Dynamic validation of model per correlation calculation-tests

Summary

This documentation is intended to describe the principal tools of assistance to the validation of models in dynamics of the structures by correlation calculation-tests. One describes in particular:

- how to import data resulting from measurements,
- validation by criterion of MAC,
- validation by comparison of calculated/simulated FRF

Contents

1 Introduction

In order to evaluate the predictive capacity of a digital model in dynamics of the structures, it can be useful, even essential to validate this one compared to measured data *in situ* . The most classical manner is the comparison of the clean modes (frequencies and deformations) calculated and identified in experiments two to two. The clean modes reflect the total behavior of the structure, and are often used like single tool for validation. The main difficulty in this case is to be able to pair the digital and experimental modes two to two.

This documentation aims to describe the methods and tools usable in Code_Aster to compare the data of calculation and measurement. One treats in section 2 importation of the data resulting from software of measurement in *Code_Aster*. In section 3, one details the use of one of the principal criteria for the validation of model: the matrix of MAC. In section 4, one approaches other means suggested in the environment of *Code_Aster* for the validation (comparison of FRF and deformations).

2 To import data measured in Code_Aster

2.1 Which data to import?

The measured data result from a software of acquisition and treatment of the signal. One can quote among them:

- LMS TestLab,
- Me' Scope,
- B&K Pulsates,
- Labview,
- …

Most this software allow to export data with the universal format, put does not have by software IDEAS (extension *.unv), given which can be read again in *Code_Aster* by `LIRE_RESU (FORMAT=' IDEAS')` .

These files in general contain the relative information with the grid of the structure and the experimental data. The files unv are ASCII files. Each whole of data is called “dataset”, and is framed in the file by two “-1”. The number which follows the first occurrence “-1” corresponds to the type of dataset. Each dataset is composed of several lines (record), and each line contains data lines in columns (field)
In the example below, one presents some lines of a dataset 55, which describes a base of clean modes.

```
    -1
    55   %VALEURS WITH THE NODES
ASTER  7.03.29 CONCEPT MODINTS1 CALC - FIELD WITH THE NODES OF REFERENCE SYMBOL
FIELD WITH THE NODES OF REFERENCE SYMBOL  DEPL - DX DY DZ DRX DRY MARTINI DRZ
ASTER  7.03.29 CONCEPT MODINTS1 CALCULATES THE 11/22/2004 AT 19:24: 57 OF TYPE
FIELD WITH THE NODES OF REFERENCE SYMBOL  DEPL
SEQUENCE NUMBER: 1 NUME_MODE: 1 FREQ:  2.66902E-01
         1         2         3         8         2         6
         2         4         1         1
 2.18331e+01  1.00000e+00  3.74657e-03
      1011     % NODE NO1011
-1.37933E-001 7.39432E-007 3.38287E-001 0.00000E+000 0.00000E+000 0.00000E+000
      1001     % NODE NO1001
-1.37933E-001-2.80459E-009 1.72767E-001 0.00000E+000 0.00000E+000 0.00000E+000
    -1
```

2.1.1 Grid

Several dated sets are used by the software of measurement to describe a grid. That presented here is the format used by LMS to export simple grids, only made up of nodes and lines connecting them. The nodes are described by dated set 2411, and connectivities by dated set 82 (example below).

```
   -1
  2411
         1         0         0         8
   0.000000000000000e+000   0.000000000000000e+000   0.000000000000000e+000
         2         0         0         8
   0.000000000000000e+000   1.199999973177910e-001   0.000000000000000e+000
         3         0         0         8
   0.000000000000000e+000   3.300000131130219e-001   0.000000000000000e+000

    -1
    -1
    82
         1        30         8
LDN
         1         2         3         0         0         0         0
    -1
```

The importation of the grid is done in Code_Aster with `PRE_IDEAS` . The description of dated sets 2411 and 82 is detailed in appendix 5.1 .

2.1.2 Rough temporal data, and FRF

It is possible to import the rough temporal data, or of the FRF in *Code_Aster*, in order to compare them with simulated data. These data are stored in the files unv under dated set 58. One gives below an example of this kind of dated set:

```
     -1
    58
FRF (H1-estimator)
answer/load
95-Oct.-12 11:52: 48
Alternate/identified FRF"
NUN
    0         4    0       139       NUN      1011   3       NUN        12  -3
         5      3124         1 4.00390e+000 1.95312e-002 0.00000e+000
        18    0    0    0 Frequency            Hz
        12    1    0    0 Chanel 3(3)         m/s2
        13    0    1    0 Chanel 1(1)         NR
         0    0    0    0 Unknown              NUN
-1.33781e-001-5.07456e-003-1.31790e-001-5.19607e-003-1.29762e-001-5.32069e-003
-1.27699e-001-5.44850e-003-1.25597e-001-5.57962e-003-1.23458e-001-5.71414e-003
-1.21279e-001-5.85217e-003-1.19060e-001-5.99383e-003-1.16800e-001-6.13924e-003
-1.14497e-001-6.28851e-003-1.12151e-001-6.44177e-003-1.09760e-001-6.59917e-003
-1.07324e-001-6.76083e-003-1.04841e-001-6.92691e-003-1.02310e-001-7.09754e-003
```

The headers describe the type of data. Here, it is about a FRF “acceleration/force”, on the degree of freedom $1011:+Z$ compared to the reference $12:-Z$.
For more details, to see the reference material of dated set 58 in appendix 5.2 .

The use of `LIRE_RESU` in this case does not pose particular problems, and is described in the CAS-test sdls112a. To note:

- the structures of data created (temporal or frequential) are filled only for the DDL corresponding to the data read. That can generate structures of incomplete data, contrary to $data\ set 55$ in which all the degrees of freedom have a defined value,
- the definite structure of data uses a local frame of reference, with the components `D1` , `D2` , and `D3` , of which the orientations are given in the components `D1X` , `D1Y` , `D1Z` , `D2X` , `D2Y` … It is not possible to display the result in Salomé.
- For more details, to see the documentation of `LIRE_RESU` .

2.1.3 Bases of identified modes

The identified modes are stored in $dataset\,55$, which is dedicated to the fields with the nodes. In $dataset\,58$, each block corresponds to a function on a node (equivalent with a function in Aster), while in $dataset\,55$, each block corresponds to a field with the nodes (one `cham_no` in Aster).

```
    -1
    55   %VALEURS WITH THE NODES
ASTER  7.03.29 CONCEPT MODINTS1 CALC - FIELD WITH THE NODES OF REFERENCE SYMBOL
FIELD WITH THE NODES OF REFERENCE SYMBOL  DEPL - DX DY DZ DRX DRY MARTINI DRZ
ASTER  7.03.29 CONCEPT MODINTS1 CALCULATES THE 11/22/2004 AT 19:24: 57 OF TYPE
FIELD WITH THE NODES OF REFERENCE SYMBOL  DEPL
SEQUENCE NUMBER: 1 NUME_MODE: 1 FREQ:  2.18331E+01
         1         2         2         8         2         3
         2         4         1         1
 2.18331e+01  1.00000e+00  3.74657e-03
      1011     % NODE NO1011
-1.37933E-001 7.39432E-007 3.38287E-001
      1001     % NODE NO1001
-1.37933E-001-2.80459E-009 1.72767E-001
    -1
```

The detailed documentation of dated set is given in appendix 5.3 .
It is important to understand certain characteristics of this storage, because the data must be recalled to the call of `LIRE_RESU` . In particular:

- Record 6 $(1{,}2{,}2{,}8{,}2{,}3)$:
  - 1: field of the mechanics of the structures,
  - 2: a clean mode is described (“normal mode”)
  - 2: 3 degrees of freedom per node,
  - 8: field of displacement,
  - 2: real field (5 for complex),
  - 6: many columns of values
- Record 7 $(2{,}4{,}1{,}1)$:
  - 2.4: specific to the clean modes,
  - 1: loading case (1 by default),
  - 1, number of the mode
- Record 8: $2.18331e+01\;1.00000e+00\;3.74657e-03\;0.00000e+00$
  - $2.18331e+01$: Eigen frequency,
  - $1.00000e+00$: modal mass,
  - $3.74657e-03$: modal damping

The value of these lines is given in `LIRE_RESU`, as the example shows it below. That makes it possible in particular Aster to differentiate in a file unv the classical clean modes from the static residues which are often calculated by the software used.

```
MODMES=LIRE_RESU (TYPE_RESU=' MODE_MECA',
                  FORMAT=' IDEAS',
                  MODELE=MODEXP,
                  UNITE=21,
                  NOM_CHAM=' DEPL',
                  MATR_RIGI =KASSEXP,
                  MATR_MASS =MASSEXP,
                  FORMAT_IDEAS=_F (NOM_CHAM=' DEPL',
                                   NUME_DATASET=55,
                                   RECORD_6= (1,2,2,8,2,3,),
                                   POSI_ORDRE= (7.4,),
                                   POSI_NUME_MODE= (7.4),
                                   POSI_FREQ= (8.1,),
                                   POSI_MASS_GENE= (8.2),
                                   POSI_AMOR_GENE= (8.3),
                                   NOM_CMP= (‘DX’, ‘DY’, ‘DZ’),),
                  TOUT_ORDRE=' OUI',);
```

2.2 Creation of an experimental model in Code_Aster

The handling of experimental data in Code_Aster requires to create the structures of adequate data, with the formalism of the code. One must thus reproduce all the stages of creation of the model, until the assembly of the matrices which are used in LIRE_RESU (keywords MATR_RIGI and MATR_MASS in the example above).

2.2.1 Case general

In the case general, the nodes all are connected the ones to the others by linear elements SEG2. The orders to be connected are the following ones:

- importation and reading of the grid with PRE_IDEAS and LIRE_MAILLAGE ,
- assignment of a mechanical modeling of type DIS_T ; one could use a modeling DIS_TR if the field with reading would have 6 degrees of freedom by nodes (for example, if one is able to measure the degrees of freedom of rotation),
- assignment of geometrical characteristics in arbitrary mass and stiffness on the nodes and segments with AFFE_CARA_ELEM ,
- assembly of the matrices with ASSEMBLY ,
- reading of the data with LIRE_RESU .

Example: CAS-test sdls112a, slightly modified in order not to take into account the orphan nodes.

```
PRE_IDEAS (UNITE_IDEAS=32, UNITE_MAILLAGE=22);

MAYAEXP=LIRE_MAILLAGE (UNITE=22);

MAYAEXP=DEFI_GROUP (reuse =MAYAEXP,
                   MAILLAGE=MAYAEXP,
                   CREA_GROUP_MA=_F (NOM=' ALL_EXP', TOUT=' OUI',),
                   CREA_GROUP_NO=_F (GROUP_MA=' ALL_EXP',),);

MODEXP=AFFE_MODELE (MAILLAGE=MAYAEXP,
                   AFFE=_F (GROUP_MA=' ALL_EXP',
                           PHENOMENE=' MECANIQUE',
                           MODELISATION=' DIS_T',),);

CHCAREXP=AFFE_CARA_ELEM (MODELE=MODEXP,
                        DISCRET= (_F (GROUP_MA=' ALL_EXP',
                                   CARA=' K_T_D_L',
                                   VALE= (1.0, 1.0, 1.0,),),
                                  _F (GROUP_MA=' ALL_EXP',
                                   REPERE=' GLOBAL',
                                   CARA=' M_T_D_L',
                                   VALE= (1.0,),),),);

ASSEMBLY (     MODELE=MODEXP,
                CARA_ELEM=CHCAREXP,
                NUME_DDL=CO ('NUMEXP'),
                MATR_ASSE= (_F (MATRICE=CO ('KASSEXP'),
                              OPTION=' RIGI_MECA',),
                           _F (MATRICE=CO ('MASSEXP'),
                              OPTION=' MASS_MECA',),),);

MODMES=LIRE_RESU (TYPE_RESU=' MODE_MECA',
                 FORMAT=' IDEAS',
                 MODELE=MODEXP,
                 UNITE=32,
                 NOM_CHAM=' DEPL',
                 MATR_RIGI =KASSEXP,
                 MATR_MASS =MASSEXP,
                 FORMAT_IDEAS=_F (NOM_CHAM=' DEPL',
                                 NUME_DATASET=55,
                                 RECORD_6= (1,2,2,8,2,3),
                                 POSI_ORDRE= (7.4,),
                                 POSI_NUME_MODE= (7.4),
                                 POSI_FREQ= (8.1,),
                                 POSI_MASS_GENE= (8.2),
                                 POSI_AMOR_GENE= (8.3),
                                 NOM_CMP= ('DX', 'DY', 'DZ'),),
                 TOUT_ORDRE=' OUI',);
```

Some advices and traps to be avoided:

- The order of the components (keyword NOM_CMP) in LIRE_RESU is not obligatory; it is possible to make a simple change of reference mark (similar for all the nodes) by choosing the order of the components judiciously.
- Attention with the keyword RECORD_6 , this one can vary; it is in particular the case when the file unv was created by *Code_Aster* itself. Indeed, it can happen that the data are printed on 6 columns, if the user printed his data on a modeling DIS_TR . The 3 last columns contain the degrees of freedom of rotation. It is the case in the CAS-test sdls112a. One can read again only the three first if the experimental model have only 3 degrees of freedom per node.
- It is possible to read data resulting from gauges of deformation. In this case,
  - NOM_CHAM=' EPSI_NOEU' ,
  - NOM_CMP= ('EPXX', 'EPYY'…) to choose according to the reference mark used.
  - To compare these data with numerical data, one will be able to use the macro-order OBSERVATION .

2.2.2 Case of the orphan nodes

It is not advised to use orphan nodes in the grid, because the associated fields are difficult to visualize in Salomé. One can nevertheless read experimental data on these nodes, on condition that their applying a specific modeling of specific type (POI1).
The case is treated in the CAS-test sdls112a.

```
MAYAEXP=CRÉA_MAILLAGE (MAILLAGE=MAYAtmp,
                      CREA_POI1=_F (TOUT=' OUI', NOM_GROUP_MA=' NOEU'),)


MODEXP=AFFE_MODELE (MAILLAGE=MAYAEXP,
                   AFFE=_F (GROUP_MA=' NOEU',
                           PHENOMENE=' MECANIQUE',
                           MODELISATION=' DIS_T',),);

CHCAREXP=AFFE_CARA_ELEM (MODELE=MODEXP,
                        DISCRET= (_F (GROUP_MA=' NOEU',
                                     REPERE=' GLOBAL',
                                     CARA=' K_T_D_N',
                                     VALE= (1.0, 1.0, 1.0,),),
                                  _F (GROUP_MA=' NOEU',
                                     REPERE=' GLOBAL',
                                     CARA=' M_T_D_N',
                                     VALE= (1.0,),),),);
```

3 Validation of model per criterion of MAC

3.1 What MAC?

MAC, Modal Criterion Insurance, is a criterion ranging between 0 and 1 giving the colinearity between two modes compared to a given standard.

$$MAC_{ij}=\frac{\left(\Phi_i^H W \Phi_j\right)^2}{\left(\Phi_i^H W \Phi_i\right)\left(\Phi_j^H W \Phi_j\right)}$$

The use of the matrices of weighting (W in the formula) is optional. When they are known, one can use the matrices of mass or stiffness of the model. It is the case when numerical data are handled, because the matrices were assembled on the model. It makes it possible to check the orthogonality of the clean modes compared to the matrices of mass and stiffness:

- $MAC_{ij}=1\, si\; i=j$
- $MAC_{ij}=0\, sinon$

But when experimental data are handled, one does not know the matrices condensed on this model. One can manufacture them by condensation of Guyan starting from the digital model, but this one not being readjusted, one is likely to make a mistake.

One can, more simply, to calculate MAC without matrix of weighting, and to look at the colinearity of the modes on the standard L_2 .

- If the objective is to check the orthogonality of the base, one can consider, at first approximation, that MAC without matrix of weighting is rather similar to MAC balanced by the matrix of mass,
- If the objective is to compare two bases of modes between them, then, the choice of this standard is equivalent to the different one: MAC will be worth 1 if the modes are colinéaires (thus if they “resemble each other”) and 0 if not.

NB: the use of MAC on experimental modes in particular makes it possible to check the capacity of the sensors to separate the modes. Indeed, more there are sensors, more the modes “will look various” seen those. MAC of two correctly identified different modes will be thus close to 0. If there is only one sensor, then MAC between two modes will always be worth 1: the modes are not separable.

3.2 Projection of fields

3.2.1 Projection of the numerical data on the experimental model with `PROJ_CHAMP`

The modes are comparable only if they are defined on the same model. One thus projects the digital base of modes, calculated with *Code_Aster* , on the experimental model, with the order `PROJ_CHAMP` .

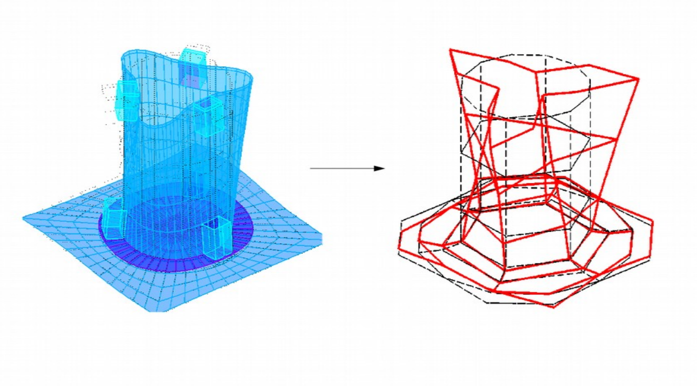

Image 3.2-1: projection of data.

Note:

- Important note: it is necessary to specify, in `PROJ_CHAMP` , the name of `NUME_DDL` experimental model, so that classifications of the experimental modes and projected digital modes are the same ones.
  - If it `NUME_DDL` is not the same one, one will not be able to calculate criterion of MAC.
- In `PROJ_CHAMP` , it is necessary to specify the dimension on which one projects: by default, one will associate the nodes of the experimental model with elements 3D of the digital model.
  - If the digital model consists of elements of plate, it should be specified with `CAS=' 2.5D'` ,
  - If the digital model is composed of elements 3D and 2D, then it is not possible to specify several types of projections. A suggested solution is to affect a modeling of plate (`DKT` for example) with the elements of skin which recover the elements 3D and to place itself in the case `'2.5D'` .
- The operator `OBSERVATION` allows to carry out the same operation, with additional options:
  - use of local reference marks sensors by sensors,
  - suppression of data measured of structure of data result (for the cases where the mesure had been made with uniaxial sensors),
  - creation of a structure of mixed data including of the accelerometer and extensiometric data, to reproduce an accelerometers measurement + gauges,
  - simulation of a “virtual gauge”.
- The description of this operator is proposed in the following paragraph.

3.2.2 Use of the macro-order OBSERVATION for the projection of the data

One proposes to give a practical example of the use of the macro-order on the following case:

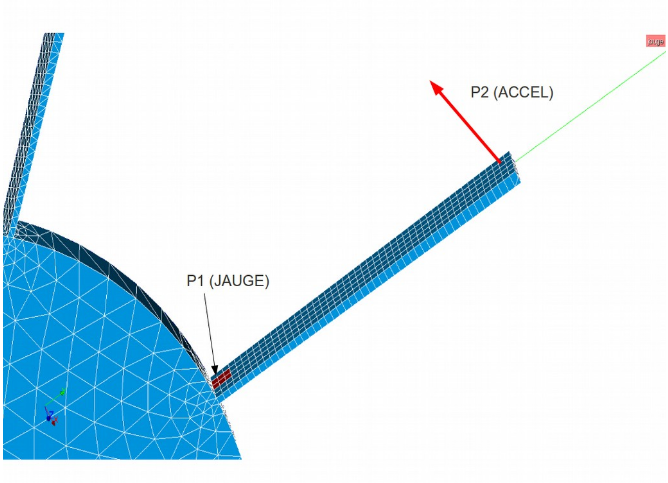

Image 3.2-2: measurement of the vibrations of one wing using a gauge and an accelerometer.

One supposes to have measured the vibrations of the aubagée wheel represented on the grid below by posing a gauge at the base of each wing and an accelerometer at the top. The identified clean modes are exported with the format unv **without passing to the total reference mark**. The vibrations at the top having been measured only in one direction, there will be a line of the form:

```
      2          4          1          1
2.18331e+01  1.00000e+00  3.74657e-03
      1         % NODE NO1
0.00000e+00  0.00000e+00  7.39432e-01
    -1
```

On the node $N01$, only the local component DZ was measured. The not measured directions are put at 0. It is not possible, in one dated set 55, to make the difference between not measured data and worthless measurements.
To compare the experimental data and the reduced digital clean modes, two operations are necessary:

- on the experimental data, one filters the modes so as to eliminate the not measured data, by keeping only one direction for the gauge and the accelerometer
  - one uses OBSERVATION without projection (PROJECTION=' NON'), because one does nothing but filter the data,

```
OBSMXT = OBSERVATION (  RESULT = MEASUREMENT,
                        MODELE_1 = MODMESUR,
                        MODELE_2 = MODMESUR,
                        PROJECTION = 'NOT',
                        TOUT_ORDRE = 'YES',
                        NOM_CHAM = ('DEPL', 'EPSI_NOEU',),
                        FILTER = (  _F (GROUP_NO = 'P1',
                                       NOM_CHAM = 'EPSI_NOEU',
                                       DDL_ACTIF = ('EPXX',),),
                                   _F (GROUP_NO = 'P2',
                                       NOM_CHAM = 'DEPL',
                                       DDL_ACTIF = ('DZ',),),),),);
```

- on the numerical data, one projects the clean modes on the experimental model:
  - one uses PROJECTION=' OUI' ,

- one calculates the average deformation for the group of nodes in red on the figure before carrying out projection: this surface corresponds to the surface actually measured by the gauge,
- one makes the changes of reference mark, by using the option 'NORMAL' : one calculates the normal with the digital grid to define the axis Z local reference mark (the second axis is defined with the keyword VECT_Y); here, one could also have used the option 'CYNLINDRIQUE' .
- one filters the components corresponding to the measured data.

```
OBSJAU = OBSERVATION (RESULT = CALCULATION,
                      MODELE_1 = MODNUME,
                      MODELE_2 = MODMESUR,
                      PROJECTION = 'YES',
                      TOUT_ORDRE = 'YES',
                      NOM_CHAM = 'EPSI_NOEU',
                      EPSI_MOYENNE =  _F (GROUP_MA=' SURF1', SEUIL_VARI= (0.1,),
                                          MASQUE= ('EPYY', 'EPZZ', 'EPXY',
                                                   'EPXZ', 'EPYZ'),),
                      MODI_REPERE = _F (GROUP_NO = ('P1', P2'),
                                        REFERENCE MARK = 'NORMAL',
                                        VECT_Y = (0. , 1. , 0.)),),
                      FILTER = (_F (GROUP_NO = 'P1',
                                    NOM_CHAM = 'EPSI_NOEU',
                                    DDL_ACTIF = ('EPXX'),),
                                _F (GROUP_NO = 'P2',
                                    NOM_CHAM = 'DEPL',
                                    DDL_ACTIF = ('DZ',),),),);
```

3.3 Calculation of MAC between two bases of modes

The calculation of MAC can be carried out with the operator MAC_MODES, which calculates the matrix of MAC between all the modes of two bases. The structure of data produced is a table, which one prints with INFO=2 in MAC_MODES.
The keyword MATR_ASSE allows to use a matrix of weighting.
The printed table has the following form:

```
 ASTER 11.01.03 CONCEPT MAC_ET CALCULATES THE 2/15/2012 AT 14:18: 54 OF TYPE
 TABLE_SDASTER
MAC                      ! NUME_MODE_1
                         !           1             2             3             4             5
--------------------------------------------------------------------------------------------
NUME_MODE_2            1!   1.00000E+00  2.17692E-14  7.49505E-16  5.23742E-22  1.66188E-21
                       2!   2.17692E-14  1.00000E+00  4.21440E-13  9.40269E-19  1.12652E-19
                       3!   7.49505E-16  4.21440E-13  1.00000E+00  7.24387E-18  1.28403E-17
                       4!   5.23742E-22  9.40269E-19  7.24387E-18  1.00000E+00  2.11012E-13
                       5!   1.66188E-21  1.12652E-19  1.28403E-17  2.11012E-13  1.00000E+00
```

One can visualize MAC produced in Excel, or use the macro-order CALC_ESSAI, which proposes a visualization in 2D. For that, throw the macro-order without keyword at the end of calculation, and to position on the mitre "expansion of models".

Image 3.3-1: Image 3.3-1: CALC_ESSAI: expansion of models.

Within the framework it low, to choose the two bases of modes to be compared (if only one of the two bases is selected, one will make MAC of the base by itself), and to click on MAC. If the selected bases are not defined on the same model, the MAC button is grayed.
The matrix of MAC which appears is the following one:

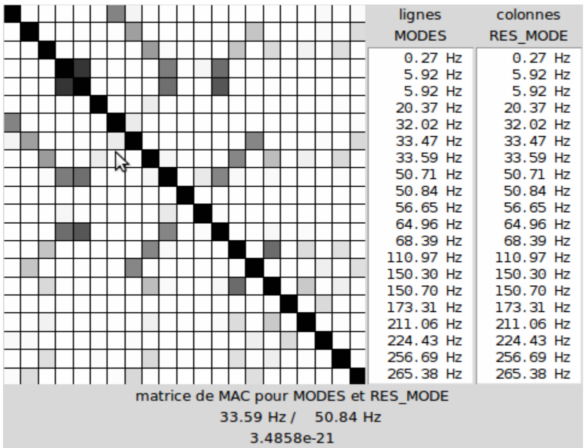

Image 3.3-2: MAC between two bases of modes visualized under CALC_ESSAI.

While passing the mouse on the boxes, one sees in bottom the frequencies of the modes concerned and the value of MAC for the latter.

NB: in appendix 5.4, one proposes a script using the library python matplotlib allowing to create diagrams of MAC in 3D more easily interpretable than that implemented by default in `CALC_ESSAI`. Later on, one studies feasibility to integrate MAC 3D by default into the operator.

4 Other methods of validation

4.1 Validation by visual comparison of modal deformations

This mode of validation is most direct. It can be done by printing in a classical way the modal deformations in Salomé.

NB: in CALC_ESSAI, in the mitre “Expansion of models”, it is possible to select one or two bases (opposite “Result 1” and “Result 2”) and to visualize them in GMSH while clicking on “Deformations”. It is not possible to currently visualize the deformations in Salomé, this development must be carried out in 2012 (by adding the possibility of superimposing the deformations).

4.2 Validation by comparison of FRF

One proposes a procedure in CALC_ESSAI allowing to compare a FRF resulting from measurement with a FRF simulated by blow of hammer. This method of validation is different, because the comparison is done on a point of measurement at the same time, but on a wide waveband. She makes it possible to check the validity even modal model.
For that, to click on “FRF” in the mitre “Expansion of models”. The following window appears:

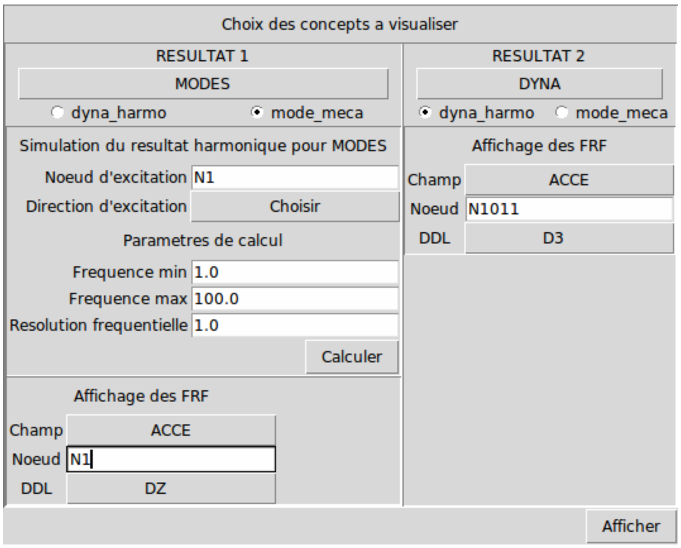

Image 4.2-1: simulations of FRF in CALC_ESSAI.

One can select on a side a concept of the modes type and simulate a FRF, and visualize other side a measured experimental FRF. By displaying the curves, one can obtain the following graph, product in XMGrace:

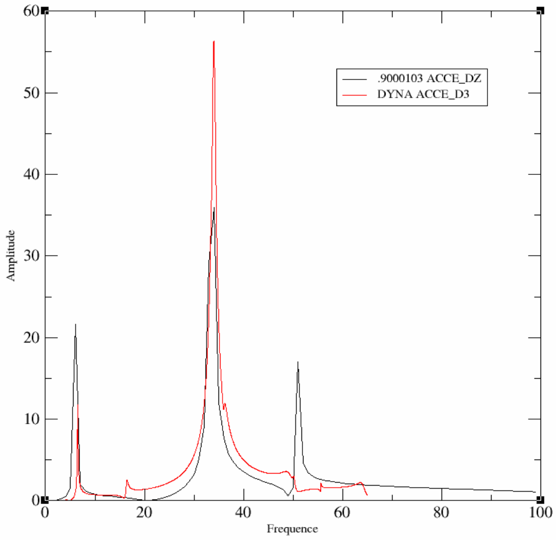

Image 4.2-2: posting of FRF in XMGrace.

5 Appendix

5.1 Documentation unv on went back set to grid

Set 2411 dated: description of the nodes:

```
Name:   Nodes - Double precision
Status: Current
Owner:  Simulation
Revision Dates: 23-OCT-1992
----------------------------------------------------------------------------
 Record 1:        FORMAT (4I10)
                 Field 1       -- node label
                 Field 2       -- export coordinate system number
                 Field 3       -- displacement coordinate system number
                 Field 4       -- color
Record 2:        FORMAT (1P3D25.16)
                 Fields 1-3    -- node coordinates in the share coordinate
                                  system

Records 1 and 2 are repeated for each node in the model.

Example:

    -1
  2411
       121         1         1        11
   5.0000000000000000D+00   1.0000000000000000D+00   0.0000000000000000D+00
       122         1         1        11
   6.000000000
```

Set 82 dated: description of connectivities : this set dated is used more only in the very particular cases of experimental grids. The elements are more generally described by dated set 2412.

```
Name:   Tracelines
Status: Obsolete
Owner:  Simulation
Revision Dates: 27-Aug-1987
Additional Comments:  This dataset is written by I-DEAS Test.
-----------------------------------------------------------------------

             Record 1: FORMAT (3I10)
                       Field 1 -    trace line number
                       Field 2 -    number of nodes defining trace line
                                    (maximum of 250)
                       Field 3 -    color

             Record 2: FORMAT (80A1)
                       Field 1 -    Identification line

             Record 3: FORMAT (8I10)
                       Field 1 -    nodes defining trace line
                               =    > 0 Draw line to node
                               =    0 move to node (has move to the first
                                    node is implied)
             Notes: 1) MODAL-PLUS node numbers must not exceed 8000.
                    2) Identification line may not Be blank.
                    3) Systan only use the first 60 characters of the
                       identification text.
                    4) MODAL-PLUS does not support traces lines to skirt than
                       125 nodes.
                    5) Supertab only use the first 40 characters of the
                       identification line for has name.
                    6) Repeat Datasets for each Trace_Line
```

Set 2412 dated: description of the elements (classical model EF):

```
Name:   Elements
Status: Current
```

```
Owner:  Simulation
Revision Dates: 14-AUG-1992
-----------------------------------------------------------------------

Record 1:        FORMAT (6I10)
                 Field 1       -- element label
                 Field 2       -- Fe descriptor id
                 Field 3       -- physical property table number
                 Field 4       -- material property table number
                 Field 5       -- color
                 Field 6       -- number of nodes one element

Record 2:  *** FOR NON-BEAM ELEMENTS ***
                 FORMAT (8I10)
                 Fields 1-n    -- node labels defining element

Record 2:  *** FOR BEAM ELEMENTS ONLY ***
                 FORMAT (3I10)
                 Field 1       -- beam orientation node number
                 Field 2       -- beam drills-end cross-country race section number
                 Field 3       -- beam  aft-end cross-country race section number

Record 3:  *** FOR BEAM ELEMENTS ONLY ***
                 FORMAT (8I10)
                 Fields 1-n    -- node labels defining element

Records 1 and 2 are repeated for each non-beam element in the model.
Records 1 - 3 are repeated for each beam element in the model.

Example:

    -1
  2412
         1        11         1      5380         7         2
         0         1         1
         1         2
         2        21         2      5380         7         2
         0         1         1
         3         4
         3        22         3      5380         7         2
         0         1         2
         5         6
         6        91         6      5380         7         3
        11        18        12
         9        95         6      5380         7         8
        22        25        29        30        31        26        24        23
        14       136         8         0         7         2
        53        54
        36       116        16      5380         7        20
       152       159       168       167       166       158       150       151
       154       170       169       153       157       161       173       172
       171       160       155       156
     -1
```

5.2 Reference material on dated set 58

```
Number: 58
Name:   Function Nodal At DOF
Status: Current
Owner:  Test
Revision Dates: 23-Apr-1993
-----------------------------------------------------------------------

         Record 1:     Format (80A1)
                       Field 1    - ID Line 1

                                                 NOTE

                           ID Line 1 is generally  used  for  the  function
                           description.


         Record 2:     Format (80A1)
                       Field 1    - ID Line 2
```

```
Record 3:      Format (80A1)
               Field 1    - ID Line 3

                                        NOTE

                   ID Line 3 is generally used to identify when the
                   function  was  created.  The dates is in the forms
                   DD-MMM-YY, and the time is in the forms HH: MM: SS,
                   with has general Format (9A1,1X, 8A1).


Record 4:      Format (80A1)
               Field 1    - ID Line 4

Record 5:      Format (80A1)
               Field 1    - ID Line 5

Record 6:      Format (2 (I5, I10), 2 (1X, 10A1, I10, I4))
                          DOF Identification
               Field 1    - Standard Function
                            0 - General gold Unknown
                            1 - Time Answer
                            2 - Spectrum car
                            3 - Spectrum cross-country race
                            4 - Frequency Function Answer
                            5 - Transmissibility
                            6 - Coherence
                            7 - Car Correlation
                            8 - Cross-country race Correlation
                            9 - Spectral Power Density (PSD)
                            10 - Spectral Energy Density (ESD)
                            11 - Probability Density Function
                            12 - Spectrum
                            13 - Cumulative Frequency Distribution
                            14 - Peaks Valley
                            15 - Stress/Cycles
                            16 - Strain/Cycles
                            17 - Orbit
                            18 - Mode Indicator Function
                            19 - Pattern force
                            20 - Partial Power
                            21 - Partial Coherence
                            22 - Eigenvalue
                            23 - Eigenvector
                            24 - Shock Spectrum Answer
                            25 - Finite Impels Filter Answer
                            26 - Multiple Coherence
                            27 - Order Function
               Field 2    - Function Number Identification
               Field 3    - Number version, gold sequence number
               Field 4    - Load Puts Number Identification
                            0 - Individual Point Excitation
               Field 5    - Answer Entity Name (“NUN” yew unused)
               Field 6    - Node answer
               Field 7    - Answer Direction
                             0 - Scalar
                             1 - +X Translation       4 - +X Rotation
                            -1 - - X Translation      -4 - - X Rotation
                             2 - +Y Translation       5 - +Y Rotation
                            -2 - There Translation      -5 - There Rotation
                             3 - +Z Translation       6 - +Z Rotation
                            -3 - - Z Translation      -6 - - Z Rotation
               Field 8    - Reference Entity Name (“NUN” yew unused)
               Field 9    - Node reference
               Field 10   - Reference Direction  (same ace field 7)

                                        NOTE

                   Fields 8.9, and 10 are only depending yew field 4
                   is zero.


Record 7:      Format (3I10,3E13.5)
                          Dated Forms
               Field 1    - Ordinate Dated Standard
```

```
                                    2 - real, individual precision
                                    4 - real, double precision
                                    5 - complex, individual precision
                                    6 - complex, double precision
                       Field 2    - Number of dated even for uneven  abscissa
                                        spacing, but number of dated been worth for
even
                                    abscissa spacing
                       Field 3    - Abscissa Spacing
                                    0 - uneven
                                    1 - even (been worth No abscissa stored)
                       Field 4    - Minimum Abscissa (0.0 yew spacing uneven)
                       Field 5    - Abscissa increment (0.0 yew spacing uneven)
                       Field 6    - Z-axis been worth (0.0 yew unused)

         Record 8:     Format (I10,3I5,2 (1X, 20A1))
                                  Abscissa Dated Characteristics
                       Field 1    - Specific Dated Standard
                                    0 - unknown
                                    1 - general
                                    2 - stress
                                    3 - strain
                                    5 - temperature
                                    6 - heat flow
                                    8 - displacement
                                    9 - reaction forces
                                    11 - velocity
                                    12 - acceleration
                                    13 - excitation forces
                                    15 - press
                                    16 - farmhouse
                                    17 - time
                                    18 - frequency
                                    19 - rpm
                                    20 - order
                       Field 2    - Length units exponent
                       Field 3    - Force units exponent
                       Field 4    - Temperature units exponent

                                                 NOTE

                           Fields 2.3 and  4  are  raising  only  yew  the
                           Specific Dated Standard is General, gold in the box of
                           ordinates, the answer/reference direction has
                           scalar, but the functions are being used for
                           nonlinear connectors in System Dynamics Analysis.
                           See Addendum 'with' for the units exponent table.

                       Field 5    - Axis label ("NUN" yew not used)
                       Field 6    - Axis units label ("NUN" yew not used)

                                                 NOTE

                           Yew fields  5  and  6  are  supplied,  they  take
                           precendence  over  program  generated labels and
                           units.

         Record 9:     Format (I10,3I5,2 (1X, 20A1))
                       Ordinate (gold ordinate numerator) Dated Characteristics

         Record 10:    Format (I10,3I5,2 (1X, 20A1))
                       Ordinate Denominator Dated Characteristics

         Record 11:    Format (I10,3I5,2 (1X, 20A1))
                       Z-axis Dated Characteristics

                                                 NOTE

                           Records 9.10, and 11 are  always  included  and
                           cut fields the same ace record 8.  Yew records 10
                           and 11 are not used, set field 1 to zero.

         Record 12:
                                   Dated Been worth

                         Ordinate            Abscissa
```

```
  Box     Type     Precision     Spacing       Format
-------------------------------------------------------------
    1      real      individual        even         6E13.5
    2      real      individual       uneven        6E13.5
    3     complex    individual        even         6E13.5
    4     complex    individual       uneven        6E13.5
    5      real      double        even         4E20.12
    6      real      double       uneven     2 (E13.5, E20.12)
    7     complex    double        even         4E20.12
    8     complex    double       uneven      E13.5, 2E20.12
--------------------------------------------------------------

                              NOTE

  See  Addendum  'B'  for  typical  FORTRAN   READ/WRITE
  statements for each box.


General Notes:

     1.  ID lines may not Be blank.  Yew No  information  is  required,
         the Word "NUN" must appear in columns 1 through 4.

     2.  ID line 1 appears one studs in Finite Element Modeling and is
         used ace the function description in System Dynamics Analysis.

     3.  Dataloaders uses the following ID line conventions
            ID Line 1 - Model Identification
            ID Line 2 - Run Identification
            ID Line 3 - Run Dates and Time
            ID Line 4 - Load Puts Name

     4.  Coordinates codes from MODAL-PLUS and MODALX are decoded into
         node and direction.

     5.  Entity names used in System Dynamics Analysis prior to I-DEAS
         Level 5 cuts has 4 character maximum. Beginning with Level 5,
         entity names will Be ignored yew this dataset is preceded by
         dataset 259. Yew No dataset 259 precede this dataset, then the
         entity name will Be assumed to exist in model bin number 1.

     6.  Record 10 is ignored by System Dynamics Analysis unless load
         box = 0. Record 11 is always ignored by System Dynamics
         Analysis.

     7.  In record 6, yew the answer gold reference names are "NUN"
         and are not overridden by has dataset 259, goal the corresponds
         ing node is non-zero, System Dynamics Analysis adds the node
         and direction to the function description yew space is sufficie

     8.  ID line 1 appears one XY studs in Test Dated Analysis along
         with ID line 5 yew it is defined.  Yew defined, the axis units
         labels also appear one the XY normal stud instead of the
         labeling based one the dated standard of the function.

     9.  For functions used with nonlinear connectors in System
         Dynamics Analysis, the following requirements must Be
         adhered to:

         a) Record 6: For has displacement-depend function, the
            standard function must Be 0; for has frequency-depend
            function, it must Be 4. In either box, the load box
            identification number must Be 0.

         b) Record 8: For has displacement-depend function, the
            specific dated standard must Be 8 and the length units
            exponent must Be 0 gold 1; for has frequency-depend
            function, the specific dated standard must Be 18 and the
            length units exponent must Be 0. In either box, the
            other units exponents must Be 0.

         c) Record 9: The specific dated standard must Be 13. The
            temperature units exponent must Be 0. For year ordinate
            numerator of force, the length and force units
            exponents must Be 0 and 1, respectively. For year
            ordinate numerator of moment, the length and force
```

```
                     units exponents must Be 1 and 1, respectively.

                  d) Record 10: The specific dated standard must Be 8 for
                     stiffness and hysteretic damping; it must Be 11
                     for viscous damping. For year ordinate denominator of
                     translational displacement, the length units exponent
                     must Be 1; for has rotational displacement, it must
                     Be 0. The other units exponents must Be 0.

                  e) Dataset 217 must precedes each function in order to
                     define the function' S use (i.e stiffness, viscous
                     damping, hysteretic damping).
```

5.3 Reference material on dated set 55

```
Name:   At Nodes dated
Status: Obsolete
Owner:  Simulation
Revision Dates: 07-Mar-1997
Additional Comments: This dataset is written and read by I-DEAS Test.
-----------------------------------------------------------------------

          RECORD 1:      Format (40A2)
               FIELD 1:          ID Line 1

          RECORD 2:      Format (40A2)
               FIELD 1:          ID Line 2

          RECORD 3:      Format (40A2)

               FIELD 1:          ID Line 3

          RECORD 4:      Format (40A2)
               FIELD 1:          ID Line 4

          RECORD 5:      Format (40A2)
               FIELD 1:          ID Line 5

          RECORD 6:      Format (6I10)

          Dated Parameters Definition

               FIELD 1: Standard Model
                            0:   Unknown
                            1:   Structural
                            2:   Heat Transfer
                            3:   Fluid Flow

               FIELD 2:  Standard Analysis
                            0:   Unknown
                            1:   Static
                            2:   Normal Mode
                            3:   Complex eigenvalue first order
                            4:   Transient
                            5:   Frequency Answer
                            6:   Buckling
                            7:   Complex eigenvalue second order

               FIELD 3:  Characteristic dated
                            0:   Unknown
                            1:   Scalar
                            2:   3 Total DOF Translation
                                 Vector
                            3:   6 Total DOF Translation
                                 & Vector Rotation
                            4:   Total Symmetric Tensor
                            5:   General Total Tensor


               FIELD 4: Specific Dated Standard
                            0:   Unknown
                            1:   General
                            2:   Stress
```

```
                         3:   Strain (Engineering)
                         4:   Element Forces
                         5:   Temperature
                         6:   Heat Flow
                         7:   Strain Energy
                         8:   Displacement
                         9:   Reaction Forces
                         10:   Kinetic Energy
                         11:   Velocity
                         12:   Acceleration
                         13:   Strain Energy Density
                         14:   Kinetic Energy Density
                         15:   Hydro-Static Presses
                         16:   Heat Gradient
                         17:   Checking code Been worth
                         18:   Coefficient Of Pressure

               FIELD 5:  Dated Standard
                         2:   Real
                         5:   Complex

               FIELD 6:  Number Of Data Been worth Per Node (NDV)


          Records 7 And 8 Are Standard Analysis Specific

          General Forms

          RECORD 7:      Format (8I10)

               FIELD 1:          Number Of Integer Dated Been worth
                         1 < Gold = Nint < Gold = 10
               FIELD 2:          Number Of Real Data Values
                         1 < Gold = Nrval < Gold = 12
               FIELDS 3-N:       Type Specific Integer Parameters


          RECORD 8:      Format (6E13.5)
               FIELDS 1-N:       Type Specific Real Parameters


          Standard For Analysis = 0, Unknown

          RECORD 7:

               FIELD 1:   1
               FIELD 2:   1
               FIELD 3:   ID Number

          RECORD 8:

               FIELD 1:   0.0

          Standard For Analysis = 1, Static

          RECORD 7:
               FIELD 1:    1
               FIELD 2:    1
               FIELD 3:    Load Puts Number

          RECORD 8:
               FIELD 11:    0.0

          For Analysis Standard = 2, Normal Mode


         RECORD 7:

               FIELD 1:    2
               FIELD 2:    4
               FIELD 3:    Load Puts Number
               FIELD 4:    Number mode

          RECORD 8:
               FIELD 1:    Frequency (Hertz)
               FIELD 2:    Modal Farmhouse
```

```
          FIELD 3:    Modal Viscous Damping Ratio
          FIELD 4:    Modal Hysteretic Damping Ratio

     Standard For Analysis = 3, Complex Eigenvalue

     RECORD 7:
          FIELD 1:    2
          FIELD 2:    6
          FIELD 3:    Load Puts Number
          FIELD 4:    Number mode

     RECORD 8:

          FIELD 1:    Real Part Eigenvalue
          FIELD 2:    Imaginary Leaves Eigenvalue
          FIELD 3:    Real Part Of Modal A
          FIELD 4:    Imaginary Leaves Of Modal A
          FIELD 5:    Real Part Of Modal B
          FIELD 6:    Imaginary Leaves Of Modal B


     Standard For Analysis = 4, Transient

     RECORD 7:

          FIELD 1:    2
          FIELD 2:    1
          FIELD 3:    Load Puts Number
          FIELD 4:    Time Step Number

     RECORD 8:
          FIELD 1: Time (Seconds)


     Standard For Analysis = 5, Frequency Answer

     RECORD 7:

          FIELD 1:    2
          FIELD 2:    1
          FIELD 3:    Load Puts Number
          FIELD 4:    Frequency Step Number

     RECORD 8:
          FIELD 1:    Frequency (Hertz)

     Standard For Analysis = 6, Buckling

     RECORD 7:

          FIELD 1:    1
          FIELD 2:    1
          FIELD 3:    Load Puts Number

     RECORD 8:

          FIELD 1: Eigenvalue

     RECORD 9:      Format (I10)

          FIELD 1:          Node Number

     RECORD 10:     Format (6E13.5)
          FIELDS 1-N:       At This Node (NDV Real Or dated
                    Been worth Complex)

     Records 9 And 10 Are Repeated For Each Node.
```

5.4 Script for the representation 3D of a diagram of MAC

This script can be recopied in bottom of a command file, by replacing the names $B1$ and $B2$ on the last line by the names of the two bases which one wishes to compare by MAC.

Caution: this script is pressed on the library `matplotlib` who must be installed.

```
def mac_plot_lib (BASE1, BASE2):
    """ calculates mac between two bases, the extract and represents it in a graph 3D
        matplotlib """
    __MAC=MAC_MODES (BASE_1=BASE1,
                    BASE_2=BASE2);

    mactmp=__MAC.EXTR_TABLE ()
    mac = mactmp ['NUMÉRIQUE_MODE_1', 'NUMÉRIQUE_MODE_2', 'MAC']. Cross ()
    mac_py = mac.values ()

    importation numpy ace Np
    from mpl_toolkits.mplot3d importation axes3d
    importation matplotlib.pyplot ace plt

    freq_1 = BASE1.LISTE_PARA () ['FREQ']
    freq_2 = BASE2.LISTE_PARA () ['FREQ']
    nume_ordre_1 = BASE1.LISTE_PARA () ['NUMÉRIQUE_ORDRE']
    nume_ordre_2 = BASE2.LISTE_PARA () ['NUMÉRIQUE_ORDRE']
    nb_freq_1 = len (freq_1)
    nb_freq_2 = len (freq_2)
    matrice_mac = np.transpose (np.array ([mac_py [kk] for kk in nume_ordre_1]))

    fig = plt.figure ()
    ax = axes3d. Axes3D (fig)

    # Create regular mesh from coordinates
    xpos, ypos = np.meshgrid (np.arange (nb_freq_1), arranges (nb_freq_2))
    xpos = xpos + 0.5* (np.ones (matrice_mac.shape) - matrice_mac)
    ypos = ypos + 0.5* (np.ones (matrice_mac.shape) - matrice_mac)
    xpos = xpos.flatten ()
    ypos = ypos.flatten ()
    dx = matrice_mac.flatten ()
    Dy = dx.copy ()
    dz = dx.copy ()
    zpos=np.zeros (nb_freq_1*nb_freq_2)

    for kk in arranges (len (xpos)):
        yew dx [kk] <1.0E-6:
            # to avoid plantings in the event of too small mac
            dx [kk] =dy [kk] =dz [kk] =1.0E-6
        ax.bar3d (xpos [kk], ypos [kk], zpos [kk],
                 dx [kk], Dy [kk], dz [kk],
                 color=mac2col (dz [kk]))

    ax.set_xlabel (u' FREQ_I')
    ax.set_ylabel (u' FREQ_J')
    ax.set_zlabel (u' MAC')
    plt.show ()


def mac2col (been worth):
    # gives the value of the color corresponding has a value of MAC
    # ranging between 0 and 1
    importation matplotlib.colors ace colors
    importation matplotlib.cm ace cm
    been worth = 1-been worth
    desc=cm.RdYlBu. _segmentdata
    segments= [desc ['blue'] [kk] [0] for kk in arranges (len (desc ['blue']))]
    num_seg=0
    for kk in segments:
        yew been worth > kk:
            num_seg = num_seg+1
    tri= (desc ['red'] [num_seg] [1],
         desc ['green'] [num_seg] [1],
         desc ['blue'] [num_seg] [1])
    return colors.rgb2hex (tri)


mac_plot_lib (B1, B2)
```

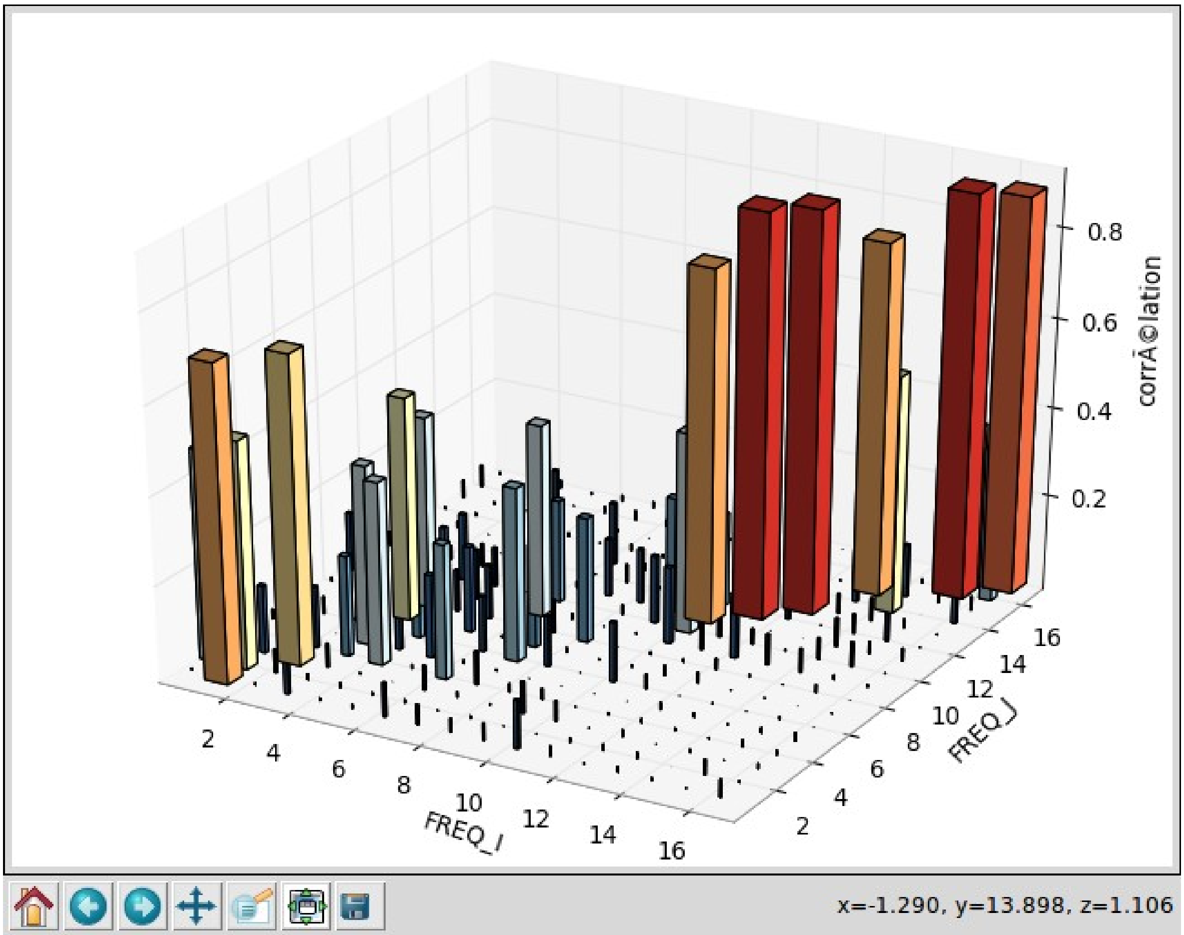

Image 5.4-1: MAC 3D.