameter "leng_crit" - shown in the message window after read-in of *.csms file.

As reference length for calibration of vehicle speed always the value specified directly by the user is used. If the length calculated from the coordinates differs significantly from this value this might result in invalid datasets failing in the validity check where the driven distance inside the measurement section is compared with the length of the MS +/- the parameter "leng_crit

Examples:

Figure 4 shows the MS file configuration for a circular test track with two measurement sections on both straights and which is driven in a singular sense of rotation.

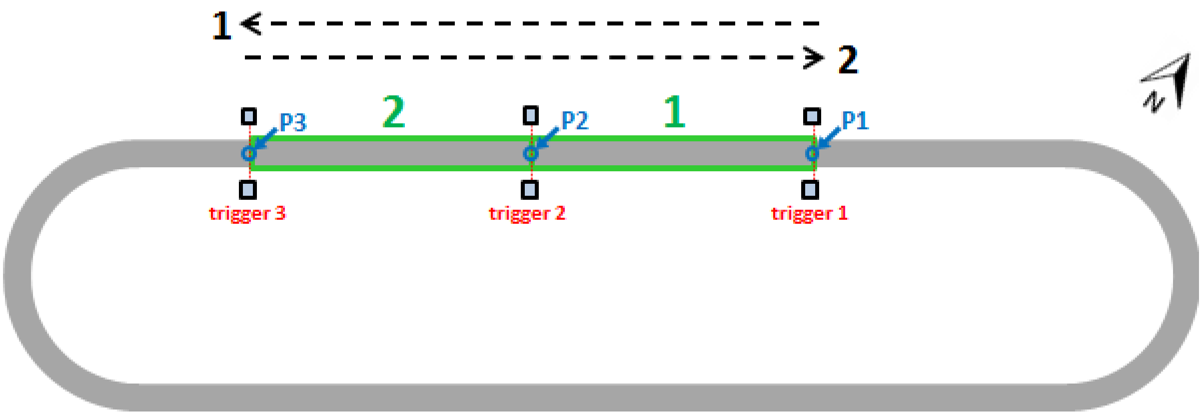


c meas. section ID	direction ID	lenght [m]	heading [°]	latitude start	longitude start	latitude end	longitude end
c [id]	[id]	[m]	[°]	[mm.mm]	[mm.mm]	[mm.mm]	[mm.mm]
1	1	250	236	*..P1..*	*..P1..*	*..P2..*	*..P2..*
2	1	250	236	*..P2..*	*..P2..*	*..P3..*	*..P3..*
3	1	250	56	*..P4..*	*..P4..*	*..P5..*	*..P5..*
4	1	250	56	*..P5..*	*..P5..*	*..P6..*	*..P6..*

Figure 4: Example 1 for test track layout and MS configuration file (circular test track driven in single sense of rotation)

In Figure 5 the MS file configuration for measurements recorded on a single straight in two measurement sections driven in two driving directions is given. Such a configuration could be used e.g. for the calibration run[3] on a test track as shown above or also for a test track which consists of a single straight with turning points at both ends.

[3] In CSE more than a single section can be configured in the calibration run (details see 4.3).



c meas. section ID	direction ID	lenght [m]	heading [°]	latitude start	longitude start	latitude end	longitude end
c [id]	[id]	[m]	[°]	[mm.mm]	[mm.mm]	[mm.mm]	[mm.mm]
1	1	250	236	..P1..	..P1..	..P2..	..P2..
2	1	250	236	..P2..	..P2..	..P3..	..P3..
2	2	250	56	..P3..	..P3..	..P2..	..P2..
1	2	250	56	..P2..	..P2..	..P1..	..P1..

Figure 5: Example 2 for test track layout and MS configuration file (measurement data recorded on two measurement sections on a single straight driven in two driving directions)

3.6. Files with measurement data recorded at the vehicle (*.csdat)

Figure 6 shows an example for the structure of the file containing the measurement data recorded at the vehicle. VECTO-CSE requires each a *.csdat-file for

i.) the calibration test (during warm up of the vehicle)
ii.) the first low speed test
iii.) the high speed test
iv.) the second low speed test

VECTO-CSE file
Klettwitz, 2012-06-24, calibration run

<t>	<lat>	<long>	<hdg>	<v_veh_GPS>	<v_veh_CAN>	<v_air>	<beta>	<n_eng>	<tq_l>	<tq_r>	...
# [s]	[mm.mm]	[mm.mm]	[°]	[km/h]	[km/h]	[m/s]	[°]	[rpm]	[Nm]	[Nm]	...
37080.01	3091.3309332	834.6905802	38.3	87.26	89.01	23.05	-0.82	1310	1352.3	1094.0	...
37080.02	3091.3319202	834.6919578	38.3	87.30	89.05	23.05	-0.81	1309	1378.7	1180.2	...
37080.03	3091.3329192	834.6933138	39.1	87.28	89.02	24.03	-0.80	1309	1359.9	1033.2	...
37080.04	3091.3339326	834.6946482	39.9	87.23	88.97	24.03	-0.81	1310	1439.6	1165.3	...
37080.05	3091.3349532	834.6959658	40.5	87.32	89.06	23.97	-0.80	1311	1404.9	1037.3	...
37080.06	3091.3359816	834.6972654	41.1	87.26	89.01	23.97	-0.82	1312	1465.6	1102.0	...
37080.07	3091.3370232	834.6985458	41.9	87.34	89.08	23.97	-0.81	1311	1457.1	1124.7	...
open number of rows ...											

Figure 6: Example structure of the *.csdat file

The order of columns is arbitrary. The program identifies the signals based on the column identifier to be specified in row 1. Row 2 and the following contain the measured values. **The temporal resolution of the *csdat files is defined with 100Hz.** This frequency is checked by VECTO-CSE during read-in. **It is allowed to cut out driving phases e.g. recorded outside the measurement sections.**

The recordings in the *.csdat-file have to start early enough that the meaningful moving averages can be calculated at the point in time when the vehicle enters the measurement section (i.e. >0.5s for the high speed test, >4.5s for the low speed test).

With the CSE Version 2.0.4 several coordinate units can be used (See Table 5). For the different units a specific column identifier has to be used.

Table 5 gives the specifications of the data signals to be provided in the measurement data files.

Table 5: Signal specifications for the measurement data file

signal	column identifier	unit	remarks
time	<t>	[s] since day start	rate fixed to 100Hz; time signal used for correlation with ambient conditions data and for check of frequency
(D)GPS latitude	<lat>	[mm.mm]	For standard GPS devices please provide minimum 5 digits after the decimal separator (refers to an accuracy of better than 1.8 meter). For the DGPS option please provide minimum 6 digits after the decimal separator (refers to an accuracy of better than 0.18 meter) 1° = 111111 m 0.00001° = 1.11 m 0.000001° = 0.11 m
	<lat_D>	[dd.dd]	
	<lat_S>	[ss.ss]	
(D)GPS longitude	<long>	[mm.mm]	
	<long_D>	[dd.dd]	
	<long_S>	[ss.ss]	
(D)GPS heading	<hdg>	[°]	
(D)GPS velocity	<v_veh_GPS>	[km/h]	not used in analysis if opto-electronic triggers are used
vehicle velocity	<v_veh_CAN>	[km/h]	raw CAN bus front axle signal
air speed	<v_air>	[m/s]	raw data (instrument reading)
inflow angle (beta)	<beta>	[°]	Important definitions for data on inflow angle: VECTO-CSE accepts values only in the range from +360° to -360°. After read in these numbers are converted to the +180° to -180° range.
engine speed cardan speed	<n_eng> <n_card>	[rpm]	Dependent of the vehicle configuration (gearbox_type) either engine or cardan speed is required: • gearbox type "MT_AMT": engine speed required • gear box type "AT": if torque converter is **not locked** during low speed test **cardan speed** has to be provided. Otherwise either engine speed or cardan speed can be provided. If both signals are available, VECTO-CSE uses engine speed
torque meter (left wheel)	<tq_l>	[Nm]	Primary torque calibration (y=kx+d) to be done in data capturing system (i.e. before import into VECTO-CSE!)
torque meter (right wheel)	<tq_r>	[Nm]	
ambient temperature on vehicle	<t_amb_veh>	[°C]	to be measured according to the specifications in the technical annex

trigger signal	<trigger>	[-]	Optional signal; required if measurement sections are identified by opto electronic triggers (option "trigger_used=1"). This signal is defined to be an arbitrary integer value which changes at a "trigger event".
tyre temperature	<t_tire>	[°C]	average value of relevant tires
tyre pressure	<p_tire>	[bar]	average value of relevant tires; optional signal
fuel mass flow	<fc>	[kg/h]	optional signal
validity	<valid>	[-]	Optional signal (1=valid; 0=invalid); This feature shall be used to label invalid data (e.g. due to close passing of another vehicle, technical or driving errors). Invalid data will be excluded by VECTO-CSE from further analysis.

Any other provided signal in the measurement data file will be also processed by VECTO-CSE. For these signals the averages for the driving phases within measurement sections are calculated. Any column identifier (except the predefined ones) can be used. These identifiers are then also used by VECTO-CSE in the result files. Additional signals to be processed by VECTO-CSE have to be existent in ALL measurement data files.

3.7. File with altitude profile (*.csalt)

Figure 7 gives an example for an altitude file. If the correction of gradient forces is enabled VECTO-CSE requires each a *.csamb-file for each combination of measurement section and driving direction as specified in the *.csms-file for the low speed – high speed – low speed sequence.

# distance from start point # [m]	altitude [m]
0.00	260.02
50.00	260.18
100.00	260.31
150.00	260.49
200.00	260.37
250.64	260.22
open nr. of rows ...	

Figure 7: Example structure of the *.csalt file

The data to be specified is explained below:

Column 1: distance from start point of the measurement section (unit: [m])

Column 2: altitude

The first row has to start with the distance “0”, the distance specified in the last line has to match with the length of the measurement section as specified in the *.csms file. Any number of rows greater than or equal to two can be specified. VECTO-CSE applies linear interpolation for altitudes from the *.csalt file.

3.8. Job-File

The Job file contains all information for a VECTO-CSE test evaluation (settings, paths to input data and a small set of input parameters). **The Job file is automatically created by the VECTO-CSE user interface in the JSON format. After a successful calculation VECTO-CSE also writes the main evaluation results into the job-file.**

3.9. Criteria-File

The criteria file can be used to save or import a set of evaluation parameters (e.g. validity criteria or settings for correction functions) as shown in the GUI in the “Criteria”-tab. The criteria file is written in the JSON format.

For reasons of traceability for each calculation the used parameters are in any case also stored in the Jobfile.

The criteria file as used by VECTO-CSE V2.0.2 is not compatible with the criteria file of previous tool versions as additional parameters have been added.

4. Evaluation algorithms

This section gives a documentation of the algorithms which are used to evaluate the input data.

4.1. Processing of data for vehicle position

In a first step VECTO-CSE converts the (D)GPS coordinates to UTM coordinates. The according results for UTM coordinates can be found in the results files (values: “Lat (UTM)” and “Long (UTM)”). For data inside of measurement sections also the theoretical position of the vehicle projected to the line defined by the start- and end-coordinates of the measurement section (result file values “Lat (root)” and “Long (root)”) is calculated. This coordinate is the reference for the identification of the vehicle position inside the measurement sections and for the allocation of the altitude if the altitude correction is applied.

4.2. Assignment of measurement data to measurement sections

For assignment of recorded data to the measurement sections as specified in the *.csms-file two options can be chosen how the point in time is determined when the vehicle enters and exits the predefined measurement sections.

Option 1: Trigger signal

CSE identifies the entry or the exit of the vehicle if the criteria 1. to 3. are met:

1. The trigger signal shows a change in integer value
2. The position of the vehicle is inside a square around a start point or an end-point of a MS as defined in the *.csms-file. The square is defined by the (+/-)-range from the parameters “delta_x_max” and “delta_y_max” (unit: [m]).
3. The heading of the vehicle is in a (+/-)-range as defined by the parameter “delta_head_max” (unit: [°])

Option 2: DGPS signal

CSE identifies the entry or the exit of the vehicle if both criteria 1. and 2. are met:

1. An imaginary line perpendicular to a measurement section going through the start point or the end-point is crossed within the (+/-)-range of the parameter “delta_y_max” (unit: [m]) to the start point or to the end-point
2. The heading of the vehicle is in a (+/-)-range as defined by the parameter “delta_head_max” (unit: [°])

Important remarks:

- If a measurement section is specified in the *.csms-file only in a single driving direction, the data recorded on this section during driving in the <u>opposite</u> direction is <u>not</u> evaluated in VECTO-CSE.

- If the end point of a MS is identical with the start point of the next MS the events for "exit" of the first MS and "entry" into the next MS happen at the same point in time.
- The validity of the allocated data is furthermore checked by comparison of driven distance (determined via the calibrated vehicle speed) inside the measurement section with the distance as specified as in the *.csms-file. If the absolute difference is greater than the parameter "leng_crit" (pre-set to 3m)[4], the particular data is not considered valid.
- DGPS use: According to the technical annex it is only valid to use "option 2" as explained above in connection with use of high accuracy DGPS systems. This factum cannot be verified within VECTO-CSE.
- For all above mentioned parameters default values are pre-set in VECTO-CSE 2.0.x as determined based on the experience with the available test data. An adaption of these parameters might be necessary for some cases in order to gain an appropriate assignment of measurement data to measurement sections.

4.3. Evaluation of the calibration test

According to the technical annex the signals for:

- vehicle speed
- air speed and
- yaw angle (beta)

shall be calibrated based on measurement data recorded at high speed driving during the warm-up phase. This evaluation is done in VECTO-CSE automatically in a pre-processing step. **From the separate "calibration test" only the calculated calibration of the yaw angle (beta) will be used for the constant speed evaluation. The vehicle and air speed here are only calculated for the validity checks relevant for the calibration test. The final values for vehicle and air speed calibration are calculated based on the high speed test data.**

Step 1: Calibration of vehicle speed

In VECTO-CSE the vehicle speed "v_veh" is determined based on the CAN (front axle) vehicle speed signal "v_veh_can" multiplied by the calibration factor "fv_veh".

The calibration factor "fv_veh" is determined by the average ratio of a reference vehicle speed ("v_ref") to the CAN (front axle) vehicle speed signal "v_veh_can" for all "datasets" [5] recorded during the calibration run. The reference vehicle speed is determined depending on the method of assignment of measurement sections as described below:

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[4] Final value of parameter to be decided

[5] A „dataset" refers to the data recorded within a measurement section.

Option 1: Trigger signal

The reference vehicle speed is calculated by division of the length of the measurement section as specified in the *.csms-file by the driving time in the measurement section as determined based on the trigger signal.

Option 2: DGPS signal

For the DGPS option the vehicle reference speed is determined by two methods:

- by directly using the DGPS vehicle speed
- by division of the length of the measurement section as specified in the *.csms-file by the driving time in the measurement section as determined based on the DGPS coordinates.

Position and velocity are determined by (D)GPS devices by different physical principles. Currently it is not known which of the two methods a) and b) result in higher accuracy. Test data as available during VECTO-CSE development showed only very small deviations of the vehicle speed as determined by methods a) and b). A general selection of the method to be used shall be made after further use of VECTO-CSE. In the current VECTO-CSE version method a) is used for further processing. Calibration factors determined by both methods are shown in the result file.

Step 2: Calibration of air speed and yaw angle

For calibration of air speed and yaw angle CSE determines the calibration factors "f_{vpe}" (position error of measured air speed) and "β_{ame}" (misalignment factor for measured yaw angle) as specified in the technical annex. The evaluation steps are done as specified below:

1. In a first evaluation step it is assumed that all datasets have been recorded in valid wind conditions assigning the label "valid=1".
2. VECTO-CSE checks if a minimum set of five[6] valid datasets per measurement section and driving direction (for the calibration test) and **per headings respectively (for the high speed test)** are available. If uneven numbers of datasets for the two driving directions or headings are available, VECTO discards the last dataset from the driving direction / heading with the higher number of available valid datasets. Such datasets and invalid datasets (according to the wind criteria) are labelled with "used=0". The labels "valid" and "used" assigned to each dataset are also shown in the VECTO-CSE output file.
3. Based on all "used=1" datasets the calibration factors "f_{vpe}" and "β_{ame}" are determined using the formulas as specified in the technical annex in section 5.1.2.8. For the yaw angle the correction factor f_{ape} (position error) is taken from generic data.
4. With these correction factors the undisturbed air flow (air speed, yaw angle and wind at the anemometer position) and the boundary layer correction as specified in the technical annex in section 5.1.2.8 is calculated resulting in the reference values for air speed, wind speed and yaw angle.

[6] The number of required valid datasets can be modified in the „options" tab, see 6.4.

5. Based on the values calculated in 5. the validity of the wind criteria for the single datasets as specified in the technical annex in section 5.1.2.2.3 is checked. If the validity of single datasets has been modified, the evaluation process is started again with point 3. If not, the calibration factors “f_{vpe}” and “β_{ame}” determined in point 3. are considered final.

Important remarks related to the evaluation of the calibration test:

- In the evaluation of the calibration test data recorded in both driving directions on a particular measurement section has to be available. This is checked by the software during read in.
- In VECTO-CSE more than one measurement section can be configured to be evaluated in the calibration test. The overall calibration factors are determined by averaging the results determined in a first step for each specified measurement section. If for a particular measurement section not enough valid datasets are available, the data for this section are completely discarded in the evaluations.
- In “step 1: calibration of vehicle speed” datasets are included in the analysis independent of the wind conditions.
- **The calculation of vehicle and air speed inside the calibration test are only done for the check of the validity criteria’s. There final values for the constant speed tests are calculated with the high speed data set.**

4.4. Evaluation of the constant speed tests

This section describes the evaluation steps performed for the measurement data recorded in the first low speed – high speed – second low speed test sequence.

Step 1: Calculation of air speed, yaw angle and wind speed

VECTO-CSE calculates the values for air speed, yaw angle and wind speed as laid down in the technical annex. This is done in the 100Hz time basis.

Step 2: Calculation of forces from driving resistances

VECTO-CSE determines the forces which apply to the vehicle from the driving resistances in the 100Hz time resolution according to the steps i. to iv.:

i. Calculation of total traction force:

The total traction force is calculated as specified below:

$$F_{trac} = \frac{(T_L + T_R) \cdot \dfrac{n_{eng} \cdot \pi}{30 \cdot i_{gear} \cdot i_{axle}}}{v_{veh}}$$

where:

F_{trac} = total traction force [N]

T_L, T_R = corrected torque for left and right wheel [Nm]
n_{eng} = engine speed [rpm]
i_{gear} = transmission ratio of engaged gear [-]
i_{axle} = axle transmission ratio [-]
v_{veh} = vehicle speed [m/s]

ii. <u>Correction for forces from road gradient and accelerations</u>

From the total traction force the forces from road gradient and accelerations are subtracted gaining the driving resistance force caused by air drag and rolling resistance. This is correction is only done if enabled in the VECTO-CSE evaluation settings:

$$F_{res} = F_{trac} - F_{grd} \cdot s_{grd} - F_{acc} \cdot s_{acc}$$

where:
F_{trac} = driving resistances force (air drag and rolling resistance) [N]
F_{res} = total traction force [N]
F_{grd} = gradient force [N]
s_{grd} = parameter for gradient correction (1=enabled, 0 =disabled) [-]
F_{acc} = acceleration force [N]
s_{acc} = parameter for acceleration correction (1=enabled, 0 =disabled) [-]

The gradient force is calculated from:

$$F_{grd} = m_{veh} \cdot g \cdot \sin\left(\frac{\Delta alt}{\Delta dist}\right)$$

where:
m_{veh} = vehicle mass as specified in *.csveh-file [kg]
g = earth gravitational acceleration (9.81) [m/s²]
Δalt = altitude difference from next to previous timestep
$\Delta dist$ = difference of driven distance from next to previous timestep

The acceleration force is calculated from:

$$F_{acc} = m_{veh} \cdot a_{avg} + \cdot \frac{I_{wh} \cdot \dot{\omega} \cdot \omega}{v_{veh}}$$

where:
m_{veh} = vehicle mass as specified in *.csveh-file [kg]
a_{avg} = vehicle acceleration calculated from the moving averaged vehicle speed signal [m/s²]
I_{wh} = wheels rotational inertia [kgm²]
$\dot{\omega}$ = wheels angular acceleration [rad/s²]
ω = wheels angular speed [rad/s]
v_{veh} = vehicle speed [m/s]

The averaging period for the signals of vehicle speed and engine speed as used for calculation of vehicle acceleration and wheel speed acceleration is defined by the parameter *acc_corr_avg* (unit: [s]).

In VECTO-CSE V2.0.2 in the default evaluation settings the gradient correction is disabled. The reasons are:

The influence of road gradient does not affect the C_dxA test result due to the general VECTO-CSE evaluation principle. So no precise altitude profile is required for base-line air drag evaluations. However, the determined values for rolling resistance on single combinations of measurement sections and driving directions are biased by road gradient forces. If a precise altitude profile is available, this influence can be eliminated.

The evaluation step “Normalisation of driving resistance forces to reference air density” as performed in VECTO-CSE versions 2.0.1 and earlier has been removed (modified calculation method for CdxA).

iii. Calculation of the air density and vapour pressure

The air density is calculated from the air temperature measured on the vehicle and the air pressure and relative humidity as measured at the stationary weather station based on the following equations:

$$p_{v,H2O} = 611 \cdot \frac{RH_{stat}}{100} \cdot 10^{\frac{7.5 \cdot t_{amb,stat}}{(237+t_{amb,stat})}}$$

$$\rho_{air} = \frac{p_{amb,stat} - p_{v,H2O}}{287.1 \cdot (t_{amb,veh} + 273.15)} + \frac{p_{v,H2O}}{461.9 \cdot (t_{amb,veh} + 273.15)}$$

where:

$p_{v,H2O}$	=	H_2O vapour pressure [Pa]
RH_{stat}	=	relative humidity measured by stationary weather station [%]
$t_{amb,stat}$	=	ambient temperature measured by stationary weather station [°C]
$t_{amb,stat}$	=	ambient temperature measured on the vehicle [°C]
$p_{amb,stat}$	=	ambient pressure measured by stationary weather station [Pa]

iv. Evaluation of the dynamic tyre diameter

The dynamic tire diameter is calculated for the high speed tests and for the low speed tests based on the following equation:

$$r_{dyn} = 30 \cdot i_{gear} \cdot axleRatio \cdot \frac{v_{veh}}{(n_{ec} \cdot \pi)}$$

where:

r_{dyn}	=	dynamic tyre diameter [m]
i_{gear}	=	gear ratio [-]
axleRatio	=	axle ratio [-]

v_{veh} = vehicle velocity [m/s]
n_{ec} = Engine or cardan speed dependent on gear box type [rpm]

The dynamic tire radius is only used for performing the validity check for the engine speed signal. The proposed method is described in the release notes of VECTO-CSE V2.0.2.

v. Correction of driving resistance force for the low speed tests

The driving resistance forces for the low speed tests are furthermore corrected by the factor $f_{roll,corr}$ as read in from the main VECTO-CSE GUI.

$$F_{res,ref} = F_{res} \cdot f_{roll,corr}$$

This feature aims for correction of a systematic change of rolling resistance in the low speed tests compared to the high speed tests as driven in the test sequence.

Example: If the rolling resistance in the low speed tests is known to be at 85% from the rolling resistance in the high speed tests a correction factor of 1/0.85 = 1.176 has to be specified in VECTO-CSE.

Default setting for $f_{roll,corr}$ is 1 (i.e. no correction).

Step 3: Check of validity criteria for datasets to be included in the analysis

VECTO-CSE identifies the data recorded inside the measurement sections (“datasets”) with the methods as described in 4.2. Datasets will be automatically excluded by VECTO-CSE from further evaluations in case of:

- invalid wind speed conditions (calibration test, low speed test, high speed test)
- invalid yaw angle conditions (calibration test, high speed test)
- stability criteria for vehicle speed not met (low speed test, high speed test)
- stability criteria for vehicle torque not met (low speed test, high speed test)
- unequal number of datasets per vehicle heading direction (high speed test)
- unequal number of datasets for a particular combination of measurement section and driving direction for the first and the second low speed test
- stability criteria for engine / cardan speed not met (low speed test, high speed test)
- The validity of the allocated data is furthermore checked by comparison of driven distance (determined via the calibrated vehicle speed) inside the measurement section with the distance as specified as in the *.csms-file. If the absolute difference is greater than the parameter “leng_crit” (pre-set to 3m)[7], the particular data is not considered valid.

For the pilot phase VECTO-CSE executes the evaluations but gives warnings in case of:

- valid range of ambient conditions exceeded

[7] Final value of parameter to be decided

- maximum deviation of average tire pressure in low speed and high speed exceeded
- maximum deviation of RRC between first and second low speed test exceeded

VECTO-CSE aborts evaluations in case of

- test track requirements not met (max. 20° direction deviations (from +/-180°) between measurement sections)
- not sufficient number of datasets available (calibration test, low speed test, high speed test)

All validity criteria can be edited in the VECTO-CSE GUI in the “options”-tab. The default settings for parameters as laid down in the technical annex can be restored via the “Set to standard”-button. The compliance of the single datasets with the single validity criteria is documented in the VECTO-CSE “ms-file”. This file can be used to identify which criteria was not met by the data. Datasets which fulfil all validity criteria are labelled in VECTO CSE with “valid = 1” (invalid datasets: “valid = 0”). In cases where unequal numbers of valid datasets e.g. for the two driving directions are available, VECTO-CSE excludes also the last dataset surplus dataset of the other driving direction from further evaluations by setting the parameters “used” to 0. In the further evaluation steps only the “used=1” datasets are considered.

Step 4: Calculation of $C_d x A_{fr}$ values for all combination of measurement sections and driving directions

For all applicable combinations of measurement sections and driving directions the following analysis is performed:

- Setup of a linear regression for all used=1 datasets from the high speed tests and the two low speed tests for $F_{res,ref}$ as a function of squared air speed (v_{air}^2) achieving an regression coefficient F_2 (unit: [Ns²/m²]) and a constant term F_0 (unit [N]). In the regression weighting factors are applied so that the cumulative weighting of all high speed datasets is 50%.

- The value for $C_d(\beta_{avrg})\cdot A_{fr}$ [m²] is calculated for each high speed dataset as follows:

$$C_d(\beta_{avrg}) \cdot A_{fr} = 2 \cdot {(F_{res,ref} - F_0)}\Big/{(v_{air}{}^2 \cdot \rho_{air,ref})}$$

- The average value for $C_d(\beta_{avrg})\cdot A_{fr}$ [m²] for the particular combination of measurement and driving direction is calculated from the $C_d(\beta_{avrg})\cdot A_{fr}$ values of all used high speed datasets.

- The average absolute yaw angle β_{avrg} is calculated from all high speed datasets

- The rolling resistance coefficient (RRC, unit [kg/t]) is calculated from

$$RRC = \frac{1000 \cdot F_0}{m_{veh} \cdot g}$$

Step 5: Determination of overall test result

The result for overall "$C_d(\beta_{avrg})\cdot A_{fr}$" and overall "$\beta_{avrg}$" is calculated from the results for all applicable combinations of measurement sections and driving directions by arithmetical averaging.

The final result for $C_d\cdot A_{fr}$ [m²] for zero cross-wind conditions is then achieved performing the yaw angle correction as specified below:

$$C_d \cdot A_{fr} = C_d(\beta_{avrg}) \cdot A_{fr} - \Delta C_d \cdot A_{fr}(\beta_{avrg})$$

where:

$C_d(\beta_{avrg}) \cdot A_{fr}$	=	average result for product of air drag coefficient and frontal area from constant speed tests comprising an average absolute yaw angle of β_{avrg}
$\Delta C_d \cdot A_{fr}(\beta_{avrg})$	=	yaw angle correction applying the generic curve for $\Delta C_d \cdot A_{fr}$ as a function yaw angle for the value of β_{avrg}. In this correction the applicable generic curve for the particular vehicle class and vehicle configuration (rigid or with trailer) is used.

During the pilot phase also an alternative method for yaw angle correction will be calculated by VECTO-CSE (yaw angle correction performed for each combination of measurement section and driving direction before averaging of final result).The according results can be identified in the result files labelled with "Option 2".

5. Output files

The overall results of the test evaluation (list of parameters see Table 6) are written by VECTO CSE into the job-file. Additionally interim results are provided by VECTO-CSE on three different levels of detail which are written into three kinds of output files:

1. The "CSE main result file" comprising overall results
2. The "MS files" with the results for all single recorded measurement sections differentiated by driving direction if applicable
3. Each a "Hz file" (either in 1Hz or in 100Hz, depending on the settings) for the calibration run, the two low speed runs and the high speed test with all input data as well as all calculated values averaged to the specified frequency

The sections below give detailed explanations on the result files. All result files are written to the subfolder "\Results" of the folder of the job-file in the CSV-format.

5.1. The CSE main result file

Filename = filename of the job-file + "CSE.csv"

Table 6 and Table 7 show the results as provided by the CSE main result file. Only data from "used" datasets are included in the analysis and provided in the CSE main result file

Table 6: Overall results provided in the CSE main result file

quantity	unit	description
fv_veh	[-]	calibration factor for CAN vehicle speed (if DGPS option is used in the calibration run: determined based on DGPS velocity signal)[8]
fv_veh_opt2	[-]	only if DGPS option is used in the calibration run: calibration factor for CAN vehicle speed based on DGPS position signal. This value is not used in the further analysis
fv_pe	[-]	position error correction factor for measured air speed
fa_pe	[-]	position error correction factor for measured air inflow angle (beta)
beta_ame	[°]	misalignment correction for measured air inflow angle (beta)
CdxA(ß)	[m²]	average Cd*A (β) of all combinations of MS ID and direction ID (before yaw angle correction)
beta	[°]	average absolute β of all combinations of MS ID and direction ID
delta_CdxA	[m²]	β-influence on CdxA calculated with beta_ave_Opt1 and the generic drag curve
CdxA(0)	[m²]	CdxA value for zero cross-wind conditions (= CdxA_ave_Opt1 - delta_CdxA_Opt1) FINAL RESULT
CdxA(0)_Opt2	[m²]	CdxA value for zero cross-wind conditions (average of CdxA(0) for all combinations of MS ID and direction ID)
Validity criteria	[-]	particular error messages on single validity criteria (ambient conditions, tire temperature conditions)

[8] In further investigations it shall be clarified which of the two calibration methods for vehicle speed based on DGPS data gives more reliable results, see also 4.3.

Table 7: Results provided per combination of measurement section and driving directions

quantity	**unit**	**description**
SecID	[-]	measurement section ID as specified in the *.csms-file
DirID	[-]	driving direction ID as specified in the *.csms-file
F0_singleMS	[N]	result for F0 from linear regression
F0_singleMS_LS1	[N]	result for F0 from linear regression (low speed data only from first test)
F0_singleMS_LS2	[N]	result for F0 from linear regression (low speed data only from second test)
CdxA(ß)	[m2]	CdxA (β) (= 2* ($F_{res,ref}$-F_0)/ (v_{air}^2 * rho_air)
CdxA0	[m2]	CdxA converted to zero cross-wind
delta_CdxA	[m2]	cross-wind correction
beta_abs_HS	[°]	average absolute beta from high speed dataset (0° refers to air flow from front!)
RRC_singleMS	[kg/t]	rolling resistance coefficient
RRC_singleMS_LS 1	[kg/t]	rolling resistance coefficient (low speed data only from first test)
RRC_singleMS_LS 2	[kg/t]	rolling resistance coefficient (low speed data only from second test)
Valid_RRC	[-]	Validity criteria for maximum difference of RRC from the two low speed runs passed (=1) or failed (=0)
t_tire_ave_LS_min	[°]	minimum tire temperature during low speed tests
t_tire_ave_LS_max	[°]	maximum tire temperature during low speed tests
t_tire_ave_HS_min	[°]	minimum tire temperature during high speed tests
t_tire_ave_HS_max	[°]	maximum tire temperature during high speed tests
F2_singleMS	[N/(m2/s2)]	result for F2 from linear regression
F2_singleMS_LS1	[N/(m2/s2)]	result for F2 from linear regression (low speed data only from first test)
F2_singleMS_LS2	[N/(m2/s2)]	result for F2 from linear regression (low speed data only from second test)

5.2. The “measurement section” (ms-)files

VECTO-CSE writes two MS-files (each one for the calibration test and one for the measurement runs). These files contain all results for the driving phases inside the measurement sections (the “datasets”).

For the calibration test: Filename = filename job-file + “MS_CAL.csv”

For the constant speed test: Filename = filename job-file + “MS_MEAS.csv”

Table 8 gives explanations to the results as provided in the ms-file for the constant speed test sequence. The ms-file for the calibration test contains fewer columns as fewer values are calculated CSE-internally.

Table 8: Results provided in the ms-file for the constant speed test sequence

quantity	unit	description
SecID	[-]	measurement section ID as specified in the *.csms-file
DirID	[-]	driving direction ID as specified in the *.csms-file
RunID	[-]	Run ID: "0" = high speed test; "1" = first low speed test; "2" = second low speed test
HeadID	[-]	Heading ID (internal quantity)
delta t	[s]	driving time inside the measurement section
length	[m]	section lenght as specified in the *.csms-file
delta s	[m]	driven distance inside the measurement section derived from vehice speed signal
v (s)	[km/h]	=delta_s/delta_t
v (GPS)	[km/h]	average vehicle speed (GPS signal)
v_veh_CAN	[km/h]	average vehicle speed (CAN signal)
v_veh	[km/h]	average vehicle speed (after calibration)
vair_ic	[m/s]	average air speed (after instrument error correction)
vair_uf	[m/s]	average air speed (undisturbed flow at anemometer height)
beta_ic	[°]	average yaw angle (after instrument error correction)
beta_uf	[°]	average yaw angle (undisturbed flow at anemometer height)
valid	[-]	overall validity of dataset
used	[-]	dataset used in final evaluations ("1"=yes, "0"=no)
val_User	[-]	validity as specified by user input
val_vVeh_ave	[-]	validity: vehicle speed range
val_vVeh_f	[-]	validity: vehicle speed stability (low speed tests)

quantity	unit	description
val_vVeh_1s	[-]	validity: vehicle speed stability (high speed test)
val_vWind	[-]	validity: maximum wind speed
val_vWind_1s	[-]	validity: maximum gust wind speed
val_tq_f	[-]	validity: stability of torque signal (low speed tests)
val_tq_1s	[-]	validity: stability of torque signal (high speed test)
val_beta	[-]	validity: average absolute beta below limit (only for high speed test)
Val_n_eng / val_n_card	[-]	validity: stability of engine / cardan speed (low and high speed test)
val_dist	[-]	validity: difference of distance from vehicle speed signal with lenght of section as specified in *.csms file
vair	[m/s]	average air speed
v_wind_ave	[m/s]	average wind speed
v_wind_1s	[m/s]	average 1s moving average of wind speed
v_wind_1s_max	[m/s]	maximum of 1s moving average of wind speed (=gust)
beta_ave	[°]	average yaw angle
beta_abs	[°]	average absolute yaw angle
v_air_sq	[m2/s2]	squared average air speed (squared in 100Hz, then aver-aged!)
n_eng / n_card	[rpm]	average engine / cardan speed
n_eng_1s_max / n_card_1s_max	[rpm]	maximum of 1s moving average of engine / cardan speed
n_eng_1s_min / n_card_1s_min	[rpm]	minimum of 1s moving average of engine / cardan speed
n_eng_float_max / n_card_float_max	[rpm]	maximum floating average of engine / cardan speed
n_eng_float_min / n_card_float_min	[rpm]	minimum floating average of engine / cardan speed
r_dyn	[m]	Dynamic tyre diameter
omega_wh	[rad/s]	average wheel rotational speed
omega_p_wh	[rad/s2]	average wheel rotational acceleration
tq_sum	[Nm]	average torque (sum l+r)
tq_sum_1s	[Nm]	average 1s moving average of torque sum
tq_sum_1s_max	[Nm]	maximum 1s moving average of torque sum

quantity	unit	description
tq_sum_1s_min	[Nm]	minimum 1s moving average of torque sum
tq_sum_float	[Nm]	average floating average of torque sum
tq_sum_float_max	[Nm]	maximum floating average of torque sum
tq_sum_float_min	[Nm]	minimum floating average of torque sum
t_float	[s]	averaging floating period ("floating" refers to averaging as defined for stability for low speed tests)
F_trac	[N]	average total traction force
F_acc	[N]	average acceleration force
F_grd	[N]	average gradient force
F_res	[N]	average force from driving resistances
F_res_ref	[N]	average force from driving resistances at reference conditions
v_veh_1s	[km/h]	average 1s moving average of vehicle speed
v_veh_1s_max	[km/h]	maximum 1s moving average of vehicle speed
v_veh_1s_min	[km/h]	minimum 1s moving average of vehicle speed
v_veh_avg	[km/h]	average "averaged" vehicle speed (as calculated for accel-eration correction)
a_veh_avg	[m/s2]	average acceleration calculated from "averaged" vehicle speed
v_veh_float	[km/h]	average floating average of vehicle speed ("floating" refers to averaging as defined for stability for low speed tests)
v_veh_float_max	[km/h]	maximum floating average of vehicle speed
v_veh_float_min	[km/h]	minimum floating average of vehicle speed
t_amb_veh	[°C]	average ambient temperature measured on the vehicle
t_amb_stat	[°C]	average ambient temperature from stationary measurement
p_amb_stat	[mbar]	average ambient pressure from stationary measurement
rh_stat	[%]	average relative humidity from stationary measurement
vp_H2O	[Pa]	average H2O vapor pressure
rho_air	[kg/m3]	average air density
t_tire	[°C]	average tire temperature
p_tire	[bar]	average tire pressure
CdxA(ß)_singleDS	[m2]	CdxA value for single high speed dataset with all low speed datasets from similar MS and Dir ID
Satellites	[-]	Number of satellites

Additionally average values for all additional signals included in the *.csdat-files are written in the ms-file.

5.3. The Hz-files

VECTO-CSE writes each a “Hz”-File (either in 1Hz or in 100Hz, depending on the settings) for each provided measurement data file (i.e. for the calibration run, the two low speed runs and the high speed run). The Hz files comprise all input data and all quantities calculated by VECTO-CSE in 100Hz time resolution arithmetically averaged to the specified frequency.

Filename = filenames csdat-file + “1Hz.csv”

Table 9 gives explanations to the results as provided in the Hz-file for the constant speed test sequence. The Hz-file for the calibration test contains fewer columns as fewer values are calculated CSE-internally.

Table 9: Results provided in the Hz-file for the constant speed test sequence

quantity	unit	description
First columns		*all quantities as read from *.csdat-file*
Zone (UTM)	[-]	UTM zone ID
Lat (UTM)	[m]	UTM Y-value (refers to latitude) of the actual vehicle position
Long (UTM)	[m]	UTM X-value (refers to longitude) of the actual vehicle position
Sec_ID	[-]	measurement section ID as specified in the *.csms-file
Dir_ID	[-]	driving direction ID as specified in the *.csms-file
Lat (root)	[m]	UTM Y-value (refers to latitude) of the reference point on the line defining the measurement section
Long (root)	[m]	UTM X-value (refers to longitude) of the reference point on the line defining the measurement section
dist_root	[m]	distance driven inside the measurement section (length on the reference line)
slope_deg	[°]	slope angle (=0 if altitude corrections is disabled)
altitude	[m]	altitude (=0 outside the measurement sections and if altitude corrections is disabled)
v_veh	[km/h]	vehicle speed (after calibration)
dist	[m]	cumulative value of driven distance
vair_uf	[m/s]	air speed (undisturbed flow at anemometer height)
vair	[m/s]	air speed (after boundary layer correction)
beta_uf	[°]	yaw angle (undisturbed flow at anemometer height)
beta	[°]	yaw angle (after boundary layer correction)
vwind_ha	[m/s]	wind speed at anemometer height
vwind	[m/s]	wind speed (after boundary layer correction)

quantity	unit	description
Vwind_1s	[m/s]	1s moving average of wind speed
omega_wh	[rad/s]	wheel rotational speed
omega_p_wh	[rad/s2]	wheel rotational acceleration
tq_sum	[Nm]	torque sum (left+right)
tq_sum_1s	[Nm]	1s moving average of torque sum
tq_sum_float	[Nm]	"floating" average of torque sum ("floating" refers to averaging as defined for stability for low speed tests)
t_float	[s]	floating period ("floating" refers to averaging as defined for stability for low speed tests)
F_trac	[N]	total traction force
F_acc	[N]	acceleration force
F_grd	[N]	gradient force
F_res	[N]	force from driving resistances
v_veh_1s	[km/h]	1s moving average of vehicle speed
v_veh_ave	[km/h]	averaged vehicle speed (as calculated for acceleration correction)
a_veh_ave	[m/s2]	acceleration calculated from "averaged" vehicle speed
v_veh_float	[km/h]	floating average of vehicle speed ("floating" refers to averaging as defined for stability for low speed tests)
t_amp_stat	[°C]	ambient temperature from stationary measurement
p_amp_stat	[mbar]	ambient pressure from stationary measurement
rh_stat	[%]	relative humidity from stationary measurement
vair_sq	[m/s]	squared average air speed

6. User Manual

6.1. General

The CSE-Tool is written in VB.Net and delivered as executable file and Visual Studio 2010 project with commented source code. It is a portable application, i.e. it is not necessary to run a setup procedure for installation. The executable file can be run from any place on a computer or in a network.

6.2. Required system settings

The regional and language options of Windows must be set in the system configurations to the following values:

a) Decimal separator: <**.**> (Dot)

b) Symbol for digit grouping: < > (Space)

List separator: <**,**> (Comma)

6.3. First program start

Copy the folder “VECTO-CSE_V2.0.x” as delivered to the computer or the network place. When the program is started for the first time, the folders “FileHistory” is generated in the application folder. Then the user interface of the VECTO-CSE-Tool is shown. If no license file (license.dat) is available in the folder of the executable, VECTO-CSE generates an “activation file”. This file then has to be sent to the JRC user support in order to gain the license file.

After the first start it is recommended to adjust the settings for standard working directory and to check the path to the executable file of a text editor (e.g. notepad.exe). These settings can be adjusted in the menu item “Tools\Preferences”.

6.4. Graphic User Interface

Figure 8 shows the VECTO-CSE main user interface. The main elements are:

- Input fields for file specifications (“…”-button to the right opens the file-browser, button to the left opens selected file in Excel or in the text editor)
- “Calibrate”-button to start the evaluation of the calibration test
- Result fields for evaluated factors from the calibration test and the high speed test
- “Evaluate”-button to start the evaluation of the low speed – high speed – low speed test sequence (this button is disabled if no valid results from calibration test are available)
- Output window for messages, warning and errors. During the calculations the main evaluation steps are stated. Main evaluation results are also shown in the message window.

- Menu bar:
    - Items for handling of job-file (“New”, “Load”, “Reload”, “Save” and “Save as”)
    - Item “Tools” for
        - Log-file handling
        - Settings (working directory, JSON settings etc.)
        - Creation of activation file
    - Item “Help” for opening of the user manual

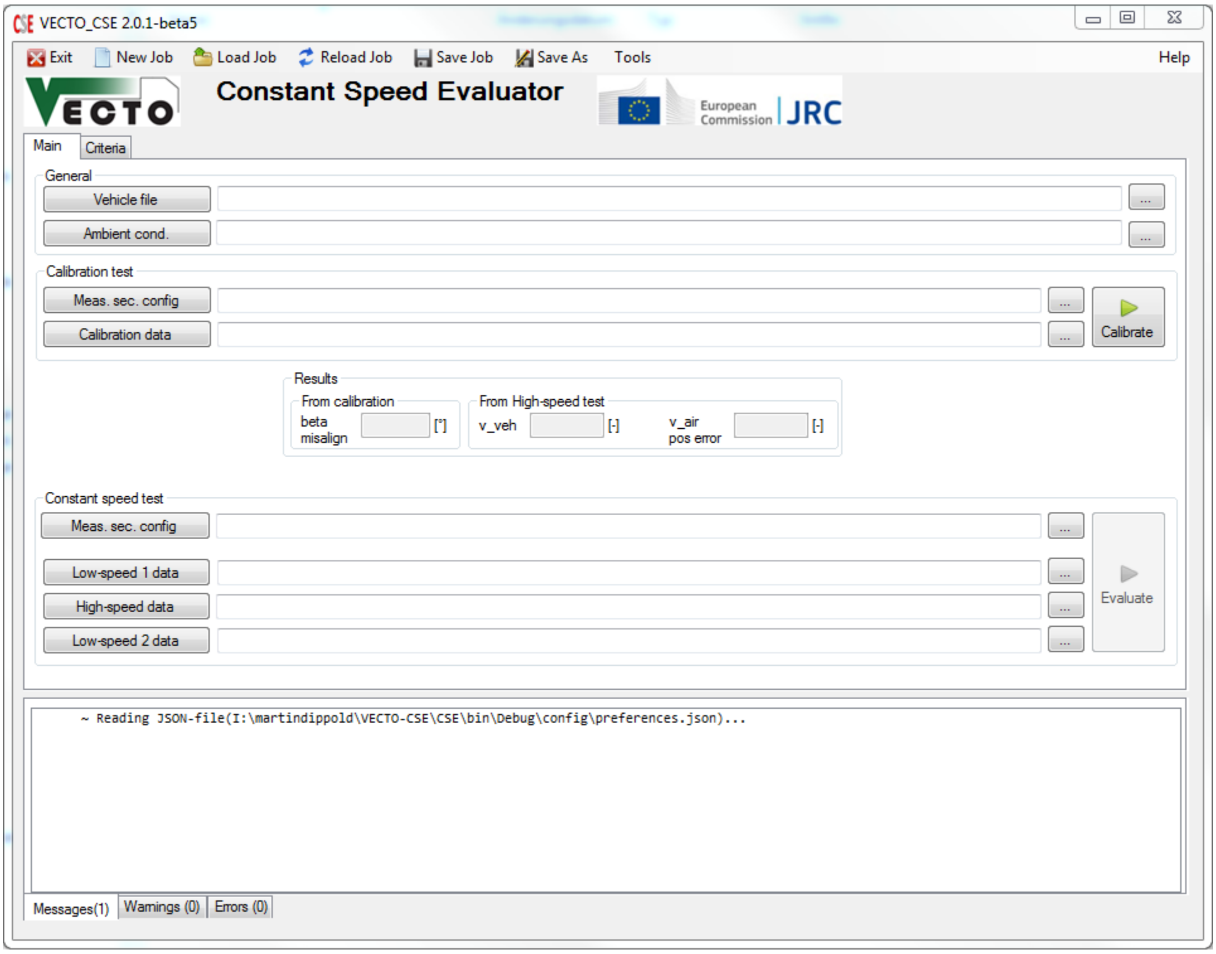

Figure 8: VECTO-CSE main user interface

Figure 9 shows the VECTO-CSE “Criteria” tab. There all evaluation parameters (validity criteria, enabling / disabling of correction functions etc.) can be edited. An explanation to each parameter is provided if the curser is moved to the related input field.

A set of parameters can imported and exported via the criteria-file (buttons at the top right). The default settings for evaluation parameters as defined in the technical annex can be restored pressing the “Reset Criteria” button.

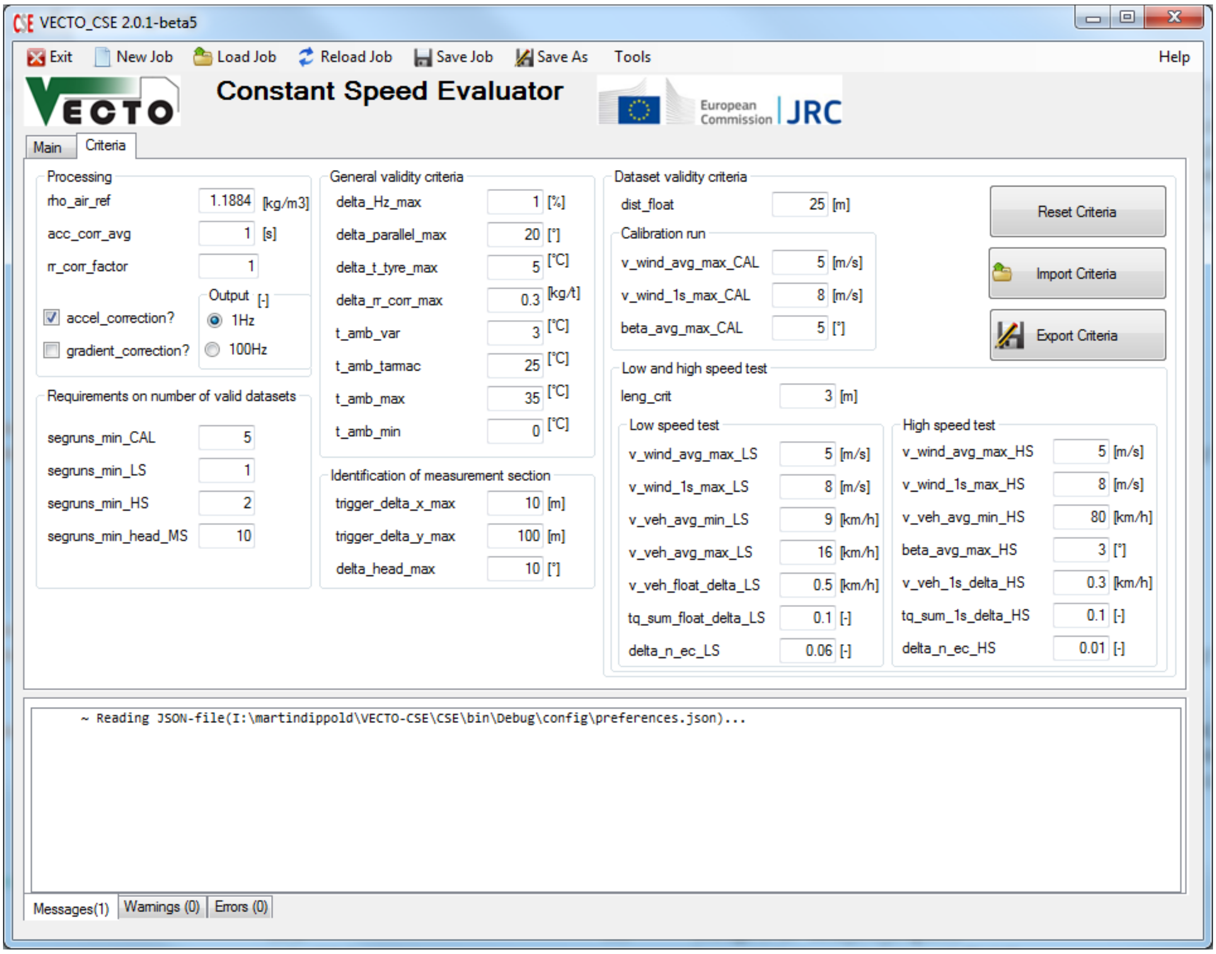

Figure 9: VECTO-CSE options tab

6.5. How to evaluate a constant speed test in VECTO-CSE

Below the single steps for the evaluation of a test series comprising a calibration test and the low speed – high speed – low speed test sequence are explained.

Step 1

Specify all input files using the browse-button ("…").

Step 2

Check or modify evaluation parameters in the "Criteria"-tab. The default settings for evaluation parameters as defined in the technical annex of the HDV CO_2 certification procedure can be restored pressing the "Reset Criteria" button.

Step 3:

Save the job-file via the "save"-button.

Step 4:

Press the "Calibrate" button to start the evaluation of the calibration test. The progress of the evaluations and potential warnings or errors are shown in the message windows. When the evaluation of the calibration test is finished successfully, the resulting calibration factors are shown in the GUI. The output files are written into the subfolder "\Results" of the folder where the job-file is located.

Step 5:

Press the "Evaluate" button start the evaluation of the low speed – high speed – low speed test sequence. The progress of the evaluations and potential warnings or errors are shown in the message windows. When the evaluation of the calibration test is finished successfully, the main results are shown in the message window. The output files are also written into the "\Results" subfolder.

Further important remarks

- A full set of evaluation settings (file-paths and options) can be reloaded by opening an existing job-file.
- Before start of evaluations (either of a calibration test or of a LS-HS-HS sequence) VECTO CSE always saves the current settings into the job-file (name and path as specified the last time). If the user does not want to overwrite the existing job-file the job-file has to be saved under a different name using the menu bar "Job\Save as".

- A calibration test can also be evaluated without data specified for the LS-HS-LS sequence.

6.6. Generic data

The data for the generic correction of yaw angle influence of the C_dxA test result is stored in the file "GenShape.shp" (subfolder "\Declaration", file format "csv"). The generic correction is defined per vehicle class ID and whether the vehicle is operated with or without trailer.

6.7. Demo data

VECTO-CSE V2.0.x is delivered with a set of demo-data. This demo data has been compiled based on original data recorded on a straight line test track with 2 measurement sections driven in both directions. Data have been modified manually extensively in order to pass all validity criteria and for confidentiality reasons.

6.8. Direct start

VECTO-CSE V2.0.x provides a direct start option. With these the program can be started without the use of the GUI (The Jobfile must be generated on every possible way). The direct start command can be result from any other program and must have the following syntax.

CSE.exe Jobfile [Output folder]

Example: C:\Downloads\2015_07_01_VECTO-CSE_2.0.2-beta6\CSE.exe C:\Downloads\2015_07_01_VECTO-CSE_2.0.2-beta6\DemoData\EvaluationDemo.csjob.json

The specification of the output folder is optional (Path must ending with "\"). If no output folder is given VECTO-CSE uses the standard output path (*Path from the Jobfile\Results*)

7. Support

Support can be obtained via

vecto@jrc.ec.europa.eu

or

rexeis@ivt.tugraz.at (methodical issues)

dippold@ivt.tugraz.at (software issues)

8. Developers Guide

This chapter is targeted to be a brief guideline to developers, who are working on the VECTO-CSE source code.

8.1. Main structure of the VECTO-CSE code

The main routine is *Main_calculation_call.calculation()* which is launched via a *BackgroundWorker* from the main GUI form. It returns a status message after the calculation is done:

- Error - The calculation was aborted due to an error
- Abort - The calculation was aborted by the user
- OK - The calculation finished successfully.

The main routine consists of two legs:

- The calibration leg which starts the calculation of the calibration parameters
- The evaluation leg which - after a successful calibration run – determines the CdxA value based on the evaluation of the low speed – high speed – low speed test sequence.

Figure 10 shows the main structure of the VECTO-CSE code.

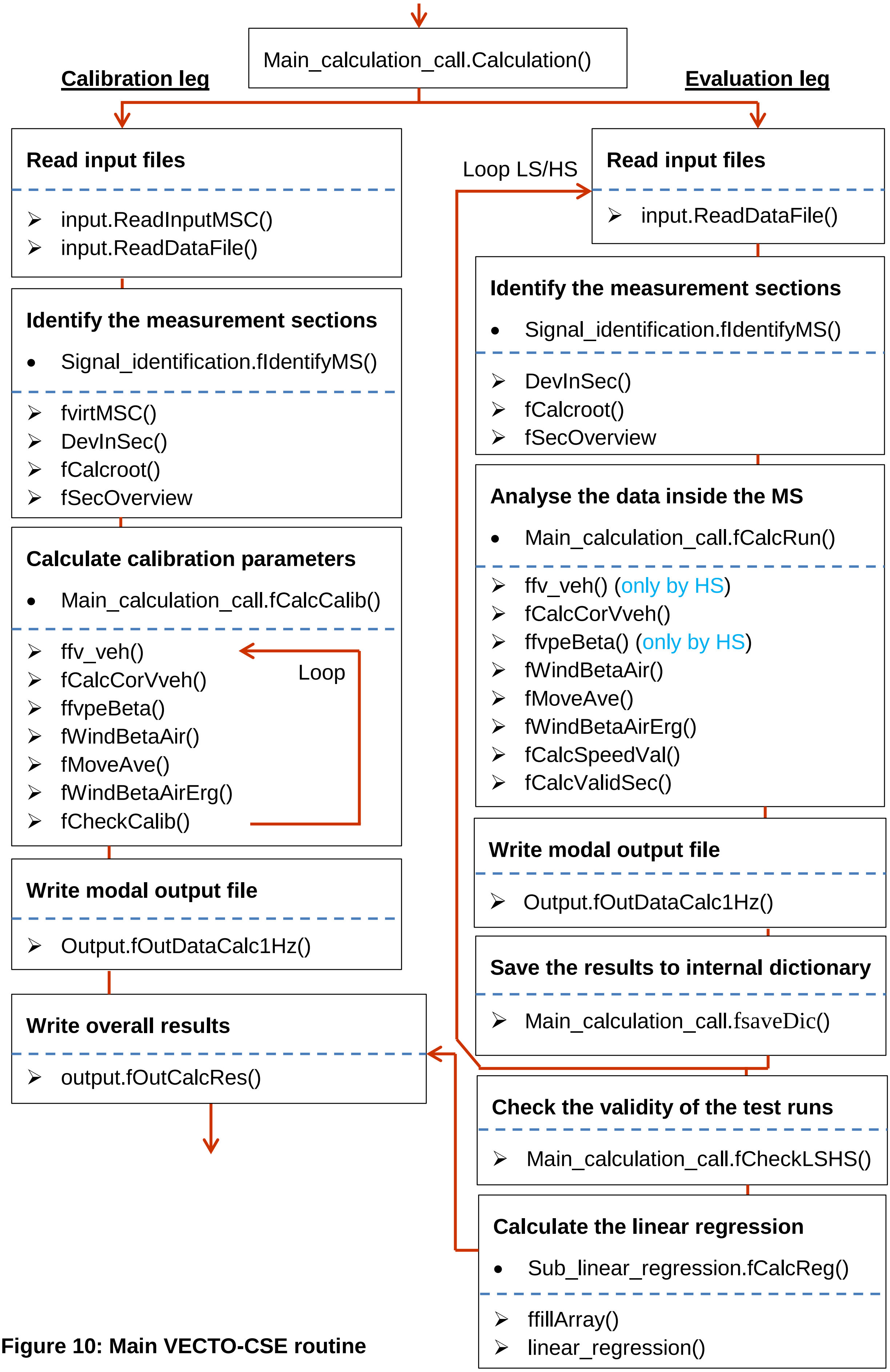

Figure 10: Main VECTO-CSE routine

input.ReadInputMSC()

- Reads the measurement section configuration (MSC) file

input.ReadDataFile()

- Reads the data files (Calibration data, Low-speed 1/2 data, High-speed data)

Signal_identification.fIdentifyMS()

- Main routine to identify which data point from the 100Hz data lies inside the given measurement sections

Signal_identification.fvirtMSC()

- Generates virtual reference points for the identification of data inside the measurement sections

Signal_identification.DevInSec()

- Function to label the data recorded inside the measurement sections in the total recorded data.

Signal_identification.fCalcroot()

- For each measured vehicle position inside a measurement section: Calculate a reference coordinate which is located on the connecting line between start and end point of the definition of the measurement section.

Signal_identification.fSecOverview

- Calculates the average values for each detected section

Main_calculation_call.fCalcCalib()

- Main sub for the calculation of the calibration parameter (v_veh, v_air pos error, beta misalign)

Main_calculation_call.fCalcRun()

- Main function for the analysis of the low speed – high speed – low speed test sequence.

Main_calculation_call.ffv_veh()

- Calculates the calibration factor v_veh

Signal_identification.fCalcCorVveh()

- Calculation of the calibrated vehicle velocity with the factor v_veh

Main_calculation_call.ffvpeBeta()

- Calculates the calibration factors for v_air and beta misalign

Main_calculation_call.fWindBetaAir()

- Calculate the calibrated and boundary layer corrected values for wind, beta and v_air

Minor_routines_calculate.fMoveAve()

- Calculate moving averages over a variable time

Signal_identification.fWindBetaAirErg()

- Calculates the averages in the detected sections for wind, beta and v_air

Main_calculation_call.fCheckCalib()

- Check if the detected sections are valid dependant of the given criteria's.

Signal_identification.fCalcSpeedVal()

- Calculate all needed data for every speed test in 100Hz and afterwards the average inside the detected sections

Main_calculation_call.fCalcValidSec()

- Control the actual speed tests after the given criteria´s.

Main_calculation_call.fCheckLSHS()

- Check if enough valid sections in all speed tests are available.

Sub_linear_regression.fCalcReg()

- Calculates the linear regression.

ffillArray()

- Function to generate the calculation arrays for the linear regression

linear_regression()

- Calculates the linear regression and afterwards the evaluation parameters (CdxA, delta_CdxA, CdxA(0), CdxA(0)_opt2)

Output.fOutDataCalc1Hz()

- Writes the calculated results in 1Hz or 100Hz into a file.

output.fOutCalcRes()

- Writes the average results for the detected sections in a file.

8.2. General programming principles

Below the main important general programming principles to be followed in the further programming of VECTO-CSE are listed.

Suggestion: Kostis please add your general guidelines as discussed in the CITnet e.g.

- Avoid global-vars, use data-instances with IO capabilities (like cVehicle and cPreferences, whenever performance is not a problem).
- Let errors bubble-up, instead of using (true/False) ErrorFlags.
- Do not put all declarations & assignments up-front in a routine - that was old-time guideline that prevents the compiler to report logic-errors (unset variables or missing if-then-else cases).
- Always do some design around data-structures, like i did above with the tentative CSV API.
- …