CORA Release 3.6

User's Manual

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1 Introduction

CORA is a software that calculates the level of correlation between two non-ambiguous signals (e.g. time histories). The result ranges between “0” and “1” depending on the quality of match. So a rating of “1” represents a perfect match within defined tolerances and “0” with a poor match.

CORA is the acronym of **COR**relation and **A**nalysis.

1.1 Corridor and cross correlation rating

CORA requires at least two curves to run an evaluation. The first curve is referred to as “reference curve” or $x(t)$, which can be a result of one test or the mean of several tests. The second curve is called “comparison curve” or $y(t)$, which can be a result of a numerical simulation or a test. The correlation between both is calculated within the time window $[t_{min}, t_{max}]$, also called the interval of evaluation.

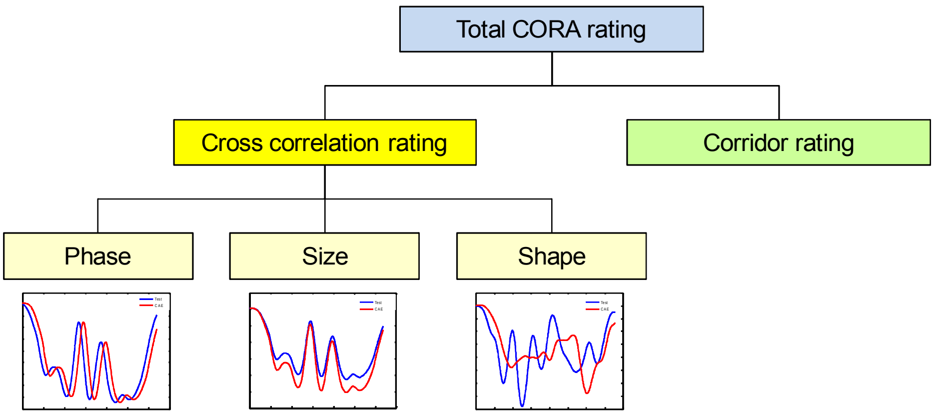

Figure 1: CORA rating structure

The correlation is calculated by using two different metrics – the corridor metric and the cross correlation metric. Both metrics are used to compensate each other’s disadvantages. Furthermore, the CORA rating tool is trying to separate engineer’s knowledge from the objective rating metric by using external parameters. So it is possible to fine-tune the evaluation to the specific needs of the applications by adjusting those metric parameters to reflect the user's knowledge of the applications. The structure of the rating is shown in Figure 1.

The corridor method evaluates the deviation between two signals by means of corridor fitting. Four curves around the reference curve define the inner and the outer corridor. If the comparison curve is within the inner corridor, the result is “1”. If the comparison curve is outside the outer corridor, the result is “0”. Otherwise an interpolation of the rating is done. The corridor rating is applied to each time-step within the interval of evaluation. The total result of the corridor method is the mean of all single time-step ratings.

The cross correlation method analyses the characteristics of signals. It starts by moving the time signal of the reference curve by multiples of the time-step Δt within the interval of evaluation. For each of these time-shifts, the cross correlation value is calculated. At the time-shift of the maximum cross correlation, the three quantification values phase shift, size, and progression are calculated. The weighted sum of these three values is the total cross correlation rating.

The results of both metrics are finally summed up to the total CORA rating by using individual weighting factors for each metric.

1.2 Biofidelity rating according to ISO/TR 9790

The technical report ISO/TR 9790 [2] defines impact response requirements suitable for assessing the lateral impact biofidelity of the six body regions head, neck, shoulder, thorax, abdomen, and pelvis of crash test dummies, sub-component test devices, and mathematical models that are used to represent a 50th percentile adult male.

The rating is done for various responses by three different methods:

- Two curves define the upper and lower limit of a response (corridor rating)
- A lower and an upper limit specify the threshold for the peak of a response (peak rating)
- A lower or an upper limit specify the threshold for the peak of a response (peak low/high rating)

The result of a correlation can be “0”, “5”, or “10” points. The final rating is the weighted sum of the results of the six body regions. Several tests are described for each body region and each test evaluates various responses. The following sliding scale is defined by ISO/TR 9790:

- Excellent biofidelity: $8.6 \leq rating \leq 10.0$
- Good biofidelity: $6.5 \leq rating < 8.6$
- Fair biofidelity: $4.4 \leq rating < 6.5$
- Marginal biofidelity: $2.6 \leq rating < 4.4$
- Unacceptable biofidelity: $0.0 \leq rating < 2.6$

The overall biofidelity rating of a side impact dummy or a mathematical model shall be greater than “2.6” to be acceptable for the evaluation of side impact occupant protection.

2 Getting started

2.1 Input Data

CORA is a command line software that is managed by an ASCII control file. The signal files, its structure (load cases and sub-load cases), and all parameters to select and tune the different metrics are specified by this file. If some parameters in the control file are missing, the user is asked to specify them in the command line directly. CORA only checks the parameters for a valid domain but not if the values make sense. The syntax of the control file is described in section 8.

The supported curve file formats are ISO/TS 13499 (ISO-MME) [3], Diadem, HyperGraph ASCII, LS-PrePost ASCII and PAM-VIEW ASCII. All curves are identified by a description which have to comply with the ISO/TS 13499 format [3]. It is possible to define a name mapping file to use different curve names (section 12).

CORA is available for Linux and MS-Windows computers. On Linux systems CORA shall be started by the script `cora.sh`. This script defines an environment variable with the path of the software's installation (***INST_PATH***). On MS-Windows computers CORA shall be started directly or by using the batch file `cora.bat`.

2.2 Results

The result of a CORA evaluation is a HTML report saved in the sub-directory “html” of the current working directory. The rating of each signal (curve) is presented on one page, respectively.

In general, the signals can be grouped in two or three levels:

- signal → load case → total rating
- signal → sub-load case → load case → total rating

The results of all signals belonging to a load case (LC) or a sub-load case (SLC) are summarised on a load case or sub-load case HTML page. The results of all load cases are listed in the document `result_cora.html`, located in the “html” directory. So it is recommended to start the review of an evaluation with this document.

The charts (images) shown on the signal pages of the HTML report are stored in the directory “images”. The HTML report refers to this directory, meaning if the report is moved to an other location, the “images” folder must be moved too.

CORA uses HTML templates with predefined variables to create the HTML reports.

CORA creates the directory “curves” to save ASCII curve files. It is located in the working directory too. Each curve file contains the curves of one chart of a signal page. The format is selected by the keyword ***OUTPUT_FORMAT*** in the control file.

Apart from the HTML files, the ASCII file `result_cora.txt` is written. It lists all input parameters as well as all results. CORA writes progress information in the file `cora.log`. The file `cora.msg` contains warnings and error messages. All of those files are located in the current working directory.

2.3 Usage

The software CORA shall be started from the command line. The first parameter has to be the control file followed by some optional command line parameters.

Linux
`cora.sh` <control file> [command line parameters]

MS-Windows
`cora.bat` <control file> [command line parameters]

CORA accepts the following command line parameters:

b the browser (HTML viewer) is started at the end of the evaluation (e.g. `result_cora.html`)

h name of the HTML main page (default: `result_cora.html`)

o name of the ASCII result file (default: `result_cora.txt`)

p no HTML output

3 Interval of evaluation

The interval of evaluation interval $[t_{min}, t_{max}]$ defines the domain of the x-axis (generally time) which is used to calculate the rating. The physical unit of t_{min} and t_{max} can be specified by the global parameter ***T_UNIT***. If this parameter is not defined, the unit specified in the file `output_units.txt` is used. The only supported units are [s] (seconds) and [ms] (milliseconds).

The interval of evaluation can be defined for each signal separately. However, its also possible to use the terms “x”, “y”, or “automatic” to enable specific functions. “x” can only be used locally. It means that the globally defined value is used. The global values for t_{min} and t_{max} are defined in the global parameter block by the keyword ***T_MIN/T_MAX***. If “y” is used, the interval of evaluation of the first signal of a load case or sub-load case is used for all remaining signals of the same load case or sub-load case. It is a local setting too. The automatically calculated interval of evaluation is enabled by the keyword “automatic”. This setting can be used globally and locally but is not available for the biofidelity rating according to ISO/TR 9790.

3.1 User-defined

The user can specify the starting and ending time signal-wise or globally. It is also possible to define the starting time manually and to use the automatism to calculate the ending time (or the other way round).

3.2 Automatic calculation

The automatic calculation of the interval of evaluation is controlled by the global keywords ***Y_NORM*** (Y_{norm}), ***A_THRES*** (a_{thres}), ***B_THRES*** (b_{thres}), ***B_DELTA_END*** ($b_{\mathrm{delta\_end}}$), and ***A_EVAL*** (α_{eval}). The starting time is calculated by $y_{thresA} = a_{thres} \cdot Y_{norm}$ with $0 < a_{thres} \leq 1$. It is possible to set ***Y_NORM*** to “extremum”. In this case, Y_{norm} is calculated as the absolute maximum of the reference curve (section 5.2.1). The ending time of the interval is calculated by $y_{B\_thres} = b_{thres} \cdot Y_{norm}$ with $0 < b_{thres} \leq 1$.

The starting time t_a is the first point in time when $|x(t)|>y_{A\_thres}$ is true. The end of the evaluation interval t_b is the last point when $|x(t)|>y_{B\_thres}$ is true. Furthermore, the time interval can be expanded by using the parameter α_{eval} .

As the bounds of the interval cannot exceed the domain of the reference curve $x(t)$, the interval is shorten automatically, if necessary. This leads to the final equation for t_{min} and t_{max} :

$$t_{min}=max\left(t_a-\alpha_{eval}\cdot(t_b-t_a),t_{\text{start x(t)}}\right) \qquad 0\leq\alpha_{eval}\leq 1$$

$$t_{max}=min\left(t_a+\alpha_{eval}\cdot(t_b-t_a),t_{\text{end x(t)}}\right) \qquad 0\leq\alpha_{eval}\leq 1$$

To shorten the interval of evaluation for curves with an almost horizontal but oscillating ending, the parameter $b_{\text{delta\_end}}$ (***B_DELTA_END***) is introduced. It defines a corridor around the end of the reference curve ($Y_{cor}=b_{\text{delta\_end}}\cdot Y_{norm}$). The ending time t_{max} is reduced until the amplitudes of the reference curve vary by no more than Y_{cor} . This algorithm can be disabled by setting ***B_DELTA_END*** to “0”.

If one of the calculated interval bounds does not match with a supporting point of the curve, reference curve and comparison curve are re-sampled to get supporting points at t_{min} and t_{max} .

At the very end, the determined interval of evaluation is checked against the domain of the comparison curve $y(t)$. If the interval is not fully covered by $y(t)$, it will be shortened to fit in the domain of $y(t)$.

3.3 Example of the calculation of the evaluation interval

The functioning of ***B_DELTA_END*** is described in this section exemplary by using the signal shown in Figure 2. The corresponding values of the curve are shown in Table 1.

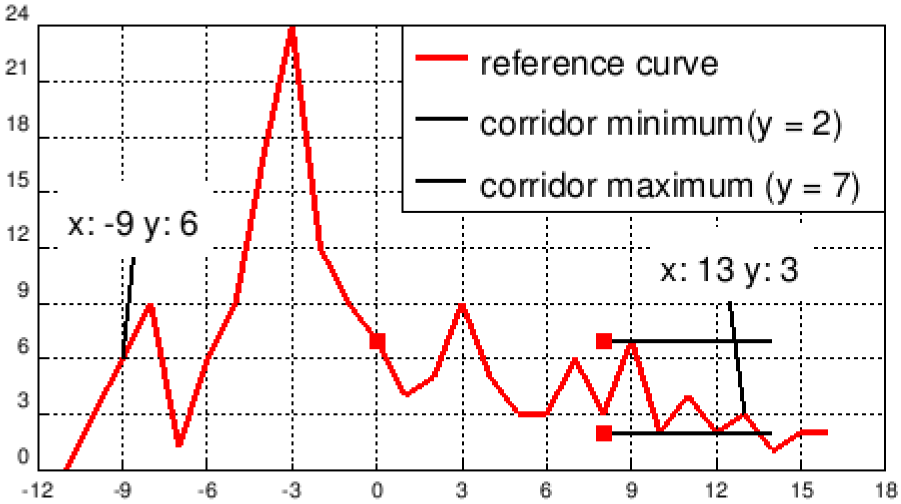

Figure 2: Example of B_DELTA_END

Table 1: xy values of the reference curve

-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	3	6	9	12	6	9	17	24	12	9	7	4	5	9	5	3	3	6	3	7	2	4	2	3	1	2	2

The following global parameters are defined:

```
A_THRES       0.24
B_THRES       0.125
A_EVAL        0.1
B_DELTA_END   0.2
T_MIN/T_MAX   automatic   automatic
Y_NORM        extremum
```

As ***Y_NORM*** is set to “extremum”, the curve maximum $y=24$ at $x=-3$ is used to calculate $y_{A\_thres}=a_{thres}\cdot Y_{norm}=0.25\cdot 24=6$ and $y_{B\_thres}=b_{thres}\cdot Y_{norm}=0.125\cdot 24=3.0$. So the interval starts when the amplitude exceeds “6” and ends when the signal falls below “3”.

The requirements to start the interval are met at $t_a=-9$. At $t_b=13$ the requirements to end the interval are met. Thus, the resulting interval length is $t_b-t_a=13-(-9)=22$.

The option ***B_DELTA_END*** is enabled in this example and it is set to “0.2”. The corresponding corridor width Y_{cor} is calculated:

$$Y_{cor} = b_{\text{delta\_end}} \cdot Y_{norm} = 0.2 \cdot 24 = 4.8$$

CORA starts the iteration at $t_{max} = 13$ and is going backwards along the x-axis. The corridor is made of the y values of the analysed time domain $t_{max} - n \cdot \Delta t$ and updated at every iteration step. The iteration stops when the maximum corridor width Y_{cor} is reached ("4.8" in this example). So the new end of the interval is now set to $t_b = 9$. The iterations of this example are shown in Table 2.

Table 2: Iterations to calculate the end of the interval of evaluation

X	Y	Corridor Lower bound	Corridor Upper bound	Corridor Width	Corridor exceeds limit of 4.8?
13	3	3	3	0	no
12	2	2	3	1	no
11	4	2	4	2	no
10	2	2	4	2	no
9	7	2	7	5	yes

The last modification of the interval is done by the parameter α_{eval} :

$$t_{min} = t_a - a_{eval}(t_b - t_a) = -9 - 0.1 \cdot 22 = -9 - 2.2 = -11.2$$

$$t_{max} = t_b + a_{eval}(t_b - t_a) = 9 + 0.1 \cdot 22 = 9 + 2.2 = 11.2$$

The first supporting point is "-11". Therefore, the curve is re-sampled to get a supporting point at "-11.2". t_{min} is set to "-11.2".

In summary, the automatically calculated interval of evaluation starts at $t_{min} = -11.2$ and ends at $t_{max} = 11.2$.

4 Calculation of the total rating

Primarily, CORA analyses the correlation of two signals and calculates a rating score depending on the goodness of correlation. However, the software calculates average ratings of the analysed signals too. The number and structure of those average ratings depends on the organisation of the signals in the control file.

Section 8.2.3 and 8.3.3 give information on the weighting factors of signals, section 8.3.1 sub-load cases, and section 8.2.1 of load cases. The weighting factors of signals, sub-load cases and load cases are normalised. The global parameter ***WF_NORM*** can be set to "NO" to show non-normalised weighting factors in the HTML report.

4.1 Total signal rating

The total signal rating C_3 of CORA is the sum of the weighted ratings of the corridor metric C_1 and the cross correlation metric C_2.

Signal rating $$C_3 = g_1 \cdot C_1 + g_2 \cdot C_2$$

The weighting factors g_1 (keyword ***G_1*** and parameter *g_1*) and g_2 (***G_2***, *g_2*) must comply with the following conditions:

Corridor rating $$0 \leq g_1 \leq 1$$

Cross correlation rating $$0 \leq g_2 \leq 1$$

Normalisation $$g_1 + g_2 = 1$$

4.2 Load case rating

The ratings of all signals of a load case C_{3_i} are combined to a load case rating C_{lc}. Every signal is assigned to an individual weighting factor (wf_i, *WF*). A load case rating is the weighted sum of its signal ratings.

Load case $$C_{\mathrm{lc}} = \sum \left(wf_i \cdot C_{3\_\mathrm{i}} \right)$$

Normalisation $$\sum wf_i = 1$$

If a load case contains no signals but sub-load cases, then the load case rating is the weighted ($wf_{\mathrm{slc\_i}}$, ***WF_SLC***) sum of the sub-load case ratings $C_{\mathrm{slc\_i}}$.

Load case $$C_{lc} = \sum \left(wf_{\mathrm{slc\_i}} \cdot C_{\mathrm{slc\_i}} \right)$$

Normalisation $$\sum wf_{\mathrm{slc\_i}} = 1$$

4.3 Sub-load case rating

The ratings of all signals of a sub-load case C_{3_i} are combined to a sub-load case rating C_{slc} . Every signal is assigned to an individual weighting factor (wf_i *WF*). So a sub-load case rating is the weighted sum of its signal ratings.

Sub-load case $$C_{slc} = \sum \left(wf_i \cdot C_{3\_\mathrm{i}} \right)$$

Normalisation $$\sum wf_i = 1$$

4.4 Overall rating

The ratings of all load cases are combined to an overall rating. This rating score C is the weighted ($wf_{\mathrm{lc\_i}}$, ***WF_LC***) sum of all load case ratings.

Overall rating $$C = \sum \left(wf_{\mathrm{lc\_i}} \cdot C_{\mathrm{lc\_i}} \right)$$

Normalisation $$\sum wf_{\mathrm{lc\_i}} = 1$$

5 Corridor method

The corridor metric assesses the compliance of a curve with corridors. One of the advantages of the corridor rating is the simplicity and the clearness of the algorithm. It reflects criteria which are used intuitively in engineering judgement. Figure 3 shows the curves used by the corridor method exemplary. Around the reference curve (black) an inner (green) and an outer (grey) corridor is drawn. The width of the corridors is mainly influenced by the parameter Y_{norm}.

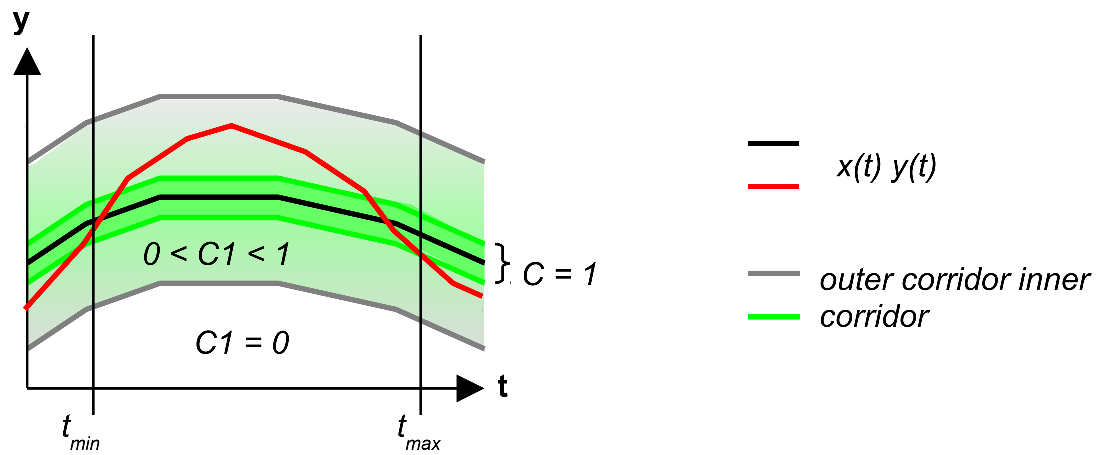

Figure 3: Corridor method

If the comparison (red) curve is within the inner corridor, the result is “1” (perfect match). If the comparison curve is outside the outer corridor, the result is “0” (poor correlation). In between the rating is interpolated.

5.1 Requirements

The reference curve and the comparison curve must both be defined between t_{min} and t_{max}. Both have n supporting points in this interval.

5.2 Determination of the corridors

The inner ($\delta_i(t)$) and out ($\delta_o(t)$) corridor can be calculated automatically or set by the user. The following requirement shall be kept to draw the corridors:

Basic requirement	$\delta_i(t) < \delta_o(t)$
Inner lower corridor	$\delta_{\mathrm{i\_lower}}(t) = x(t) - \delta_i(t)$
Inner upper corridor	$\delta_{\mathrm{i\_upper}}(t) = x(t) + \delta_i(t)$
Outer inner corridor	$\delta_{\mathrm{o\_lower}}(t) = x(t) - \delta_o(t)$
Outer lower corridor	$\delta_{\mathrm{o\_upper}}(t) = x(t) + \delta_o(t)$

5.2.1 Automatic corridors

As shown in Figure 3, two corridor areas are defined around the reference curve. The simplest method to define corridors of constant width is shown below:

Inner corridor	$\delta_i(t) = a_0 \cdot Y_{norm}$
Outer corridor	$\delta_o(t) = b_0 \cdot Y_{norm}$
Boundary conditions	$0 \leq a_0 \leq 1$, $0 \leq b_0 \leq 1$, and $a_o < b_0$

a_0 and b_0 define the relative half width of the corridors and can be defined globally (section 8.1.4) and locally (section 8.2.3 and 8.3.3) in the control file. The parameter Y_{norm} is the reference amplitude that is used to calculate the corridors. It is either a user-defined value or the maximum absolute amplitude of the reference curve (setting “extremum”).

Y_{norm} set to “extremum”	$Y_{norm} = max(min(x(t)), max(x(t)))$

If the reference curve is the average curve of several tests (n_{Test}), it is possible to use the standard deviation $\sigma(t)$ to calculate the corridor width. The standard deviation, influenced by the scaling parameters a_s and b_s , is added to the corridors. A corridor can also defined by using the standard deviation only (***Y_NORM*** must be set to “0”). However, if $\sigma(t)$ is used to influence the corridors, then the width of the corridors is not constant.

Standard deviation $\sigma(t)=\sqrt{\frac{\sum_{i=1}^{n_{Test}}(x_i(t)-x(t))^2}{n_{Test}}}$

Inner corridor $\delta_i(t)=a_0\cdot Y_{norm}+a_s\cdot\sigma(t)$

Outer corridor $\delta_o(t)=b_0\cdot Y_{norm}+b_s\cdot\sigma(t)$

Boundary conditions $0\le a_0\le 1$, $0\le b_0\le 1$, and $a_o<b_0$

If a test curve has values outside the outer corridor, the corridor is locally enlarged to include all test curves.

5.2.2 User-defined corridors

CORA offers the possibility to work with user-defined corridors, provided in a separate file. They must be specified for the complete interval of evaluation and it is essential that the condition $\delta_i(t)<\delta_o(t)$ is maintained for the complete interval. Furthermore, the curves must be use the output unit system.

5.3 Rating

At first the corridor rating is calculated at every time step t_i within the interval of evaluation $[t_{min}, t_{max}]$. The total corridor rating C_1 is the average of all time step ratings c_i .

$$c_i=\begin{cases} 1 & \text{if} \quad |y(t_i)-x(t_i)|<\delta_i(t) \\ \left(\frac{\delta_o(t)-|y(t_i)-x(t_i)|}{\delta_o(t)-\delta_i(t)}\right)^k & \\ 0 & \text{if} \quad |y(t_i)-x(t_i)|>\delta_o(t) \end{cases} \quad \text{with} \quad k\in N_{>0}$$

$$C_1=\frac{\sum_{i=1}^{n}c_i}{n} \quad \text{with} \quad 0\le C_1\le 1$$

The interpretation of the equation of c_i is simple. If the distance between reference and comparison curve is bigger than δ_o, the correlation is poor ($c_i=0$). If the distance between reference and comparison curve is smaller than δ_i, the correlation is good ($c_i=1$). In between an interpolation (“0” to “1”) is performed. The exponent k describes decline of the rating between “1” and “0”. The bigger k, the higher is the decline of the rating of a curve compared to its distance to the inner corridor.

5.4 Disadvantages

The corridor method compares the values of the two curves at each time step. A distortion of the phase can lead to a very poor rating.

6 Cross correlation method

The cross correlation method analyses three characteristics of a signal – progression V (Figure 4), phase shift P (Figure 5), and size G (Figure 6). The result of each sub rating ranges from “0” (no correlation) to “1” (perfect match). The cross correlation rating C_2 is the sum of those individually weighted sub-ratings.

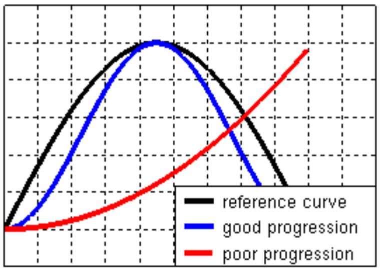

Figure 4: Progression rating

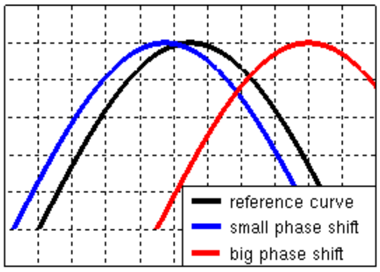

Figure 5: Phase shift rating

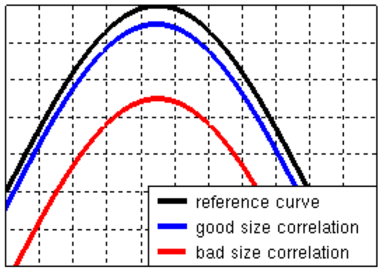

Figure 6: Size rating

6.1 Requirements

The reference curve and the comparison curve shall be both defined between t_{min} and t_{max}. Both have n supporting points of a constant Δt within this interval.

6.2 Procedure

As mentioned above, the corridor method can lead to poor results if the two curves have a time shift. Therefore, this metric tries to eliminate this problem first. So the cross correlation metric starts with moving the reference curve by multiples of Δt (Figure 7). For each of these moved states the cross correlation value K is calculated. K ranges from “-1” to “1” and is a rating of the progression of the curve. The time shift with the maximum K value is used to calculate the three parts of the cross correlation rating.

Maximum cross correlation $\quad K = max(K_{\delta_i})$ with $\delta = m_0 \cdot \Delta t$

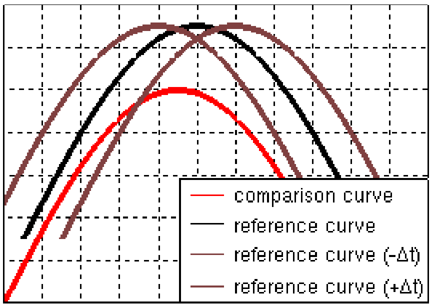

Figure 7: Phase shift to calculate the cross correlation

6.3 Maximum cross correlation

The cross correlation K_{xy} is calculated according to the following equation:

$$K_{xy}(m)=\frac{\sum_{i=0}^{n-1} x(t_{min}+(m+i)\cdot\Delta t)\cdot y(t_{min}+i\cdot\Delta t)}{\sqrt{\left(\sum_{i=0}^{n-1} x^2(t_{min}+(m+i)\cdot\Delta t)\cdot\sum_{i=0}^{n-1} y^2(t_{min}+i\cdot\Delta t)\right)}} \quad \text{with } -1\leq K_{xy}\leq 1$$

The reference curve is shifted by an alterable time shift of $m\cdot\Delta t$ with $m=0,1,-1,2...$. The range of m and thus, the maximum time shift of the reference curve is limited by the global parameter INT_{min} . Minimum and maximum time shift are calculated by the following equations:

$$t_{shiftmin}=-(1-INT_{min})\cdot(t_{max}-t_{min})$$

$$t_{shiftmax}=(1-INT_{min})\cdot(t_{max}-t_{min})$$

Therefore, the signals $x(t)$ and $y(t)$ are at least overlapping within the interval $t_{overlap}$.

$$t_{overlap}\geq INT_{min}\cdot(t_{max}-t_{min}) \quad \text{with } (0<INT_{min}<1)$$

The range of m is obtained as follows:

$$m_{min}=\frac{t_{shiftmin}}{\Delta t}$$

$$m_{max}=\frac{t_{shiftmax}}{\Delta t}$$

The parameter n to calculate $K_{xy}(m)$ is not constant, but is reduced to $n_{min}=\mathrm{INT}_{min}\cdot n$ for m_{min} and m_{max} .

The examples shown in section 6.8 may help to understand the time shift of the reference curve. The cross correlation K is the maximum of all $K_{xy}(m)$:

$$K=K_{xy}(m_0)=max_m(K_{xy}(m))$$

6.4 Progression rating V

The progression rating is derived from K :

Progression rating $\quad V=\left(\frac{1}{2}(K+1)\right)^{k_V} \quad$ with $k_V \in N_{>0}$ and $0 \leq V \leq 1$

The exponent k_V describes the decline of the rating between “1” and “0”. A linear, quadratic or any other regression relationship can be defined accordingly.

6.5 Phase shift rating P

The phase shift rating is controlled by the parameters D_{MIN} and D_{MIN} . Both are used to calculate the signal specific time values δ_{min} and δ_{max} .

$$\delta_{min}=D_{MIN}\cdot(t_{max}-t_{min}) \text{ with } 0<D_{MIN}\leq 1$$

$$\delta_{max}=D_{MAX}\cdot(t_{max}-t_{min}) \text{ with } 0<D_{MAX}\leq 1$$

D_{min} and D_{max} can be specified globally or locally. The phase shift rating P is calculated at the maximum cross correlation K and the corresponding time shift δ as follows:

Phase shift rating

$$P=\begin{cases} 1 & \text{if} \quad |\delta|<\delta_{min} \\ \left(\dfrac{|\delta_{max}-|\delta||}{\delta_{max}-\delta_{min}}\right)^{k_P} & \\ 0 & \text{if} \quad |\delta|>\delta_{max} \end{cases} \qquad \text{with} \quad k_G \in N_{>0}$$

It is similar to the rating done for the corridor method with two given boundary values. The exponent k_P describes the decline of the rating between “1” and “0”.

6.6 Size rating G

The size rating is done by comparing the square of the areas between the curves and the time axis. Since both curves have equidistant supporting points, the following ratio can be calculated:

$$F_x[t_{min}+\delta, t_{max}+\delta]$$

$$F_y[t_{min}, t_{max}]$$

$$\frac{F_x}{F_y}=\frac{\sum_{i=1}^{n} x^2(t_{min}+i\cdot\Delta t)}{\sum_{i=1}^{n} y^2(t_{min}+\delta+i\cdot\Delta t)}$$

The following equation is used to calculate the size rating:

Size rating

$$G=\begin{cases} \left(\dfrac{F_x}{F_y}\right)^{k_G} & \text{if} \quad F_y>F_x \\ \left(\dfrac{F_x}{F_y}\right)^{k_G} & \end{cases} \qquad \text{with} \quad k_G \in N_{>0}$$

The exponent k_G describes the decline of the rating between “1” and “0”.

6.7 Rating

The cross correlation rating C_2 is a combination of the three sub-ratings V, P, and G.

Cross correlation rating $$C_2 = g_V \cdot V + g_P \cdot P + g_G \cdot G$$

Boundary condition $$0 \leq (g_V, g_P, g_G) \leq 1$$

The weighting factors g_V, g_P and g_G can be defined globally (***G_V***, ***G_P***, ***G_G***) and locally (*g_V*, *g_P*, *g_G*). To guarantee $0 \leq C_2 \leq 1$, the condition $g_V + g_P + g_G = 1$ must be met.

6.8 Example of the maximum time shift calculation

Figure 8 and Figure 9 depict an example of the time shift calculation. The baseline condition is shown on the left and the shifted curves with i_{min} and i_{max} on the right.

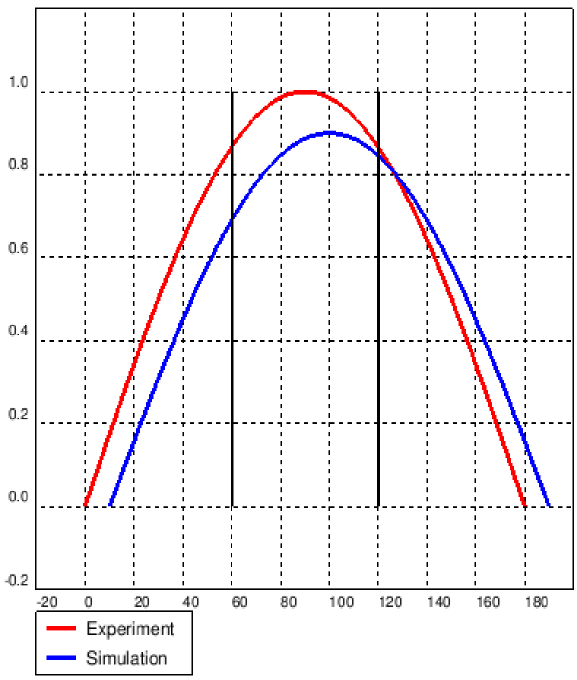

Figure 8: Baseline condition

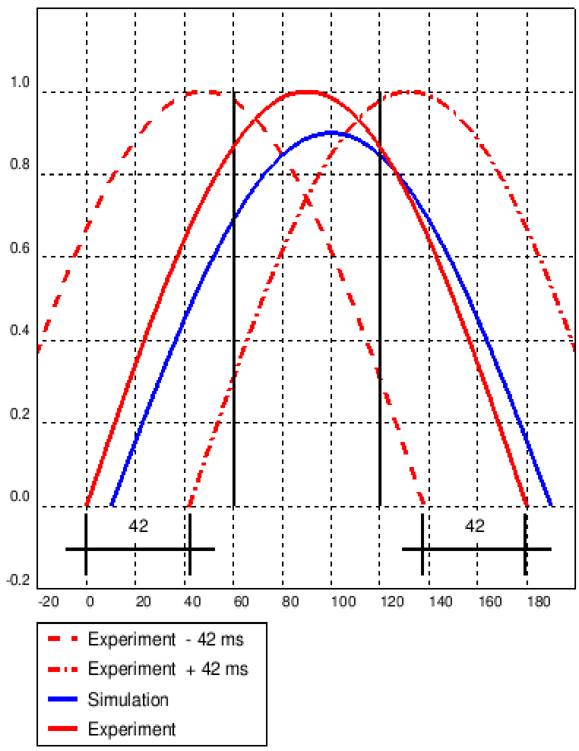

Figure 9: Shifted test curve

The following parameters are defined:

```
T_MIN/T_MAX  60  120
INT_MIN      0.3
```

According to the equations in shown in section 6.3, the minimum overlap is calculated as follows:

$$t_{shiftmin}=-(1-INT_{min})\cdot(t_{max}-t_{min})=-(1-0.3)\cdot(120-60)=-42$$

$$t_{shiftmax}=(1-INT_{min})\cdot(t_{max}-t_{min})=(1-0.3)\cdot(120-60)=42$$

The time shift reduced the overlap of reference curve and interval of evaluation to $t_{overlap}$:

$$t_{overlap}=INT_{min}\cdot(t_{max}-t_{min})=0.3\cdot(120-60)=18$$

6.9 Disadvantages

It is essential to select a reasonable size of the evaluation interval and the maximum phase shift. Otherwise small parts of the curves which have a good similarity but large phase-shift can influence the cross correlation values significantly. Especially periodic functions could be affected.

7 Biofidelity rating according to ISO/TR 9790

The keyword ***METHOD*** must be set to “ISO9790” to enable the biofidelity rating according to ISO/TR 9790 [2]. Furthermore, the required corridor files must be specified in the signal parameter block (parameter *a_t*). The signal parameter *Y_norm* selects the rating metric. The allowed terms of *Y_norm* are described in the following sections.

The complete set of tests defined in ISO/TR 9790 can be applied by defining a load case for each body region and a sub-load case for each test. The weighting factors and corridors are not hard-coded in the CORA software. They have to be specified in the control file. The definition of those corridor files is described in section 8.2.3.

7.1 Corridor method

Two corridor curves (upper and lower) define the inner corridor. The maximum distance between the two corridor curves is added to the upper curve and subtracted from the lower curve to get the outer corridor. If the test curve values are totally within the inner corridor, the rating is “10”. A rating of “5” is given, if all curve values are within the limits of the outer corridor. Otherwise the rating is “0”. Figure 10 shows the ISO-corridor rating exemplary.

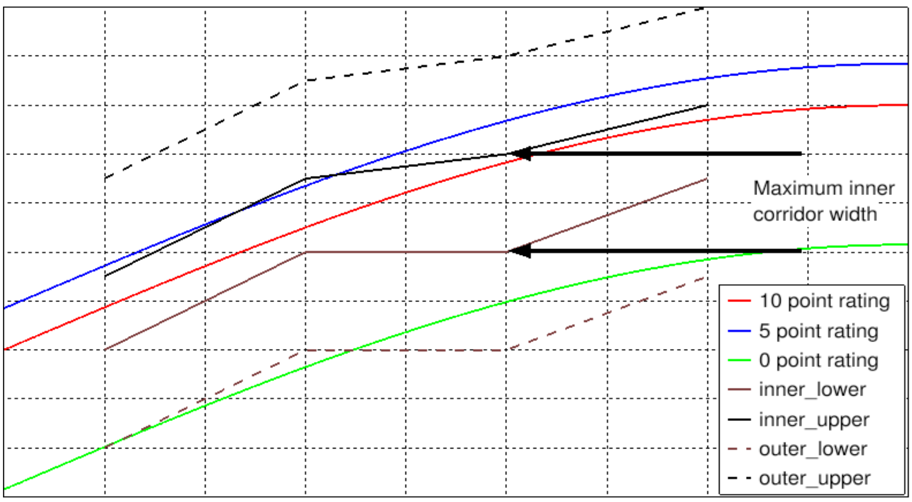

Figure 10: Example of the corridor rating

The term “corridor” selects the corridor rating procedure of ISO/TR 9790.

7.2 Peak method

This method requires corridors at a certain level, shown in Figure 11. The rating is calculated like the corridor rating, but only the peak value (maximum or minimum) of a response is evaluated.

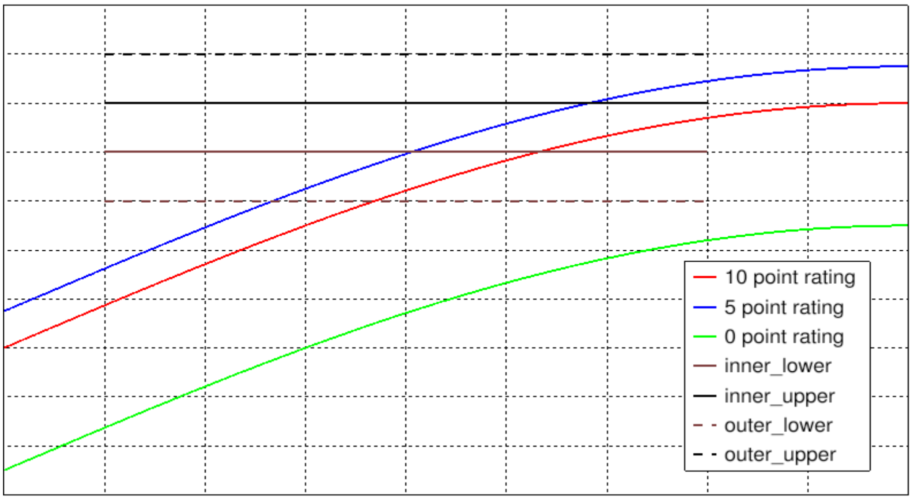

Figure 11: Example of the peak rating

The term “peak” enables the peak rating procedure.

7.3 High/low peak method

This method evaluates only the peak value of a curve and not the compliance with a corridor. If the peak value is above (“peak_low”) or below (“peak_high”) a specified threshold, the rating is set to “10”. Otherwise the rating is “0”. An example of this method is shown in Figure 11.

This method is enabled by the terms “peak_high” or “peak_low”.

7.4 Alternative high/low peak method

The only difference to the method described in section 7.3 is the possibility to get an additional rating of “5”. This result is given, if half or twice of a threshold is reached. Figure 12 shows an example of this method.

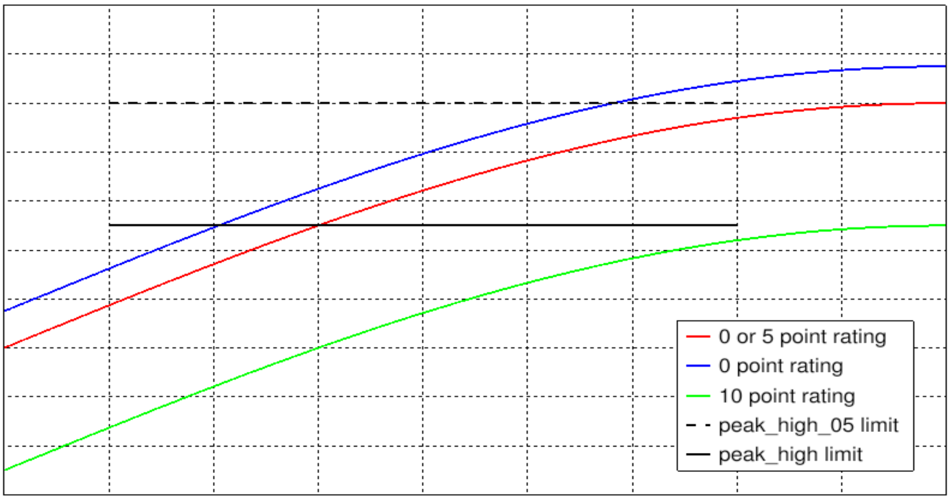

Figure 12: Example of the peak high and the alternative peak high rating

The terms “peak_high_5” or “peak_low_5” enables an alternative peak rating algorithm.

8 Control file

The ASCII control file uses a block format. Comment lines starts with a hashmark ("#") and can be placed anywhere in the file. In-line comments can be placed at the end of a command and shall start with a semicolon (";"). It is not possible to split commands to several lines. The maximum allowed line length is 4095 characters.

The keywords and parameters must be separated by at least two blank characters. Blanks at the beginning or at the end of a line will be cut automatically.

The file structure is:

- global parameters
- load case 1
  - parameters of load case 1
  - curve files for load case 1
  - signals of load case 1
- load case n
  - parameters of load case n
  - sub-load case n.1
    - parameters of sub-load case n.1
    - curve files for sub-load case n.1
    - signals of sub-load case n.1
  - sub-load case n.m
    - parameters of sub-load case n.m
    - curve files for sub-load case n.m
    - signals of sub-load case n.m

At least one load case must be defined. The use of sub-load cases is optional.

8.1 Global parameters

Global parameters define or adjust settings which are used by all load cases and sub-load cases. They can be overruled by parameters of load cases and sub-load cases. Those parameters are also called local parameters. Many parameters of CORA can be defined globally and locally. If local parameter is set to “x”, the global setting is used.

The global parameters block starts with the keyword ***BEGIN GLOBAL_PARAMETERS*** and is closed with the keyword ***END GLOBAL_PARAMETERS***. The order of the parameters within this block is arbitrary.

8.1.1 Parameters to calculate the interval of evaluation

A_EVAL <real> Domain: $[0,1]$

Expand the automatically calculated interval of evaluation (see α_{eval} in section 3.2)

A_THRES <real> Domain: $[0,1]$

This parameter is used in conjunction with the keyword ***Y_NORM*** to calculate the starting time of the interval of evaluation automatically (see a_{thres} in section 3.2).

B_THRES <real> Domain: $[0,1]$

This keyword is used in conjunction with ***Y_NORM*** to calculate the ending time of the interval of evaluation automatically (see b_{thres} in section 3.2).

B_DELTA_END <real> Domain: $[0,1]$

This keyword is used to shorten the end of the interval of evaluation if it is calculated automatically (see $b_{\text{delta\_end}}$ in section 3.2).

Disable option: “0”

T_MIN/T_MAX <real> <real> Domain: { $(-\infty, \infty)$, automatic}

This keyword defines the starting and the ending time of the interval of evaluation $[t_{min}, t_{max}]$ for all signals.

If the term “automatic” is used (for both or only one), CORA calculates reasonable intervals signal-wise (section 3.2). The parameter ***T_UNIT*** defines the time unit of

T_MIN/T_MAX. If ***T_UNIT*** is not specified, the output time unit, defined in the configuration file `output_units.txt`, is used.

T_UNIT <string> Domain: {s, ms}

Specifies the time unit for ***T_MIN/T_MAX***, *t_min*, and *t_max* and the user-defined corridor curves when using option *a_t*

Y_NORM <real> Domain: { $(-\infty, \infty)$, extremum}

The keyword defines the reference value for the calculation of the corridor widths for all signals. The term “extremum” enables the use of the maximum absolute amplitude of the reference curve (see Y_{norm} in section 5.2.1).

ISONAME_1-2/11-12 <string> <string> Domain: {YES, NO}

A signal name according to ISO/TS 13499 codes several information about a signal. So the 1st character specifies the test object, the 2nd character the seating position and the 11th and 12th character specify additional information about the location of the measurement (e.g. type of the dummy used).

CORA offers the possibility to ignore (set to “NO”) those characters when analysing and compiling the signal names of the reference and comparison data.

Example:

```
ISONAME_1-2/11-12     YES   NO
```

S1HEAD0000H3ACXP is equivalent to S1HEAD0000HFACXP

S1HEAD0000H3ACXP is not equivalent to S3HEAD0000HFACXP

8.1.2 Parameters to format the HTML report

DES_GLO <string>

Description of the evaluation (title)

DES_MOD <string>

Additional description of the evaluation (sub-title)

FONT_SMALL <integer> Domain: $N_{>0}$

Pixel size of the small fonts used in the signal pages of the HTML report

FONT_LARGE <integer> Domain: $N_{>0}$

Pixel size of the large fonts used in the signal pages of the HTML report

OUTPUT_FORMAT <character> Domain: {H, L, P}

This keyword defines the format of the exported ASCII curves. It can be set to Hyper-Graph, LS-PrePost or PAM-VIEW. Only the first character is recognised – “H”, “L”, or “P”.

PreT_LC/PostT_LC <real> <real> Domain: { $R_{>0}$, -1, -2}

This keyword is used to define the shown domain of the x-axis in the charts. The interval of evaluation is the baseline domain but it can be expanded by a percentage of the length of this interval:

Start $$t_s = t_{min} - PreT_{LC}(t_{max} - t_{min})$$

End $$t_e = t_{max} - PostT_{LC}(t_{max} - t_{min})$$

Some specific values enables some pre-defined settings. If the first value is set to “-1”, the x-axis starts at the first time sample of the reference signal. When using “-2”, the x-axis starts at “0”. If the second value is set to “-1” the x-axis ends at the last time sample of the reference signal.

WF_NORM <string> Domain: {YES, NO}

Switch to enable or disable the output of normalised weighting factors.

8.1.3 Small signals

MIN_NORM <real> Domain: $[0,1]$

This keyword controls the mechanism to detect major and minor axes of a sensor with multiple directions in space (e.g. x, y, and z acceleration of a dummy head). Minor axes can be handled by special procedures to reduce their influence on a load case or sub-load case rating.

If signal names specified in a load case or a sub-load case differ only in its direction in space (x, y, and z), then those signals are treated as a sensor with multiple axes and the ***MIN_NORM*** algorithm can be applied.

Disable option: "0"

CORA searches the reference data set or if more than one reference data set is given, the average reference data set, for signals that differ only in direction in space (sensor with multiple axes). If so, the absolute maximum amplitude of every signal of such a sensor is calculated ($MaxX$, $MaxY$, and $MaxZ$). The maximum of those values is $MaxT$ and is treated as the major axis of this sensor.

$$MaxT = max(MaxX, MaxY, MaxZ)$$

An axis of a sensor is treated as a minor axis signal if the following condition is met:

$$(MaxX, MaxY, MaxZ) < (MIN_{NORM} \cdot MaxT)$$

The following changes are applied to minor axis signals:

- Interval of evaluation: interval of $MaxT$ is used
- Corridor method: $Y_{norm} = MIN_{NORM} \cdot MaxT$
- Cross correlation method: is calculated but its not considered in the signal evaluation (weighting factor *g_2* is set to "0")

8.1.4 Parameters to tune the corridor method

a_0/b_0 <real> <real> Domain: $[0,1]$

Relative width of the inner (***a_0***) and outer (***b_0***) corridor (see a_0 and b_0 in section 5.2)

a_sigma/b_sigma <real> <real> Domain: $[0,1]$

This keyword defines two factors two include the standard deviation $\sigma(t)$ of the reference signals in the calculation of the inner (***a_sigma***) and the outer (***b_sigma***) corridor (see a_s and b_s in section 5.2). This function only makes sense if multiple reference curves are given.

Disable option: "0"

G_1 <real> Domain: $R_{>0}$

Weighting factor of the corridor rating C_1 (see g_1 in section 4)

K <integer> Domain: $N_{>0}$

Exponent factor (progression) for the calculation of the corridor rating (see k in section 5.3)

8.1.5 Parameters to tune the cross correlation method

D_MIN <real> Domain: $[0,1]$

The parameter limits the allowed phase shift to calculate the phase shift rating (see D_{MIN} in section 6.5). ***D_MIN*** is only applied to the interval of evaluation.

D_MAX <real> Domain: $[0,1]$

The parameter limits the allowed phase shift to calculate the phase shift rating (see D_{MAX} in section 6.5). ***D_MAX*** is only applied to the interval of evaluation.

G_V <real> Domain: $R_{>0}$

Weighting factor of the progression rating V (see g_V in section 6.7)

G_P <real> Domain: $R_{>0}$

Weighting factor of the phase shift rating P (see g_P in section 6.7)

G_G <real> Domain: $R_{>0}$

Weighting factor of the size rating G (see g_G in section 6.7)

G_2 <real> Domain: $R_{>0}$

Weighting factor of the cross correlation rating C_2 (see g_2 in section 4)

INT_MIN <real> Domain: $[0,1]$

This parameter defines the maximum time shift used by the cross correlation method. The result of $INT_{min} \cdot (t_{max} - t_{min})$ is the minimum remaining overlapping time of reference curve and comparison curve (see INT_{min} in section 6.3).

K_V <integer> Domain: $N_{>0}$

Exponent factor (progression) of the calculation of the progression rating V (see k_V in section 6.4)

K_P <integer> Domain: $N_{>0}$

Exponent factor (progression) of the calculation of the phase shift rating P (see k_P in section 6.5)

K_G <integer> Domain: $N_{>0}$

Exponent factor (progression) of the calculation of the size rating G (see k_G in section 6.6)

8.1.6 Definition of the weighting factors by physical dimensions

DIM_WEIGHTS <string> <real> <real> <real> <real> <real>

The 13th and 14th character of an ISO signal name define the physical dimension of a signal. For example “AC” stands for linear accelerations. The weighting factors **G_V**, **G_P**, **G_G**, **G_1** and **G_2** can be pre-defined for all signals of the same physical dimension.

The following parameters can be defined (sequentially in the following order):

- physical dimension, terms according to ISO/TS 13499
- G_V, section 8.1.5
- G_G, section 8.1.5
- G_P, section 8.1.5
- G_1, section 8.1.4
- G_2, section 8.1.5

This optional keyword can be used only once for each physical dimension.

8.1.7 *Example of a global parameter block*

The parameters of the corridor method are printed in blue and parameters of the cross correlation method are printed in red.

```
BEGIN GLOBAL_PARAMETERS
# comment
  A_EVAL                0.00   ; another comment
  A_THRES               0.05
  B_THRES               0.07
  B_DELTA_END           0.1
  T_MIN/T_MAX           automatic     1.0
  T_UNIT                s
  Y_NORM                extremum
  DES_GLO               what it is
  DES_MOD               Model 42
  FONT_SMALL            13
  FONT_LARGE            16
  ISONAME_1-2/11-12     YES    NO
  OUTPUT_FORMAT         LSPOST
  PreT_LC/PostT_LC      0.0    0.1
  WF_NORM               YES
  MIN_NORM              0.20
  a_0/b_0               0.7    0.9
  a_sigma/b_sigma       0.2    0.5
  K                     2
  G_1                   0.50
  D_MIN                 0.05
  D_MAX                 0.10
  INT_MIN               0.3
  K_V                   1.0
  K_G                   1.0
  K_P                   1.0
  G_V                   0.33
  G_G                   0.33
  G_P                   0.33
  G_2                   0.50
  DIM_WEIGHTS           AC     0.4    0.4    0.2    0.55   0.45
END GLOBAL_PARAMETERS
```

8.2 Load case parameters

The definition of a load case starts with ***BEGIN LOADCASE*** and ends with ***END LOADCASE***. Within this block a curve file block (between ***BEGIN DATAFILES*** and ***END DATAFILES***) and a signal block (between ***BEGIN SIGNALS*** and ***END SIGNALS***) shall be defined.

8.2.1 General Parameters

NAM_LC <string>

Name of the load case (title)

DES_LC <string>

Additional description of the load case (sub-title)

METHOD <string> Domain: {CORA, ISO9790}

This keyword selects the type of rating performed for all signals of a load case. It can be either set to "ISO9790" or to "CORA". The later (default) uses the corridor metric (section 5) and cross-correlation metric (section 6).

This keyword is optional.

MinOrd_LC <real> Domain: $R_{>0}$

This factor scales the minimum value of the y-axis of the charts shown in the HTML report. The default value is "1.0".

$$y_s = MinOrd_{lc} \cdot y_{min}$$

This keyword is optional.

MaxOrd_LC <real> Domain: $R_{>0}$

This factor scales the maximum value of the y-axis of the charts shown in the HTML report. The default value is "1.0".

$$y_s = MaxOrd_{lc} \cdot y_{max}$$

This keyword is optional.

PreT_LC <real> Domain: { $R_{>0}$, x}

See also the description of the global parameter ***PreT_LC/PostT_LC*** in section 8.1.2. If the term "x" is specified, then the global setting is used.

This keyword is optional.

PostT_LC <real> Domain: { $R_{>0}$, x}

See also the description of the global parameter **PreT_LC/PostT_LC** in section 8.1.2. If the term “x” is specified, then the global setting is used.

This keyword is optional.

WF_LC <real> Domain: $R_{>0}$

Weighting factor of the load case (section 4)

8.2.2 Data file block parameters

A data file is a file that contains at least one curve. The supported file formats are ISO/TS 13499 (ISO-MME), Diadem, HyperGraph ASCII, LS-PrePost Curve and PAM-VIEW ASCII Format 3 (section 2.1). Each data file must be specified in a single line with some additional parameters. The shown order of the parameters must be kept.

<Name of the data file> Type: string

Name of the data file

<System of units> Type: string

The physical unit of length, mass, and time have to be specified. They must be separated by “-” or “.”. If displacements (ISO code “DS”) use a different length unit than distances (ISO code “DC”), a second unit of the length can be specified in front of the other units.

<Dimension of linear accelerations> Type: string, Domain: {YES, NO}

CORA accepts [g] as unit of linear accelerations (1 g = 9.81 m/s²). If the accelerations of the data file are using [g], the term “YES” must be specified otherwise “NO” is required.

<Time shift> Type: real, Domain: $(-\infty, \infty)$

The time shift is applied to all curves of a data file. It must be specified in the unit of the data file.

Example:

```
# Name          unit          g       time-shift
  FileTest1     mm.K.s        YES     0.0
```

8.2.3 Signal block parameters

All signal parameters must be specified sequentially in a single line and the following order.

<*Name*> Type: string

Name of the signal. Signal names, that comply with ISO/TS 13499 should be used.

<*WF*> Type: real, Domain: $R_{>0}$

Signal weighting factor (see wf in section 4)

If ***METHOD*** CORA:

<*Y_norm*> Type: real, Domain: { $(-\infty, \infty)$, extremum}

This parameter is used to calculate the interval of evaluation as well as the corridors of the corridor method (see Y_{norm} in section 5.2.1 and 8.1.1). *Y_norm* can be a number or set to “extremum” (section 8.1.1).

If ***METHOD*** ISO9790:

<*Y_norm*> Type: string

Specifies the rating method (section 7)

<*t_min*> Type: real, Domain: { $(-\infty, \infty)$, x}

The parameter defines the start of the interval of evaluation. If a number is specified, the time unit defined by the global parameter ***T_UNIT*** is expected. Besides a number, several expressions to enable special functions can be specified:

“x”	the global setting is used (***T_MIN/TMAX***, section 8.1.1)
“y”	the setting of the first signal of the same (sub-)load case is used
“automatic”	*t_min* is calculated automatically (section 3.2)

<*t_max*> Type: real, Domain: { $(-\infty, \infty)$, x, y}

The parameter defines the end of the interval of evaluation. If a number is specified, the time unit defined by the global parameter ***T_UNIT*** is expected. Besides a number, several expressions to enable special functions can be specified:

"x"	the global setting is used (***T_MIN/T_MAX***, section 8.1)
"y"	the setting of the first signal of the same (sub-)load case is used
"automatic"	*t_max* is calculated automatically (section 3.2)

If ***METHOD*** CORA:

<*g_V*> Type: real, Domain: { $R_{>0}$, x}

Weighting factor of the progression rating V (section 8.1.5)

If the term "x" is specified, the global setting is used.

If ***METHOD*** ISO9790:

<*g_V*> Type: string

If the physical dimension of the x-axis is not time, then a different dimension can be specified alternatively. The codes of all allowed physical dimensions are described in ISO/TS 13499.

<*g_P*> Type: real, Domain: { $R_{>0}$, x}

Weighting factor of the phase shift rating P (section 8.1.5)

If the term "x" is specified, the global setting is used.

<*g_G*> Type: real, Domain: { $R_{>0}$, x}

Weighting factor of the size rating G (section 8.1.5)

If the term "x" is specified, the global setting is used.

<*g_1*> Type: real, Domain: { $R_{>0}$, x}

Weighting factor of the corridor rating C_1 (section 8.1.4)

If the term “x” is specified, the global setting is used.

<g_2> Type: real, Domain: { $R_{>0}$, x}

Weighting factor of the cross correlation rating C_2 (section 8.1.5)

If the term “x” is specified, the global setting is used.

<a_0> Type: real, Domain: { $[0,1]$, x}

Relative width of the inner corridor (section 8.1.4)

If the term “x” is specified, the global setting is used.

<b_0> Type: real, Domain: { $[0,1]$, x}

Specifies the relative width of the outer corridor (section 8.1.4)

If the term “x” is specified, the global setting is used.

<a_t> Type: string, Domain: {file name, NOTSPEC}

This parameter specifies the name of a file that contains corridor curves. Up to four curves can be specified in this file. Details are given in section 9. A curve requires at least two supporting points. Furthermore, the time unit, defined by the global parameter ***T_UNIT***, is expected.

This function can be disabled by using the term “NOTSPEC”.

<a_s> Type: real, Domain: { $[0,1]$, x}

This parameter defines a scaling factor (a_s) to influence the inner corridor by means of the standard deviation (section 8.1.4).

If the term “x” is specified, the global setting is used.

<b_s> Type: real, Domain: { $[0,1]$, x}

This parameter defines a scaling factor (b_s) to influence the outer corridor by means of the standard deviation (section 8.1.4).

If the term “x” is specified, the global setting is used.

<*D_min*> Type: real, Domain: { $[0,1]$, x}

The parameter limits the allowed phase shift to calculate the phase shift rating (section 8.1.5). Contrary to the global definition, the value must be specified in the time unit of the outputs (section 11).

If the term “x” is specified, the global setting is used.

<*D_max*> Type: real, Domain: { $[0,1]$, x}

The parameter limits the allowed phase shift to calculate the phase shift rating (section 8.1.5). Contrary to the global definition, the value must be specified in the time unit of the outputs (section 11).

If the term “x” is specified, the global setting is used.

<*Filter*> Type: character, Domain: {0, A, B, C, D}

This parameters selects the channel filter class to filter the signals prior any data processing (section 14). The following settings are accepted:

“0”	no filter applied
“A”	CFC1000
“B”	CFC600
“C”	CFC180
“D”	CFC60

8.2.4 Example of a load case parameter block

All parameters of the corridor method are printed in blue and the parameters of the cross correlation method are printed in red.

```
BEGIN LOADCASE
# loadcase 1
  NAM_LC                 LC_1
  DES_LC                 Description_LC1
  WF_LC                  1.0
  PreT_LC                x
  PostT_LC               0.0
  METHOD                 CORA

  BEGIN DATAFILES
#   Name                 unit          g      time-shift
```

```
#   Test 1 to 3 will be used to calculate average test curves
    FileTest1           mm.K.s        YES    0.0
    FileTest2           m.g.s         YES    0.0
    FileTest3           mm.m.K.ms     YES    2.0
#   Simulation
    FileSimulation      m.K.s         No     -10.0
  END DATAFILES

  BEGIN SIGNALS
#   Signals
#   1  Name, 2  WF, 3  Y_norm, 4  t_min, 5  t_max, 6  g_V, 7  g_G, 8  g_P, 9  g1, 10  g2
#   11  a_0, 12  b_0, 13  a_t, 14  a_s, 15  b_s, 16  D_min, 17  D_max, 18  Filter
#   1                2    3          4    5    6    7    8    9    10   11   12  13       14   15 16 17 18
    S1HEAD0000H3ACXP 0.4  extremum  x    0.1  x    x    x    x    x    0.1  1.0 NOTSPEC  0.3  1  x  x  A
    S1CHST0000H3DSXC 0.6  extremum  0.1  0.2  0.3  0.4  0.3  0.4  0.6  0.1  1.0 cor.dat  0    0  x  x  0
  END SIGNALS

END LOADCASE
```

8.3 Sub-load case parameters

The parameters of load cases and sub-load cases are almost identical. Differences are shown in the following sections.

8.3.1 General Parameters

The load case keywords ***NAM_LC***, ***DES_LC*** and ***WF_LC*** are replaced by specific sub-load case parameters. All other keywords and parameters remain the same.

NAM_SLC <string>

Name of the sub-load case (title)

DES_SLC <string>

Additional description of the sub-load case (sub-title)

WF_SLC <real> Domain: $R_{>0}$

Weighting factor of the sub-load case (section 4)

8.3.2 Data file block parameters

A sub-load case uses the same parameters as defined for a load case (section 8.2.2).

8.3.3 Signal block parameters

A sub-load case uses the same parameters as defined for a load case (section 8.2.3).

8.3.4 Example of a load case block with two sub-load cases

The following example uses the biofidelity rating method. Only the red signal parameters are taken into account when using this method.

```
BEGIN LOADCASE
  METHOD                  ISO9790
  NAM_LC                  LC_1
  DES_LC                  Description_LC1
  WF_LC                   1.0
  PreT_LC                 0.0
  PostT_LC                0.0

  BEGIN SUBLOADCASE
    NAM_SLC               SLC_1
    DES_SLC               Description SLC 1
    WF_SLC                5.0

    BEGIN DATAFILES
#     Name                unit          g      time-shift
      Test1.dat           mm.K.s        YES    0.0
    END DATAFILES

    BEGIN SIGNALS
#     Signals
      00SENS000000FOX0  8  corridor  x  x  x  x  x  x  x  x  x  corridor_1.dat  x  x  x  x  D
      00SHLD000000DSY0  6  peak      x  x  x  x  x  x  x  x  x  corridor_2.dat  x  x  x  x  C
    END SIGNALS

  END SUBLOADCASE

  BEGIN SUBLOADCASE
    NAM_SLC               SLC_2
    DES_SLC               Description SLC 2
    WF_SLC                5.0

    BEGIN DATAFILES
#     Name                unit          g      time-shift
      Test2.mme           mm.K.s        YES    0.0
    END DATAFILES

    BEGIN SIGNALS
#     Signals
      00ABDO000000DSY0  9  peak_low  x  x  AC  x  x  x  x  x  x  corridor_3.dat  x  x  x  x  B
    END SIGNALS

  END SUBLOADCASE

END LOADCASE
```

9 Corridor files

User-defined corridors can be specified in the signal parameters block by the parameter *a_t*. Various ASCII format are supported (section 2.1). Depending on the selected metrics, a fixed number of curves in a defined order is required. The content is controlled by the keyword ***METHOD*** (section 8.2.1) and the signal parameter *Y_norm* (section 8.3.3).

The time unit of the corridor files is set by the keyword ***T_UNIT***.

9.1 Corridor method

If the parameter ***METHOD*** is set to “CORA”, the following corridor curves shall be specified:

- lower inner corridor curve
- upper inner corridor curve
- lower outer corridor curve
- upper outer corridor curve

9.2 Biofidelity method

If the parameter ***METHOD*** is set to “ISO970”, the number and order of the corridor curves depends on the settings of the signal parameter *Y_norm*.

9.2.1 Corridor and Peak rating

If the signal parameter *Y_norm* is set to “corridor” or “peak”, the following curves shall be specified:

- lower inner corridor curve
- upper inner corridor curve

The outer corridors are calculated automatically by adding and subtracting the maximum width of the inner corridors to the corridor curves.

9.2.2 Peak low/high rating

If the signal parameter *Y_norm* is set to “peak_high”, “peak_low”, “peak_high_5”, or “peak_low_5” the following curve shall be specified:

- lower or upper limit curve

10 Configuration file

The configuration file `cora.cfg` is written in ASCII format and is located in the sub-directory “config” of the software's installation directory. It contains several settings to build-up the HTML report. Comment lines starts with a hashmark (“#”).

10.1 Keywords

The order of the keywords is arbitrary.

BROWSER <file name>

This parameter specifies the command to start the preferred HTML viewer (browser). If CORA was started with the command line parameter “-b”, the HTML report (e.g. `res-ult_cora.html`) is immediately shown in the specified browser after the completion of the CORA analysis.

Example:
```
BROWSER       c:\Programme\Mozilla Firefox\firefox.exe
```

color <integer> Domain: $N_{>0}$

The parameter defines a colour by specifying name, pigment content value of the colours red, green, and blue and finally opacity. All values must range from “0” to “1”.

backgroundcolor <string>

The parameter sets the background colour of the charts shown in the HTML report. The colour must be pre-defined with the keyword ***color***.

Example:
```
backgroundcolor       cyan
```

foregroundcolor <string>

The parameter sets the foreground colour of the charts shown in the HTML report. It is used to draw the frames of chart and legend as well as the axes. The colour must be pre-defined with the keyword ***color***.

innercolor <string>

The parameter sets the colour of the inner corridor curves. The colour must be pre-defined with the keyword ***color***.

outercolor <string>

The parameter sets the colour of the outer corridor curves. The colour must be pre-defined with the keyword ***color***.

experimentcolor <string>

The parameter sets the colour of the reference curve. The colour must be pre-defined with the keyword ***color***.

simulationcolor <string>

The parameter sets the colour of the comparison curve. The colour must be pre-defined with the keyword ***color***.

intervalcolor <string>

The parameter sets the colour of two vertical lines that show the starting (t_{min}) and ending (t_{max}) time of the interval of evaluation. The colour must be pre-defined with the keyword ***color***.

referencecolor <string>

The parameter sets the colour of the shifted reference curve that is the base of the cross correlation rating. The colour must be pre-defined with the keyword ***color***.

Example:

```
color                 cyan    0.00    1.00    1.00    1.00
referencecolor        cyna
```

10.2 Obsolete Keywords

Previous releases of CORA used 3rd party tools to create the charts. This function is still available and can be enabled by using one of the following keywords:

HYPERGRAPH <file name>

The keyword specifies the command to start Altair HyperGraph to create the charts of the HTML report.

LSPOST <file name>

The keyword specifies the command to start LS-PrePost to create the charts of the HTML report.

PAMVIEW <file name>

The keyword specifies the command to start PAM-VIEW to create the charts of the HTML report.

Example:

```
HYPERGRAPH   c:\program files\altair\hg.exe
```

When using one of those keywords, the following parameters must be defined too.

CURVE_COLORS <string>

The keyword specifies the colours that have to be used by the third party software to create the charts.

Example:

```
CURVE_COLORS   6=magenta   5=cyan   7=yellow   8=crimson
9=darkcyan
```

11 Definition of the output units

The configuration file `output_units.txt` is using an ASCII format and it is located in the sub-directory “config” of the software's installation directory.

Every physical dimension, used by a CORA evaluation, must be assigned to a physical unit. The used dimension code shall comply with ISO/TS 13499 (13th and 14th character of the ISO channel name). The units are described by their SI description. It is possible to use equations of basic units to describe derived units. However, it is not allowed to use derived units to describe other units.

A copy of `output_units.txt` with the most common physical dimensions and their corresponding unit is delivered with the CORA software package. So there is usually only a need to edit this file, if different units are required for the HTML report (e.g. [mm] instead of [m]).

11.1 Syntax

Comment lines shall start with a hashmark (“#”). It is also possible to add a comment at the end of a line. Those in-line comments start with a hashmark too.

A physical dimension is defined by two capital letters according to [3], separated by a semicolon (“;”) from its unit.

Example:

```
# Comment
AC; m/(s*s)  # comment
```

11.2 Basic units

The following basic units are supported by CORA:

Time
second [s] and millisecond [ms]

Mass
kilogram [kg] and ton [t]

Length
metre [m] and millimetre [mm]

In addition, the unit [g] is supported for linear accelerations (1 g=9.81 m/s²).

11.3 Derived units

Only units, derived from the basic units of time, mass, and length (section 11.2) can be converted from the system of units of a data file to that of the corresponding outputs (HTML report). The following examples demonstrate the conversion of units:

Example of supported conversions:
```
# Power PO
PO; W                 # Watt
PO; mW                # Milliwatt
PO; (kg*m*m)/(s*s*s)  # equivalent to [W]
```

Example of not supported conversion:
```
# Power PO
PO; N*m/s             # [N] is a derived unit (N=(kg*m)/(s*s))
PO; kg*m/s^3          # character “^” not supported, use (s*s*s)
PO; (kgm)/(s*s*s)     # missing character "*", use (kg*m)
PO; (Kg*m)/(s*s*s)    # case sensitivity error, use (kg*m)
```

12 Signal name mapping file

Generally, it is recommended to use signal names that comply with ISO/TS 13499 coding. However, CORA offers the possibility to use arbitrary signal names. If so, a name mapping file must be prepared that associates those names with ISO/TS 13499 names. This ASCII file (“`name_mapping.txt`”) shall either be located in the working directory or in the “config” directory of the software's installation.

Comment lines starts with a hasmark (“#”). Each name mapping line must start with the ISO name followed by alternative names. All names must be separated by a semicolon (“;”).

Example:

```
# Comment
S1HEAD0000H3ACXA; X-Acceleration; H350_Dummy-Head-Acc-X
```

The setting of the global keyword ***ISONAME_1-2/11-12*** (section 8.1.1) shall be considered when using the name mapping function.

Example:

```
ISONAME_1-2/11-12     YES   YES
```

The signal name S1HEAD0000H3ACXA is equivalent to 00HEAD0000HFACXA and the other way round.

13 Program flow

This chapter describes the program flow in detail.

(1) Analysis of the command line parameters

(2) Reading the configuration file (`config.txt`) and the signal name mapping file (`name_mapping.txt`)

(3) Reading the control file

(3.1) Global parameters

At first, the software searched for the keyword ***BEGIN GLOBAL_PARAMETERS***. The subsequent lines must contain all global parameters (section 8.1). This block ends with the keyword ***END GLOBAL_PARAMETERS***.

(3.2) Load cases

A load case block starts with the keyword ***BEGIN LOADCASE*** and ends with ***END LOADCASE***. The definition of a load case must start with the general load case parameters (section 8.2.1) followed by the data files block (section 8.2.2) and the signal parameters block (section 8.2.3).

The data file block starts with ***BEGIN DATAFILES*** and ends with ***END DATAFILES***. Each line of this section must comply with the definitions described in section 8.2.2. The first up to the second of last line defines the reference data. If more than one reference data file is specified, average reference data are calculated. The last line of this section specifies always the comparison data. Therefore, at least two data files (two lines) must be specified within this block.

The signal parameters block starts with ***BEGIN SIGNALS*** and ends with ***END SIGNALS***. The signal block selects the curves of the data files that have to be evaluated. All curves should use the name conventions according to ISO/TS 13499. These names are used to identify the curves in the data files. Alternative names, defined in the name mapping file are considered too. All signal parameters (section 8.2.3) must be specified in the defined order, even if they are not used.

Any number of additional load cases can be defined after the keyword ***END LOADCASE***.

(3.3) Sub-load cases (if existing only)

A sub-load case adds a new hierarchy level to the rating. A load case which has sub-load cases cannot contain signals.

A sub-load case starts with ***BEGIN SUBLOADCASE*** and ends with ***END SUBLOADCASE***. It must contain some general parameters (section 8.3.1), a data file block (between ***BEGIN DATAFILES*** and ***END DATAFILES***, section 8.3.2) and a signal parameters block (between ***BEGIN SIGNALS*** and ***END SIGNALS***, section 8.3.3). The syntax of these blocks is identical to that of a load case.

Any number of additional sub-load cases can be defined after the keyword ***END SUBLOADCASE***.

(4) Check of the weighting factors

The weighting factors of signals, sub-load cases, and load cases are normalised. More information about the weighting factors is given in section 4.

(5) Reading the curves

The format of the curve files (data files) is automatically detected. CORA identifies all curves of a data file but only read those that are specified in the signal definition block.

The following data processing is applied to the read curves:

(5.1) Filtering (if specified)

(5.2) Conversion of the physical units (see `output_units.txt`)

(5.3) Shifting of the curve along the x-axis (if specified)

(5.4) Re-sampling

CORA requires curves of the same sampling rate. Therefore, the minimum sampling rate of all specified curves of a signal is calculated. This rate is increased to an integral number of supporting points within the interval of evaluation if this interval is set manually. In case of using the automatically calculated interval of evaluation, the starting and ending time of the whole signal is used instead.

All curves are interpolated by a cubic spline function (section 15).

(5.5) Calculation of the mean reference curve

A mean reference curve $x(t)$ is calculated if more than two reference data files are specified in the data files block of a load case or sub-load case.

$$x(t) = \frac{\sum_{i=1}^{n_{Test}} x_i(t)}{n_{Test}}$$

(6) Generation of the corridor curves (CORA method only and *a_t* set to "NOTSPEC")

The inner and outer corridor is generated around the only reference curve or the mean reference curve. The values defined by global keywords (***Y_NORM***, ***a_0/b_0***, ***a_sigma/b_sigma***) and local parameters (*Y_norm*, *a_0*, *b_0*, *a_s*, *b_s*) are used.

The calculation of Y_{norm} depends on the interval of evaluation. If it is defined manually, then Y_{norm} is calculated within this interval. Otherwise it is calculated for the entire reference curve (between starting and ending time of the curve).

(7) Definition of the interval of evaluation (CORA method only)

The bounds of the interval can be defined globally (***T_MIN/T_MAX***) or locally (*t_min*, *t_max*). If the term "automatic" is specified, the corresponding limit is calculated by using the algorithms of CORA (section 3.2).

CORA checks, if the interval of evaluation exceeds the domain of the reference curve $x(t)$ or the evaluated curve $y(t)$. If so, the interval will be shortened automatically.

When the automatic algorithm is used, the spline interpolation is done a second time to get a pair of values at the begin and end of the interval.

(8) Small signals (CORA method only)

If the global parameter ***MIN_NORM*** is not equal “0”, a special treatment for small signals is activated (section 8.1.3).

(9) Reading the corridor files to be used with the CORA corridor method (CORA method: parameter *a_t* used) or the biofidelity rating (ISO9790 method only)

(10) Corridor correlation (CORA method only)

The rating C_1 according to the corridor metric is calculated for each signal (section 5).

(11) Cross correlation (CORA method only)

The rating C_2 according to the cross correlation metric is calculated for each signal (section 6).

(12) Total signal rating

The total rating C_3 is calculated for each signal (section 4).

(13) Signal rating (ISO9790 method only)

The biofidelity rating C_3 is calculated (section 7).

(14) Calculation of the rating of sub-load cases, load cases and the final total rating

(15) Output of the ASCII result file

CORA exports the processed files (curves, corridors etc.).

(16) Output of the HTML report

14 CFC Filter

In accordance with the SAE J211 [4], a 4-channel Butterworth low pass filter can be applied to the signals prior any other signal processing.

$$Y(t)=a_0 \cdot X(t)+a_1 \cdot X(t-1)+a_2 \cdot X(t-2)+b_1 \cdot X(t+1)+b_2 \cdot X(t+2)$$

$Y(t)$ is the filtered curve (output) and $X(t)$ the original curve (input). The filter constants a and b are calculated by using the following equations:

$$a_0=\frac{\omega_a^2}{1+\sqrt{2}\cdot\omega_a+\omega_a^2}$$

$$a_1=2\cdot a_0$$

$$a_2=a_0$$

$$b_1=\frac{-2\cdot(\omega_a^2-1)}{1+\sqrt{2}\cdot\omega_a+2\cdot\omega_a^2}$$

$$b_2=\frac{-1+\sqrt{2}\cdot\omega_a-\omega_a^2}{1+\sqrt{2}\cdot\omega_a+\omega_a^2}$$

ω_a is derived from ω_d and T is the sampling rate in seconds. To prevent phase shifts, the filtering has to run twice – forward and backward.

$$\omega_a=\frac{\sin\omega_d\frac{T}{2}}{\cos\omega_d\frac{T}{2}}$$

$$\omega_d=2\cdot\pi\cdot CFC\cdot 2.0775$$

15 Spline interpolation

All curves are interpolated by harmonic cubic splines to get a consistent sampling rate. A brief summary of the methodology is given in this section. Further information is available in [1]. A cubic spline for $n+2$ points $((x_{0,}y_0),(x_{1,}y_1),...(x_{\mathrm{n+1}},y_{\mathrm{n+1}}))$ must be chosen, resulting in the following equation:

$$\begin{pmatrix} 2 & \lambda_0 & 0 & 0 & 0 & 0 & ... \\ \mu_1 & 2 & \lambda_2 & 0 & 0 & 0 & ... \\ 0 & \mu_2 & 2 & \lambda_2 & 0 & 0 & ... \\ . & . & . & . & . & . & . \\ 0 & 0 & 0 & 0 & \mu_n & 2 & \lambda_n \\ 0 & 0 & 0 & 0 & 0 & \mu_{n+1} & 2 \end{pmatrix} \cdot \begin{pmatrix} M_0 \\ M_1 \\ M_2 \\ .. \\ M_n \\ M_{n+1} \end{pmatrix} = \begin{pmatrix} r_0 \\ r_1 \\ r_2 \\ ... \\ r_n \\ r_{n+1} \end{pmatrix}$$

With the following parameters, the equation can be solved by inverting the matrix and calculating the M values:

$$\Delta x_i = x_{i+1} - x_i \qquad 0 \le i \le n$$

$$\Delta y_i = x_{i+1} - y_i \qquad 0 \le i \le n$$

$$\lambda_i = \frac{\Delta x_i}{\Delta x_{i-1} + \Delta x_i} \qquad 1 \le i \le n \text{ and } \lambda_0 = 0$$

$$\mu_i = 1 - \lambda_i \qquad 1 \le i \le n \text{ and } \mu_{n+1} = 0$$

$$r_i = \frac{6}{\Delta x_{i-1} + \Delta x_i} \cdot \left(\frac{\Delta y_i}{\Delta x_i} - \frac{\Delta y_{i-1}}{\Delta x_{i-1}}\right) \qquad 1 \le i \le n \text{ , } r_0 = 0 \text{ , and } r_{n+1} = 0$$

The coefficients a , b , c , and d of the cubic polynomials $s_i(x)$ can be calculated according to the following equations:

$$s_i(x) = d_i + c_i(x - x_i) + b_i(x - x_i)^2 + a_i(x - x_i)^3 \qquad 0 \le i \le n$$

$$a_i = \frac{1}{6} \frac{(M_{i+1} - M_i)}{\Delta x_i}$$

$$b_i = \frac{1}{2} M_i$$

$$c_i = \frac{\Delta y_i}{\Delta x_i} - \frac{1}{6} \Delta x_i (2\mathrm{M}_i + M_{i+1})$$

$$d_i = y_i$$

16 Encryption of the global parameters

CORA offers the possibility to protect the global parameters from any modification by encryption. Encryption is not introduced to hide the global parameters but to ensure that these parameters are used. The file `result_cora.enc` is written automatically at the end of an evaluation when encrypted parameters are used. It contains the results (see also `result_cora.txt`) and all global parameters that have been used. This file is encrypted as well.

The global parameters must be sourced out to a separate ASCII file that shall be encrypted afterwards. A password shall be specified to encrypt the file. No password is required to use encrypted parameters in a CORA evaluation.

16.1 Encryption

An additional tool (`cora_encrypt`), delivered with the CORA software package, shall be used to encrypt the file with the outsourced global parameters. It is a command line tool, available for Linux and MS-Windows computers.

`cora_encrypt -e` <file name1> <file name2> <password>

<file name1>
ASCII file with the global parameters (input)

<file name2>
Encrypted binary file (output)

<password>
Password to encrypt the file. It can be of arbitrary length and can contain any character except blanks and characters which are not printable.

16.2 Decryption

The tool `cora_encrypt` cannot be used to decrypt an encrypted parameter file but it can be used to decrypt encrypted results, written in `result_cora.enc`.

`cora_encrypt -d` <file name1> <file name2> <password>

<file name1>
Binary file with the encrypted results (input)

<file name2>
ASCII file with the decrypted CORA results and the used global parameters (output)

<password>
The password, used to encrypt the global parameters, must be specified

16.3 Usage of encrypted parameters

When using the option to protect the global parameters, only the parameters shall be sourced out. The keywords that describe the global parameter block (***BEGIN GLOBAL PARAMETERS*** and ***END GLOBAL PARAMETERS***) still remain in the control file. The encrypted parameters are included by the keyword ***PARAM_FILE***.

PARAM_FILE <file name>
The parameter specifies a file with encrypted global parameters. If this keyword is specified, no other global parameter is allowed in the control file.

16.4 Example

16.4.1 Encrypted parameter file

An example of an ASCII file with the global parameters is shown below. This file must be encrypted (section 16.1) before use.

```
# Global parameter block
  A_EVAL                0.00
  A_THRES               0.05
  B_THRES               0.07
  B_DELTA_END           0.1
  T_MIN/T_MAX           automatic     1.0
```

```
  T_UNIT               s
  Y_NORM               extremum
  DES_GLO              what it is
  DES_MOD              Model 42
  FONT_SMALL           13
  FONT_LARGE           16
  ISONAME_1-2/11-12    YES    NO
  OUTPUT_FORMAT        LSPOST
  PreT_LC/PostT_LC     0.0    0.1
  WF_NORM              YES
  MIN_NORM             0.20
  a_0/b_0              0.7    0.9
  a_sigma/b_sigma      0.2    0.5
  K                    2
  G_1                  0.50
  D_MIN                0.05
  D_MAX                0.10
  INT_MIN              0.3
  K_V                  1.0
  K_G                  1.0
  K_P                  1.0
  G_V                  0.33
  G_G                  0.33
  G_P                  0.33
  G_2                  0.50
  DIM_WEIGHTS          AC     0.4    0.4    0.2    0.55   0.45
END GLOBAL_PARAMETERS
```

16.4.2 Control file

This is example shows how to include an encrypted parameter file in a control file.

```
BEGIN GLOBAL_PARAMETERS
# encrypted parameter file
  PARAM_FILE           test.enc
END GLOBAL_PARAMETERS
```

17 Proposed settings

Based on the experiences with CORA over the past years, the following global settings are recommended for the use with responses of crash test dummies. However, other settings are possible and the user is encouraged to tune them to his own needs.

17.1 Interval of evaluation

A_THRES	0.030
B_THRES	0.075
A_EVAL	0.010
B_DELTA_END	0.200
T_MIN/T_MAX	automatic automatic

17.2 Corridor method

Y_NORM	extremum
K	2
G_1	0.50
a_0/b_0	0.05 0.50
a_sigma/b_sigma	0 0

17.3 Cross correlation method

D_MIN	0.01
D_MAX	0.12
INT_MIN	0.80

K_V	10
K_P	1
K_G	1
G_V	0.50
G_G	0.25
G_P	0.25
G_2	0.50

17.4 HTML report

FONT_SMALL	12
FONT_LARGE	14

18 References

[1] Feldmann, D.: „Repetitorium der Ingenieur-Mathematik Teil 2“, Binomi Verlag GbR, Barsinghausen, Germany, 1993

[2] “ISO/TR 9790: Road Vehicles – Anthropomorphic side impact dummy – lateral impact response requirements to assess the biofidelity of the dummy”, International Organization for Standardization (ISO), Geneva, Switzerland, 1999

[3] “ISO/TS 13499: Road Vehicles – Multimedia exchange format for impact tests”, International Organization for Standardization (ISO), Geneva, Switzerland, 2002

[4] “SAE J211/1: “Instrumentation for Impact Test – Part 1 – Electronic Instrumentation”; SAE International, Troy MI, USA, 2007

19 Release notes

19.1 CORA 3.6.1

Bugfix

- Selection of the signal filter class in sub-load cases

19.2 CORA 3.6

New

- Keyword ***T_UNIT*** to select the unit of ***T_MIN/T_MAX***, *t_min*, and *t_max* (section 8.1.1)
- The shifted signal to calculate the cross correlation is now shown in the HTML report

Change

- Calculation of the time shift of the cross correlation method → ***INT_MIN*** (section 6.3); WARNING: this change may affect the rating results; however, the rating is less sensitive against the total length of the signals
- A warning is shown if the time shift is limited by the length of the signal

Bugfix

- Handling of ISO-MME files