EVAL

SIEMENS Industrial Turbomachinery standard fatigue life evaluation tool

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General

- EVAL is the standard fatigue life evaluation tool at SIEMENS Industrial Turbomachinery
- Developed and used at SIEMENS in Finspong in different versions since the mid 1990's
- Current version is 3.4
  - Programming languages: Python, Fortran 90, C++
  - Operative system: Linux
  - External libraries: SMR Mem-Com
  - Supported FE programs: ABAQUS, ANSYS
  - Supported post-processors: ABAQUS

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General ideas

- EVAL shall aid the daily work of the stress engineers by:
  - providing a computer implementation of the most up-to-date lifing methods, as defined by SIEMENS current best-practice documents
  - providing a flexible tool that swiftly can be updated and enhanced to meet the users needs
  - providing a tool that can evaluate large FE-models and help locate critical locations

- Flexibility is a key factor, and the main motivation for developing and maintaining an in-house code, as this leads to:
  - full control of the implemented methods
  - a possibility for high development speed and responsiveness

- The program must be easy to develop and maintain, as (normally) the budget only allows for staff to work part-time with the code

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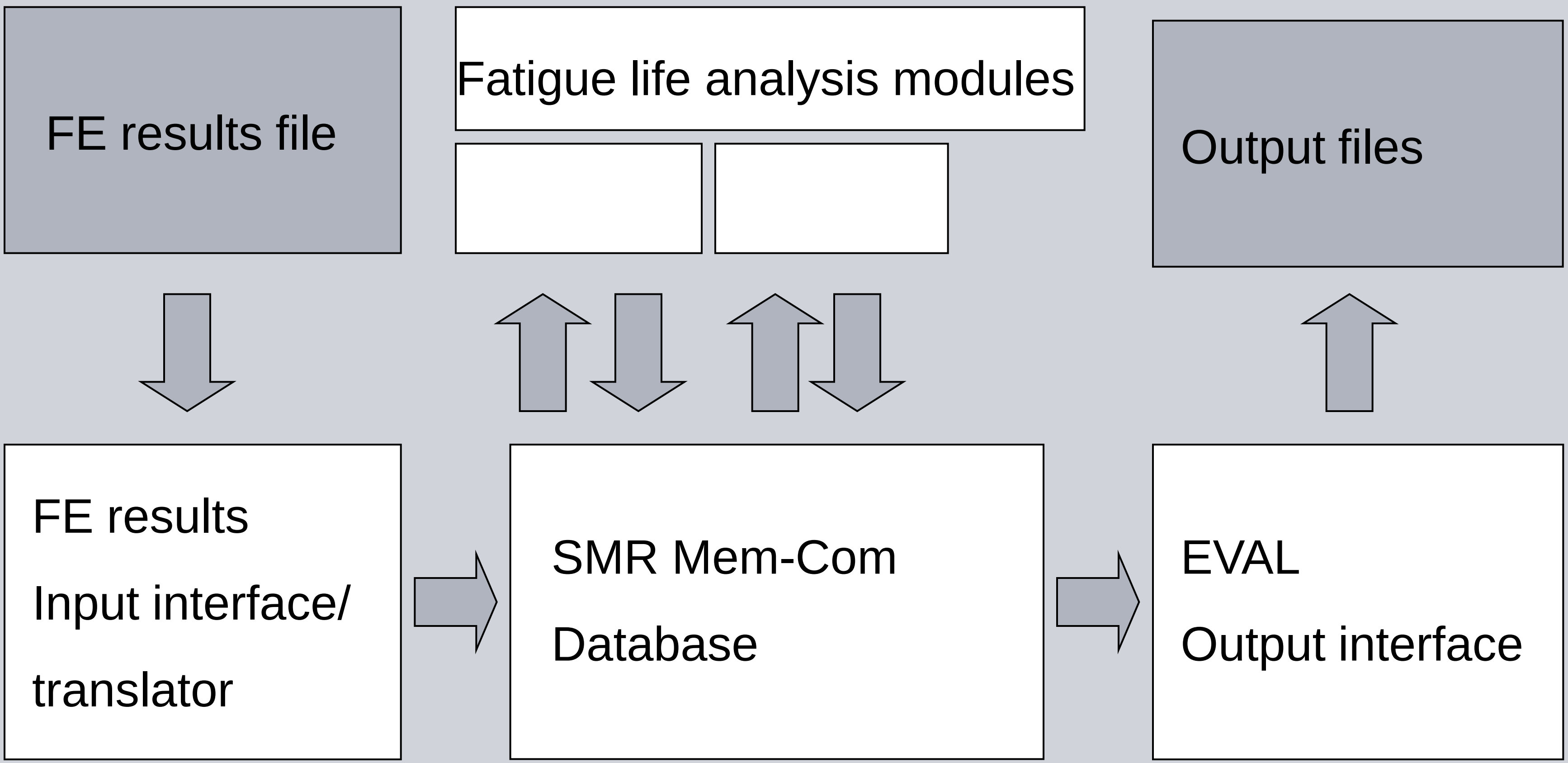
Structure: modules



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Programming languages

- The main modules were originally programmed in C, but has since 2003 been ported to Python

- The choice of Python as the main programming language may seem odd, but it is motivated by:
  - Productivity is higher during development than for C, C++ or Fortran (as experienced by us)
  - Python is platform independent
    (while changing platform used to be a hassle for the C code, we now have run the Python code on 4 different platforms without changing the code)
  - The performance of the Python code is not as bad as its reputation (The use of dynamic data types has sometimes made the Python code run faster than the old (maybe not perfect) C code)

- We think that using Python is a step towards the goal of having a flexible and easily maintainable code.

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SMR Mem - Com

- From the beginning the core of the program has been the Mem-Com database

- The Mem-Com database is a fast platform-independent database developed and sold by the swiss company SMR (www.smr.ch)
- Throughout all years we have been very satisfied, and had very little problems, with the database
- When there has been issues, such as porting to new platforms, the support has been excellent!

- The database has interfaces in Python, C, C++, Fortran 77 and Fortran 90
(which has proved very convenient, as will be shown subsequently)

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ABAQUS interface

- The ABAQUS output database is accessed with ABAQUS own interface routines.
- Both a Python and C++ interface is available.
- The implementation of the interface routines is not identical, and functionality that gives the best performance is only available in C++.
- We have therefore recently felt forced to use C++ for the ABAQUS interface, yielding 10 times faster execution time for the C++ interface compared to the old Python interface
  (but there is a fear that we might run into platform-dependent problems as before. The future will tell us…)

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ANSYS interface

- ANSYS provoides an interface routine library, written in Fortran 90
- An interface module that reads results from the ANSYS .rst file is therefore written in Fortran 90
- Currently only version 11 of ANSYS is supported

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Analysis

Supported Elements

- 3D solid
- 2D plane stress and strain
- 2D axi-symmetric
- 3D shell elements

FE results

- Stresses and strains are treated as un-averaged results on nodes
- The results can be read from multiple result files

Supported analysis types

- Elastic stress-range
- Strain-life crack initiation life, based on elastic stress-range and Neuber's method
- Strain-life crack initiation life, based on elasto-plastic FE-results
- Stress amplitude and mean stress according to Sines
- HCF evaluation based on Goodman diagram
- Company specific methods for crack initiation life for turbine blade alloys

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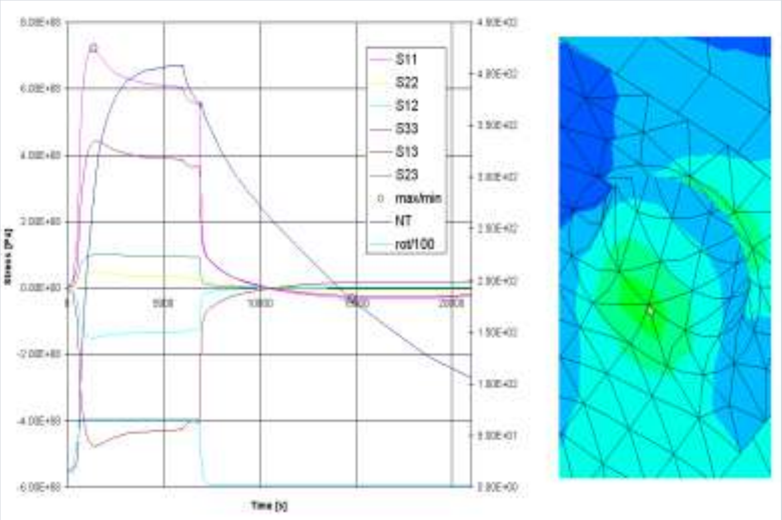
Low cycle fatigue evaluation: Stress range

- Focus is to find the major cycle (no cycle counting is available)

For all timepoints [t_i t_e] in the results files:

Find $$\Delta\sigma_E = \max_{\substack{t_i<t_1\le t_e \\ t_i<t_2\le t_e}} \mathrm{VonMises}(\sigma_{mn}(t_1)-\sigma_{mn}(t_2))$$



Damage temperature T_0 is by default the maximum of the temperatures at the time points generating the maximum stress-range $\Delta\sigma_E$.

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Strain-life: Neuber's rule

Uses the results from the stress-range calculation

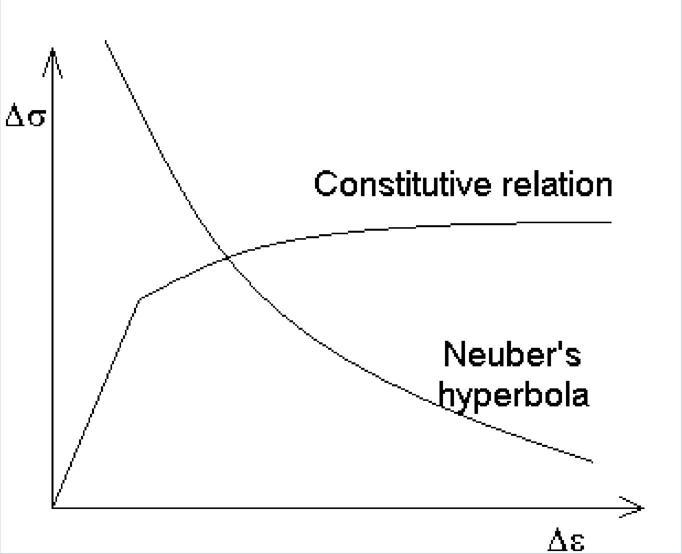
The strain-range is calculated by solving:

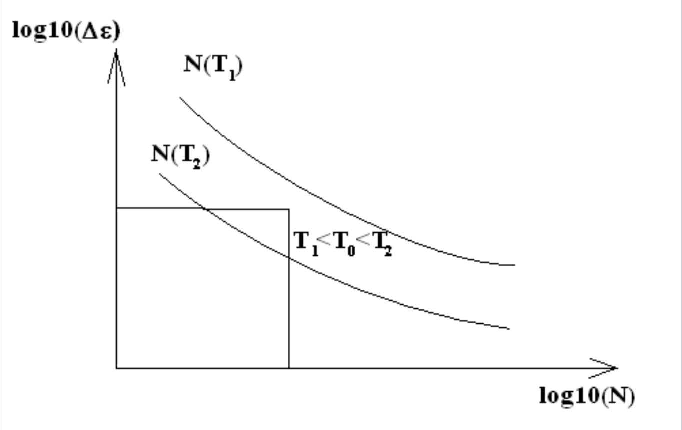
$\Delta\sigma = f(\Delta\varepsilon, T_0)$ (Cyclic constitutive)

$\Delta\sigma \cdot \Delta\varepsilon = (\Delta\sigma_E)^2 / E(T_0)$ (Hyperbola)

The crack initiation life is calculated by interpolation in the strain-life $N(\Delta\varepsilon, T_0)$ data

Mean stress (or R_ε) dependence is handeled by using correct $N(\Delta\varepsilon, T_0)$-data





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Strain-life: based on elasto-plastic FE-results

If an elasto-plastic FE-simulation has been performed, the mechanical strain range can be evaluated directly from the FE-results:

For all timepoints [t_i t_e] in the results files :

$$\text{Find } \Delta\varepsilon = \max_{\substack{t_i<t_1\leq t_e \\ t_i<t_2\leq t_e}} \frac{1}{\sqrt{2(1+\upsilon)}}\sqrt{\left(\Delta\varepsilon_{XX}-\Delta\varepsilon_{YY}\right)^2+\left(\Delta\varepsilon_{YY}-\Delta\varepsilon_{ZZ}\right)^2+\left(\Delta\varepsilon_{ZZ}-\Delta\varepsilon_{XX}\right)^2+6\left(\Delta\varepsilon_{XY}^2+\Delta\varepsilon_{YZ}^2+\Delta\varepsilon_{XZ}^2\right)}$$

where $\Delta\varepsilon_{MN}=\varepsilon_{MN}(t_1)-\varepsilon_{mn}(t_2)$

Damage temperature T_0 is the maximum of the temperatures at the time points generating the maximum strain-range $\Delta\varepsilon$.

The crack initiation life is calculated by interpolation in the $N(\Delta\varepsilon,T_0)$ data

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Running EVAL

- EVAL is run in batch mode on a calculations server.
- EVAL is controlled by keywords in an input file, with a syntax similar to ABAQUS syntax

```
*ABQ FILES
../mech_start/disc2_inner_holes_mech_start_restart.fil
../mech_stop/disc2_inner_holes_mech_stop_restart.fil
*DB FILE
EVAL_D2_INNER_HOLES_N
*HISTORY, ALL
*NODE
ELSETS
EVALELEM
*GLOBAL,LIST=100
*READ
NT
S
*MATERIAL FILE
638103_IN718_EVAL_MIN.in
*ANALYSIS
STRESS_RANGE
NEUBER_LCF
*PRINT SUM UNV
STRESS_RANGE
NEUBER_LCF
NEUBER_STRAIN
```

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Material data

- Material data are given in the EVAL control file in tabular form, specific to the chosen analysis method, i.e.:
  - Stress vs. strain (Cyclic)
  - Strain-range vs. life
  - Elastic properties
  - …

```
*MATERIAL NEUBER_LCF, NAME=XXX
STR_STN,TEMP=400
0.1     ,1.E-8
1500.E6,0.008
2000.E6,0.020
STR_STN,TEMP=500
0.1     ,1.E-8
1300.E6,0.008
1700.E6,0.020
STN_LIFE,TEMP=400
0.007,30000
0.009,3000
0.013,300
STN_LIFE,TEMP=500
0.006,30000
0.008,3000
0.011,300
Y_MOD
20.,1.99E11
100.,1.95E11
200.,1.90E11
300.,1.84E11
400.,1.79E11
500.,1.73E11
600.,1.67E11
700.,1.59E11
```

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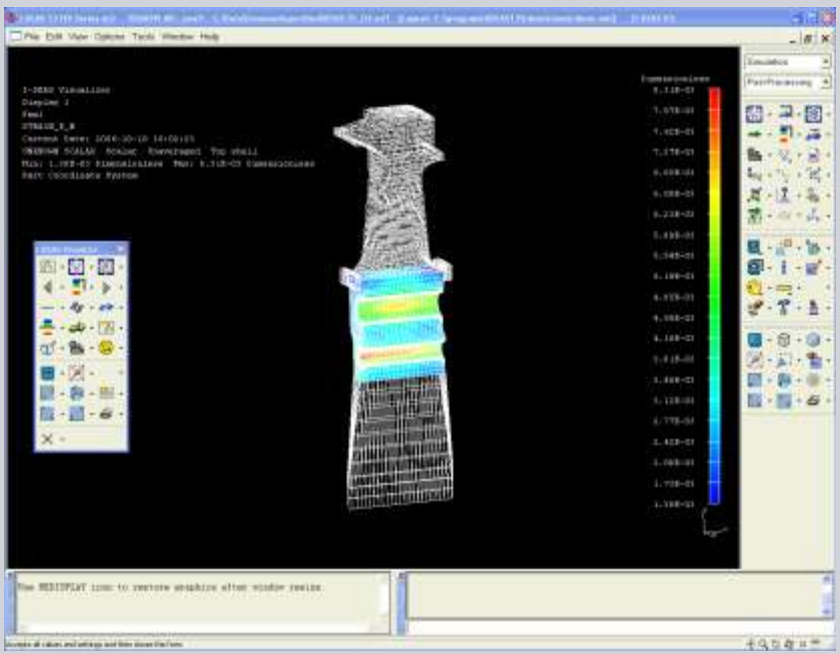
Output files

- The EVAL results are written to text files for manual evaluation
- Results are also written to an ABAQUS .odb file for import and graphical post-processing in e.g. ABAQUS/Viewer



```
Evaluation program run results summary.

Current Date: 2010-05-20 15:02:10
Program Version: 3.4.3

Current results type: STRESS_RANGE

DISC1, STRESS_RANGE
INDEX, MAX STRESS RANGE, NODAL VARIATION %
    1,     1.256163E+09             0.02
    2,     1.255906E+09             0.02
...
   99,     1.061955E+09             0.17
  100,     1.061420E+09             0.08

INDEX, ELEMENT NO, ELEMENT TYPE, NODE NO, SECTION NO
    1,       5881,        CAX8,    11211,          1
    2,       5881,        CAX8,    11210,          1
...
   99,       4075,        CAX8,    12722,          1
  100,       4063,        CAX8,    12719,          1

INDEX, INCR_1, INCR_2,       TEMP_1,        TEMP_2, NOTCH FACTOR SET
    1,      4,     28,  1.591400E+02,  3.244624E+02,               2
    2,      4,     28,  1.610149E+02,  3.235745E+02,               2
...
   99,      4,     28,  1.716035E+02,  3.248787E+02,               2
  100,      4,     28,  1.776024E+02,  3.223724E+02,               2

Current results type: NEUBER_LCF
MATERIAL, NO  NAME
         1  IN901_Rm1_MIN

DISC1, LCF_LIFE
INDEX,       LCF LIFE, NODAL VARIATION %, NEUB. STR_RNG, NODAL VARIATION %
    1,  1.364300E+03,              0.10,  7.036686E-03,              0.03
    2,  1.365686E+03,              0.13,  7.034779E-03,              0.03
...
   99,  2.770238E+03,              0.69,  5.824566E-03,              0.18
  100,  2.771938E+03,              0.60,  5.823612E-03,              0.16

INDEX, ELEMENT NO, ELEMENT TYPE, NODE NO, SECTION NO, MAT.NO
    1,       5881,        CAX8,    11211,          1,      1
    2,       5881,        CAX8,    11212,          1,      1
...
   99,       7178,        CAX8,    12722,          1,      1
  100,       4063,        CAX8,    12718,          1,      1

INDEX, INCR_1, INCR_2,       TEMP_1,        TEMP_2,      DAM_TEMP
    1,      4,     28,  1.591400E+02,  3.244624E+02,  3.244624E+02
    2,      4,     28,  1.574147E+02,  3.253111E+02,  3.253111E+02
...
   99,      4,     28,  1.716035E+02,  3.248787E+02,  3.248787E+02
  100,      4,     28,  1.800244E+02,  3.214678E+02,  3.214678E+02
```

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Summary

- EVAL is providing SIEMENS with a flexible tool, allowing new lifing methods or updates of existing methods to be implemented (the experience is that it can done within weeks of work)
- The flexibility and ease of maintenance is obtained by a modular structure of the program, and the use of Python as programming language.
- The methods implemented so far allows the stress engineers to evaluate the bulk of all fatigue calculations at SIEMENS Industrial Turbomachinery, which is analysis of the start-steady load-stop-cycle. All nodes in large FE-models are analysed in one calculation, making it easy to find the critical locations.
- The program is run on the same computation server that is used for the FE-calculations, and the post-processing of the results are done in the same graphical software that is used by the FE-codes (Currently ABAQUS/Viewer and HyperView).

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