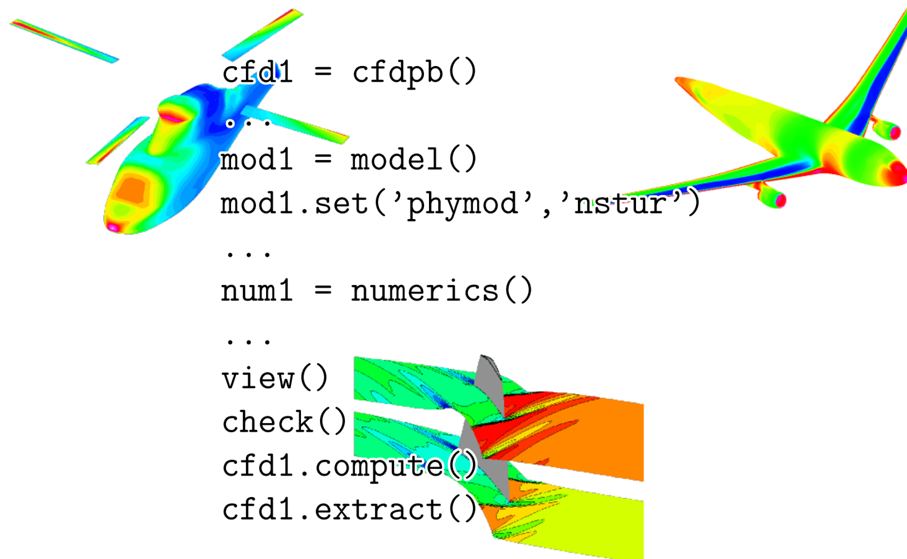
User's Starting Guide



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1. INTRODUCTION

1.1 What is *elsA*?

elsA is a software simulation tool developed by ONERA since 1997, and in collaboration with CERFACS since 2000.
elsA solves the compressible, Reynolds-averaged, Navier-Stokes (RANS) equations [1], in integral form, in fixed or moving reference frames. Turbulence is modeled by either algebraic or transport equation models [2]. Numerical procedure is based on a finite-volume conservative formulation on block-structured meshes. Both steady and unsteady simulations can be performed.
elsA users can interact with *elsA* in two ways:

- through a high-level scripting interface, built upon Python, one of the best scripting language out there. This guide aims to provide newcomers with the basics required to run their first simulation;

- through a Graphical User Interface (GUI), called PyG*elsA*, *not described in the present document*.

To run a simulation, several steps must be taken:

1. first, a full description of the problem is required; this amounts to:
   - discretise the computational space (sections 2.3 and 2.4),
   - specify the boundary conditions, both in space (section 2.4.2) and time (section 2.4.3),
   - specify the physical model (section 2.5),
   - specify the numerical algorithm (section 2.6);

2. run the simulation (section 2.7);

3. extract useful information from the computation, for example convergence residuals, lift, or Mach number distribution (section 2.8).

These three steps are detailed in the present document. A very simple concrete valid script, illustrating the basic ingredients included in any *elsA* scripts, is presented at the end of this introductory chapter (1.8).

[1] Neglecting viscosity, Navier-Stokes equations degenerate to Euler equations.
[2] In addition to RANS, LES and DES formulation are also available.

1.2 What's in this document?

Exhaustive rules and conventions governing how to write a valid Python script file to interact with *elsA* are specified in the *elsA* User's Reference Manual. Since *elsA* scope is very large, going from low subsonic to hypersonic flow regimes, with sophisticated physical and numerical modeling, it is understandable that the User's Reference Manual can be quite difficult to use by newcomers. The reader can get a good idea of the very large number of options by browsing through the *elsA* Validation Base (EVB)[3].
However, to get started with *elsA*, it is not necessary for newcomers to be aware of all the many technical details. The primary purpose of this guide is thus *to reduce the learning time* of the *elsA* system. In the following sections, we give detailed instructions on how to create *typical* *elsA* script files or portions of files. These instructions are given in the form of simple examples. Hopefully, users should be able to easily extend these simple examples to their own applications.
Chapter 2 covers the basics that most users need to learn in order to get started using *elsA*. Chapter 3 covers multi-zone treatment. Normalization and units issues are discussed in Chapter 4. The mechanism of default values is explained in Chapter 5. Many additional information are covered in Chapter 6 and Chapter 7; these issues are felt to be important, but not as crucial as the basic items covered in Chapter 2. Specific information concerning *elsA* on parallel platforms are given in chapter 8. Chapters 9 and 10 briefly cover troubleshooting and frequently asked questions, respectively.

1.3 Who should read this document?

Every one wanting to use *elsA* seriously must read this document. However, please note that:

- this document is not an introduction to Computational Fluid Dynamics (CFD): see the *elsA* Theoretical Handbook or any standard CFD textbook for such an introduction;
- we will *not* describe all functions of *elsA* in this guide, because some of them are only required for special applications; nor we will explain every parameter in detail; please refer to *elsA* User's Reference Manual for such kind of information.

1.4 More information

Other information about *elsA* can be found in the following places:

- *elsA* User's Reference Manual provides a complete description of all *elsA* features;

[3] `http://elsa.onera.fr/elsA/validation/valid.html`

- *elsA* Graphical User Interface is described in another document [4];
- *elsA* installation is covered in the *elsA* Development Process Tutorial (/ELSA/MDEV-03036);
- many additional information, including how to contact *elsA* support team, may be found at *elsA* WEB site: `http://elsa.onera.fr`.

Also, we strongly advise readers to consult the EVB, which contains more than 100 carefully validated test cases: instead of starting from scratch, it is often a better idea to start from an existing valid script, as close as possible to the planned computation, and then to customize it to the specific computation to be performed. You can consult EVB scripts:

- browsing the URL: `http://elsa.onera.fr/elsA/validation/valid.html`
- a very basic script is available at `http://elsa.onera.fr/elsA/use/test/sh_cart_2blk.py`; this script, which does not require any mesh or init files, is often convenient to check that *elsA* installation is correct.

1.5 Environment and installation

In the following, we assume that you have access to a working *elsA* installation. We also assume that you are using a Unix shell compatible with `ksh` [5]. In some cases, you may even have access to several "productions": single/double precision, optimized/debug, serial/parallel (MPI), static/dynamic (shared) libraries ... To run *elsA*, you must set three environment variables:

- `ELSAHOME`: consult the local *elsA* expert to know its value.
- `ELSAPROD`: this variable will control which "production" will be used. For example on SGI, `sgi` is sequential double precision, `sgi_mpi` parallel double precision, `sgi_r4` single precision, `sgi_dbg` debug version, and so on.
- `PYTHONPATH`: this controls where the Python interpreter will search extension modules, such as `elsA.py` or `elsA_user.py`. Most of the time, you can use the following setting:

  ```
  export PYTHONPATH=$ELSAHOME/Dist/lib/py
  ```

[4] `http://elsa.onera.fr/ExternDocs/user/MU-02044.pdf`

[5] with other shells such as `csh` , you have to modify the following examples; for instance:
```
export PYTHONPATH=$ELSAHOME/Dist/lib/py # ksh
```
must be replaced by:
```
setenv PYTHONPATH $ELSAHOME/Dist/lib/py # csh
```

In some cases, you may have to set additional environment variables:

- LD_LIBRARY_PATH (or LD_LIBRARY64_PATH): this may be required if you use dynamic shared libraries. Most of the time, you can use the following setting:

  ```
  export LD_LIBRARY_PATH=$ELSAHOME/Dist/bin/$ELSAPROD:$LD_LIBRARY_PATH
  ```

- PYTHONHOME: this may be required if the platform where the *elsA* system was built is different from the platform where you actually run the software. It is often possible to guess the correct PYTHONHOME: just enter the shell command:

  ```
  ksh> which python
  /home/user_lambda/bin/python
  ```

  In this example, you should enter:

  ```
  export PYTHONHOME=/home/user_lambda
  ```

Finally, the *elsA* executable itself must be available, as any other Unix command. The most convenient way is probably to modify your PATH environment variable:

```
export PATH=$PATH:$ELSAHOME/Dist/bin/$ELSAPROD
```

Having set all these environment variables, you should be able to launch *elsA*. Actually, two *elsA* interpreters are available:

- elsA.x, the basic Unix executable [6];
- elsa: this is a convenient wrapper of elsA.x, providing addtional user-oriented features.

Depending on your personal taste, you can choose to run *elsA* interactively, or to run script files:

- To enter interactive mode, just type:

  ```
  elsa
  ```

  or:

  ```
  elsA.x
  ```

[6] a symbolic link, elsA , to elsA.x is also provided

If everything is OK [7], *elsA* banner is first printed on screen, followed by the interpreter prompt.
With elsa [8]:

```
Welcome to the elsA Python interface ; type '^D' or 'close()' to exit
elsA >>>
```

With elsA.x, You should get a slightly different prompt, for example:

```
Python 2.4.4 (#5, Feb 12 2007, 11:31:02)
[GCC 3.4.4 20050721 (Red Hat 3.4.4-2)] on linux2
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

In this case, before invoking *elsA* features, you *must* import Python module `elsA_user`, by entering the line:

```
from elsA_user import *
```

- In non-interactive mode, you must first create a script file; when this is done, just type:

  ```
  elsa my_script.py
  ```

  or:

  ```
  elsA.x my_script.py
  ```

  In this case, the script must contain the line:
  `'from elsA_user import *'` before any invocation of *elsA* methods [9].

You are now able to begin learning *elsA* [10]. Enjoy!

1.6 What is Python?

Python is a modern Object-Oriented (OO) interpreted scripting language; it is freely available; it has a clean, easy to learn syntax. The real power of Python lies in its extensibility, through the mechanism of *modules*. In fact, *elsA* can be viewed as a standard Python module. Additional useful features of Python will be introduced through examples in the following.

---

[7] if not, see chapter 9

[8] see also 9.1, *p. 58*

[9] in the following examples, to save space, this line may be omitted; however, never forget to insert it!

[10] Please note that, since *elsA* only use dynamically allocated memory, contrary to most traditional FORTRAN codes, which use statically allocated memory, the same *elsA* executable can be used, regardless of the problem size.

1.7 *elsA* syntactic rules

To define their computation, *elsA* users must write Python scripts: however, only a very limited knowledge of the Python language is required. Basically, users interact with *elsA* by creating objects, setting some attributes, and invoking a small number of methods upon these objects.
To create objects, in most cases we use constructors:

```
my_cfd = cfdpb(name='my_cfd')    # create a cfdpb object, name is 'my_cfd'
b0     = block(name='b0')        # create a block object, name is 'b0'
ext    = extractor(name='ext')   # create an extractor object
```

Once an object has been built, its internal state, i.e. the value of its attributes, can be modified; two syntaxes are available [11]:

- Long form:

  ```
  ext.set('var','xyz mach')  # set attribute 'var' to value 'xyz mach'
  ```

- Short form:

  ```
  ext.var = 'xyz mach'
  ```

The "short" form is more compact [12]; however, for large scripts, with many objects, it may lead to increased "start-up" time. So we recommend to use the "long" form.

1.7.1 boundary objects

Currently, boundary objects can be created with two equivalent syntax:

```
# Syntax 1 : Using a constructor, requiring a window object:
win_i = window('block_name', name='win_i')
# boundary_type: walladia, outpres, ...      (Physical    boundary) ,
#                match, nearmatch,  nomatch (Topological boundary)
bndy_i = boundary('block_name','win_i','boundary_type',name='bnd')

# Syntax 2 : Using specific construction method:
# 2.1 Physical boundary, using an indirection to a 'bndphys' object:
bndy_i = new_boundary('bndy_i','block_name','bndphys_j', FAMILY_ID, \
                      (1,65, 33,33, 1,2))
# 2.2 Topological join
join_i = new_join    ('join_i','block_name','join_j', FAMILY_ID, \
                      (1,65, 33,33, 1,2))
```

The second method avoids the explicit creation of a window object, which, in many cases, is not used elsewhere in the script; it is also more compact (see also 2.4.2, *p. 22* and 6.1. *p. 46*).

[11] Single (') or double (") quotes are allowed; our advice: prefer single quote.
[12] this is the reason why it is used by many examples in this document

1.8 A concrete example

For the impatient reader, let us present a simple, yet complete, *elsA* script This first example script computes the flow through a rectangular nozzle, using two blocks. Mesh files (respectively Flow) files are located in directory `Nozzle_m` (respectively `Flow_i`). In this example, we do not instantiate geometric objects (`block`, `mesh`, `init` explicitly; instead, we ask *elsA* to generate them "internally" (attribute `<cfdpb>.automatic_block_gen'`). This will be quite useful when many blocks are involved.

```
#------------------------------------------------------------------------------
# Your very first elsA script
#------------------------------------------------------------------------------

from elsA_user import *

#==============================================================================
# STEP 1 : PROBLEM DESCRIPTION
#==============================================================================

#------------------------------------------------------------------------------
# PROBLEM CREATION
# must be at the beginning of the script file (or interactive session)
nozzle = cfdpb(name='nozzle')

# ====================================================
# I- Geometry and (Space and Time) Problem Definition
# ====================================================

nozzle.set_block_creation_mode('automatic')
nozzle.set('automatic_block_gen', 'db_directory')

nozzle.set('cfd_nb_block', 2)

#--------------------
# MESH
#--------------------
# 2 Mesh files are expected in directory : 'Nozzle_m'
# (Default format : 'bin_v3d')
nozzle.set('cfd_mesh_dir',        'Nozzle_m')

#---------------------
# Flow initialisation
#---------------------
# 2 Flow (init restart) files are expected in directory : 'Nozzle_i'
# (Default format : 'bin_v3d')
nozzle.set('cfd_flow_ini_dir',    'Nozzle_i')

#---------------------
# restart file
```

```
#---------------------
# 2 Flow (output restart) files will be created in directory : 'Nozzle_o'
nozzle.set('cfd_flow_out_dir','Nozzle_o')


# -----------------------------------------
# Boundary definition
# -----------------------------------------
import topo_and_bnd


# ====================================================
# II- (Physical) MODEL
# ====================================================

mod_nozzle = model(name='mod_nozzle')
mod_nozzle.fluid  = 'pg'
mod_nozzle.phymod = 'euler'
mod_nozzle.gamma  = 1.4


# ====================================================
# III- NUMERICS
# ====================================================

num_nozzle = numerics(name = 'nozzle_num')

# Spatial Discretization Scheme
num_nozzle.flux = 'jameson'
num_nozzle.artviscosity = 'dissca'
num_nozzle.avcoef_k2    = 1.0
num_nozzle.avcoef_k4    = 0.032
num_nozzle.avcoef_sigma = 1.0

# Time Integration Scheme
num_nozzle.ode       = 'rk4'
num_nozzle.time_algo = 'steady'
num_nozzle.cfl       = 1.
num_nozzle.inititer  = 1
num_nozzle.niter     = 100


# ====================================================
# IV- EXTRACTION DEFINITION
# ====================================================

# -----------------------------------------
# RESIDUALS (Convergence check)
# -----------------------------------------

# Screen output (L_2 and L_1)
```

```
extractResS = extractor(name='extractResS')
extractResS.title    = 'block 1 & 2'
extractResS.var      = 'residual_cons'

# File (Tecplot) output

extractResF = extractor(name='extractResF')
extractResF.title    = 'block 1 & 2'
extractResF.var      = 'residual_cons'
extractResF.file     = 'nozzle_residual.tp'


# -----------------------------------------
# Aerodynamic data
# -----------------------------------------
extractMach = extractor(name='extractMach')
extractMach.var      = 'xyz mach'
extractMach.file     = 'mach'
extractMach.loc      = 'node'


#============================================================================
# STEP 2 : COMPUTATION
#============================================================================

nozzle.compute()


#============================================================================
# STEP 3 : EXTRACTION
#============================================================================

nozzle.extract()

# End script nozzle.py
```

It is good practice to gather boundary definition in a separate script, here `topo_and_bnd.py`:

```
from elsA_user import *
from EpConstant import *

F_0 = 1
F_W = 2

# Definition of Physical Boundary (bndphys objects)
b_sym   = bndphys('sym',      name='b_sym')
b_wall  = bndphys('wallslip', name='b_wall')
b_out   = bndphys('outsup',   name='b_out')
b_inlet = bndphys('inj1',     name='b_inlet')
```

```
stagPres=1.352092
stagEnth=3.
txv=1.
tyv=0.
tzv=0.
b_inlet.set('stagnation_pressure',stagPres)
b_inlet.set('stagnation_enthalpy',stagEnth)
b_inlet.set('txv',txv)
b_inlet.set('tyv',tyv)
b_inlet.set('tzv',tzv)


# Number of Boundary Objects   : 12

new_boundary('b1W','Block0000','b_inlet',F_0,  ( 1,    1,    1,   17,    1,   17))
new_boundary('b1S','Block0000','b_sym',  F_0,  ( 1,   23,    1,    1,    1,   17))
new_boundary('b1N','Block0000','b_wall', F_W,  ( 1,   23,   17,   17,    1,   17))
new_boundary('b1B','Block0000','b_sym',  F_0,  ( 1,   23,    1,   17,    1,    1))
new_boundary('b1F','Block0000','b_wall', F_W,  ( 1,   23,    1,   17,   17,   17))

new_boundary('b2E','Block0001','b_out',  F_0,  (23,   23,    1,   17,    1,   17))
new_boundary('b2S','Block0001','b_sym',  F_0,  ( 1,   23,    1,    1,    1,   17))
new_boundary('b2N','Block0001','b_wall', F_W,  ( 1,   23,   17,   17,    1,   17))
new_boundary('b2B','Block0001','b_sym',  F_0,  ( 1,   23,    1,   17,    1,    1))
new_boundary('b2F','Block0001','b_wall', F_W,  ( 1,   23,    1,   17,   17,   17))

new_join('b1E','Block0000','b2W', F_0, (  23,   23,    1,   17,    1,   17))
new_join('b2W','Block0001','b1E', F_0, (   1,    1,    1,   17,    1,   17))
```

2. GETTING STARTED

In the following, we will briefly show what are the basic elements of a CFD computation performed with *elsA*. Each section will introduce a new concept, corresponding to a Python class [1]. To keep the discussion as simple as possible, we do not discuss multi-zone computations in this chapter. Chapter 3 is entirely devoted to multi-zone specific information.

2.1 Some terminology

We start with some terminology, in order to avoid misunderstandings. Browsing the extensive CGNS documentation may also help, since this document tries to stick to the CGNS terminology.
elsA solves the compressible fluid dynamics equations, using space and time discretization. The three-dimensional (3D) computational space is discretized with a single- or a multi-zone structured mesh:

- `mesh` : *elsA* uses a cell-center formulation [2] in direct oriented structured meshes, defined node by node :
  $x(i,j,k)$, $y(i,j,k)$, $z(i,j,k)$ (see also paragraph 2.3.3)
  Meshes must be provided by the users [3].

- `grid` : The conservative relationships are applied to grid cells. Several grids can be associated to a single mesh object. This happens for example in multi-grid algorithm, and also in the context of mesh sequencing (chapter 6.2). Users do not have direct access to `grid` objects: instead, they have access to `mesh` and `block` objects.

- `cell` : The elementary volume on which the conservative relationships are applied. In *elsA*, a cell has 8 nodes and is limited by 6 interfaces [4] [5] through which the numerical fluxes are computed.

- `block` : It is the basic object used by *elsA* to solve the aerodynamic problem. It corresponds to a region of the discretized physical space defined by a mesh to which are associated boundary and initial conditions. In most cases, several blocks are needed. Communication between the blocks is done through "join" boundaries.

---

[1] defined in `elsA_user` module
[2] unknowns are associated with the "center" of cells
[3] an exception is to set `<mesh>.generator='cartesian'`.
[4] in 2D: 4 nodes and 4 interfaces
[5] some nodes may be coincident, leading to degenerate cells

Solving the discretized numerical problem involves two different process: spatial discretization and time integration. Internally, the *elsA* numerical kernel computes flux of conservative variables through each cell interface, and source terms inside each cell volume. How flux (and source terms) are computed is governed by the spatial discretization algorithm. After spatial discretization, a numerical time integration of the resulting Ordinary Differential Equation (ODE) system is performed, either explicitly, or using some kind of implicit operator. *elsA* can perform unsteady computations, thus giving time-accurate solutions. In this type of computation, the global time step must be small enough to capture the unsteady time scales of interest. When only the final steady solution is of interest, it is usually more efficient to use a pseudo-unsteady formulation: the solution is advanced in pseudo-time until convergence is achieved within a prescribed tolerance.

2.2 Problem definition

In the following sections, to be as concrete as possible, we will illustrate every concept using examples.
The very first object created by the user belongs to the `cfdpb` class. This object can be seen as the root of a "tree" to which all the other objects will be linked.

```
nozzle = cfdpb(name='nozzle')
```

Only one object of type `cfdpb` can exist at a given time. Only a few attributes are meaningful for `cfdpb` objects[6]:

- its name;
- the `config` attribute (see also 2.3.2), with allowed values: `'3d'` (default), `'2d'`, `'1d'`, `'axi'`;

  ```
  my_cfdpb = cfdpb('my_cfdpb')
  my_cfdpb.set('config', 'axi')
  ```

In the following sections, we will briefly show how to fully specify the CFD problem to be solved.
Remark
There is a large freedom in the order in which Python instructions specifying the problem to solve can be entered. For instance, you can choose to define all the numerics before the modeling items; doing it the other way will be equivalent.

2.3 Mesh definition

This section explains how the computational space is discretized. Presently, *elsA* accepts multi-zone structured meshes, with generalized geometrical relationships between individual meshes (see Chapter 3).

[6] except when using the automatic (block) generation feature

2.3.1 Single-zone structured mesh

The class managing mesh data is `mesh`:

```
m = mesh(name='m')
m.set('file',  'mesh.tp')
```

Note that the user is not required to specify mesh dimensions explicitly. This is left as an option:

```
IMAX = 45    # Python variables
JMAX = 17
KMAX = 17
m = mesh(name='m')
m.im = IMAX
m.jm = JMAX
m.km = KMAX
```

Giving mesh dimensions explicitly enables some checks by *elsA*. However, in most cases, users do not take the trouble to enter mesh dimensions, and *elsA* uses the dimensions stored inside mesh files to infer the computational mesh dimensions [7]. For multi-block configurations, explicitly defining mesh objects one by one may become cumbersome and error prone. See section 3.1 for a faster way to specify mesh files.

2.3.1.1 Mesh File Format

elsA accept several mesh format to read spatial coordinate data:

- formatted Tecplot BLOCK [8];

  ```
  m1 = mesh(name='m1')
  m1.set('file',   'm1.tp')
  m1.set('format', 'fmt_tp')
  ```

- formatted VOIR3D ;
- binary VOIR3D . With the help of method `<cfdpb>.set_binv3d`, binary VOIR3D files can be used on different platforms, and with different productions (ELSAPROD), for example `nec`, `sgi_i4_r8`, `dec_r4`.

  ```
  # In this example binary files are created with:
  # integers coded with four bytes
  # floats   coded with eight bytes

  my_cfdpb.set_binv3d('i4', 'r8')
  ```

A complete FORTRAN code that creates a valid formatted Tecplot grid file is given in Appendix A. Multi-zone structured meshes are discussed in chapter 3.

[7] *elsA* also checks consistency between mesh dimensions and topology definition provided by boundary objects.

[8] Currently, *elsA* do not accept Tecplot POINT format.

2.3.2 *Important special case: 2D or axi-symmetric configuration*

For 2D or axi-symmetric configuration, one can provide mesh files in two ways:

- a mesh file containing the point coordinates of two `K`-planes; in 2D, the two planes must of course be parallel; `K=1` and `K=Kmax` boundaries can be omitted [9]. In axi-symmetric case, it is up to the user to insure that the 2 planes are correctly rotated; `K=1` and `K=Kmax` boundaries must be defined, with `type ='axisym'`.

- however, it is usually much easier, and less prone to errors, to provide only a single plane (`K=1`); then *elsA* will be able to generate internally the correct geometry. In the axi-symmetric case, you can set:
  `<cfdpb>.axi_formul='axi_source'`
  axi-symmetric terms are computed as source terms;
  `<cfdpb>.axi_formul='standard'`
  axi-symmetric terms are computed as fluxes.

In the axi-symmetric case, if the user chooses to provide a single plane, it must be one of the three coordinate planes: `xy`, `xz` or `yz`.

```
# 2D
pb_2d = cfdpb(name='pb_2d')
pb_2d.config = '2d'
...
m_2d = mesh(name='m_2d')
m_2d.file = 'mesh_1plan')

# axi
pb_axi = cfdpb(name='pb_axi')
pb_axi.config = 'axi'
# two planes will be generated by rotating through y axis
pb_axi.axis_rot = 'y'
...
m_axi = mesh()
m_axi.file = 'mesh_1plan')
```

2.3.3 *What is a correct mesh ?*

A very common error for newcomers is to provide an incorrect mesh file. Let us give some advices here:

- A mesh must be direct-oriented. A mesh is defined by its nodes $x(i, j, k)$, $y(i, j, k)$, $z(i, j, k)$. The (i, j, k) trihedral is assumed direct, by definition. The (x, y, z) trihedral must be direct with respect to (i, j, k). For example, let us consider a 3D mesh and x, z corresponding to i and j, respectively; in this case, the y-direction must be oriented from $k = kmax$ to $k = 1$;.

[9] If defined, they must be defined with `type='inactive'`.

- Cell volumes must be strictly positive;
- Cell face surfaces must be positive or null [10].

A convenient way to analyse mesh quality is provided by two methods: `<mesh>.display` and `<block>.metrics`:

```
from elsA_user import *
c=cfdpb(name='c')
c.config = '2d'
m=mesh(name='m')
m.file ='ROOT_DB/nacaProfile/naca_eu.mai'
m.format='fmt_tp'
m.display()

b=block(name='b')
b.mesh='m'
b.metrics()
```

Let us give an example of the results obtained using the `<block>.metrics` method:

```
GeoMetrics statistics :
 Grid :   257 X 33 X 2

  Minimum Volume = 1.5348375e-06  (cell indices : i=128 j= 1  k =1)
  Maximum Volume = 1.8564431e+00  (cell indices : i=256 j=32  k =1)

  Minimum Surface (type K)  = 1.5348375e-06  (interface indices : i=128 j= 1 k =1)
  Maximum Surface (type K)  = 1.8564431e+00  (interface indices : i=  1 j=32 k =1)
```

Please, look carefully at the printed diagnostics: avoid spending expensive computer resources on an inadequate mesh.

2.4 Block concept

Class `block` is an abstraction: a block object corresponds to a region of the physical space. To be useful, a mesh object must be attached to a block object :

```
m = mesh()
m.file = 'mesh_file')
...
b=block()
b.mesh = 'm'
```

[10] Null surfaces occur for example when axes are present.

2.4.1 Window concept

Class `window` provides a way to select a sub-part of a block:

```
b =  block()
# first syntax
w = new_window('b', family, (i1, i2, j1, j2, k1, k2))
# second syntax
w = window('b', name='w')
w.iw1 = i1
w.iw2 = i2
w.jw1 = j1
w.jw2 = j2
w.kw1 = k1
w.kw2 = k2
```

Here, `i1, i2, j1, j2, k1, k2` corresponds to the indexes of the underlying mesh points. By convention, mesh point numbering starts at 1 in each direction. As a special case, the region defined by a window can degenerate to a surface, for example if `i1 = i2 = 1`. Windows may also be used to define `extractor` objects (see 2.8) [11].

Remark : With old versions of *elsA*, it was necessary to *explicitly* instantiate a large number of `window` objects, which were used in the definition of `init`, `extract` and `boundary` objects. With the current version, most (if not all) `window` objects can be removed, resulting in shorter scripts.

The following two sections show how space and time boundary conditions are attached to block objects.

2.4.2 Block boundary conditions

To run a simulation, for every block, each external interface (section 2.1) must be associated with one, and only one, boundary condition. Since *elsA* only uses structured meshes, it is convenient to associate to every `boundary` object a rectangular window (topological information) [12]. It is important to separate boundaries in two groups:

- "Internal" boundaries, or "joins", which describe information about how the zones are connected to one another (see Chapter 3).
- "Physical" boundary conditions; here the physical boundary condition is fully described by a specific object, of type `bndphys` [13]. The most frequently used types are briefly described in the following paragraphs.

---

[11] See section 6.1, for another convenient way to define `extractor` objects.

[12] More complex situations can be handled with the `<boundary>.type='collect'` feature.

[13] Of course, the same `bndphys` object can be used by many different `boundary` objects; this factorization greatly simplifies script check and maintenance.

```
family_code = 10
b_wall = bndphys('wallslip', name='b_wall')
bnd = new_boundary('bnd', 'b_wall', family_code,  (1, 1, j1, j2, k1, k2))
```

In both cases (join and physical boundary), a `window` object is implicitly created (Python `tuple (1, 1, j1, j2, k1, k2)`).
The argument of type `bndphys`, here `b_wall`, is used by the kernel to select which numerical treatment to apply. In 3D, for each block, the external interfaces belonging to the 6 external block faces must be defined: so we must create at least 6 boundary objects However, it frequently happens that block faces are split into several windows, thus enabling different boundary conditions along the same block face. Note that in multigrid computations, users do not have to create different boundaries associated with the different grid levels: *elsA* kernel takes care of all the indexes management; this is one of the reasons why users do not have access to grid objects (see 2.1). A very broad range of different boundary treatment is available: see *elsA* User's Reference Manual for an exhaustive list.

2.4.2.1 *symmetry : `<bndphys>.type='sym'`*

This boundary is very useful in fully symmetric configurations, since it allows computation to be performed with half the mesh points.

2.4.2.2 *Wall*

This boundary comes in different versions:

- `<bndphys>.type='wallslip'`: slip wall condition for inviscid flows (no normal velocity) [14];
- `<bndphys>.type='walladia'`: adiabatic wall (used in viscous computation);
- `<bndphys>.type='wallisoth'`: isothermal wall (used in viscous computation)Ex. :

  ```
  bnd = bndphys('wallisoth', name='bnd')
  bnd.wall_temp = 2.
  ```

- `<bndphys>.type='walladia_wl'`: adiabatic wall, with wall law treatment (used in viscous computation)
- `<bndphys>.type='wallisot_wl'`: isothermal wall, with wall law treatment (used in viscous computation)

[14] Additional qualifiers `prescor` and `extrap` can be optionally set by users.

2.4.2.3 *Subsonic inlet:* `<bndphys>.type='inj1'`

```
b_inlet = bndphys('inj1', name='b_inlet')
b_inlet.set('stagnation_pressure',stagPres)
b_inlet.set('stagnation_enthalpy',stagEnth)
b_inlet.set('txv',txv)
b_inlet.set('tyv',tyv)
b_inlet.set('tzv',tzv)
```

2.4.2.4 *Supersonic outlet:* `<bndphys>.type='outsup'`

2.4.2.5 *Non reflexion:* `<bndphys>.type='nref'`

```
some_state = state(name='some_state')
some_state.set('ro',  1.0)
some_state.set('rou', 9.998476951564e-01)
some_state.set('rov', 0.0)
some_state.set('row', 1.745240643728e-02)
some_state.set('roe', 2.971576866041e+00)

b_ref = bndphys('nref', name='b_ref')
b_ref.state =  'some_state'
```

2.4.3 *Block Initialization*

To perform CFD computations, some initialization is always required. `init` class takes care of this: at least one `init` object must be attached to any block object:

```
b = block(name='b')
i = init('b', name='i')
```

To initialize the conservative variable vector field, we can:

- Initialize with a uniform constant state vector; *elsA* provides a specific class, `state`:

  ```
  roInf  = 1.
  rouInf = 1.
  rovInf = 0.
  rowInf = 0.
  roEInf = 0.
  s = state(name='s')
  s.ro  = roInf
  s.rou = roInf
  s.rov = roInf
  s.row = roInf
  s.roe = roInf
  i.state = 's'
  ```

- Initialize from a re-start file, which, in most cases, comes from a previous run.

```
i.file = 'my_restart_file'
```

For multi-bock configurations, explicitly defining init objects may become cumbersome and error prone. See section 3.1 for a faster way to specify the initialization process.

2.5 Physical model

Objects of class `model` define *which* system of equations will be solved by *elsA*.

2.5.1 Fluid model

The user should select one of three options:

- `<numerics>.phymod='euler'`: viscous effects are neglected;
- `<numerics>.phymod='laminar'`: laminar computation;
- `<numerics>.phymod='nstur'`: turbulent computation.

Sutherland's law is used to compute fluid viscosity.

2.5.2 Turbulence modeling

An impressive number of turbulent models are available, the collection of which may appear daunting to newcomers; one can give several explanations for this proliferation:

- first of all, the "universal" best turbulence model simply does not exist, and the research must go on;
- everybody has his own preferred model and wants to find it in *elsA*;
- In an industrial context, the time and money needed to validate a turbulence model on a large number of realistic configurations is usually very large; this implies that removing an "old-fashioned" turbulence model is difficult, since users would be afraid of losing part of their experience.

The beginner is advised to experiment by himself with several models, as well as to ask some help from turbulence modeling experts.

1. Algebraic models The primary advantage of algebraic models is their reduced cost compared with transport equation model; they can give good results providing they are used for configurations to which they have been designed (attached boundary layers and wakes):

- Baldwin-Lomax:
  `<model>.turbmod='baldwin'` it has been successfully used in wing design and missile flow simulation.
- Michel:
  `<model>.turbmod='michel'`
  used in turbo-machinery computations (mainly for historical reasons).

With algebraic models, computation initialization is usually straightforward. However, these models are generally not mesh topology independent, and so are difficult to apply in complex geometries (corner flows ...).

2. Transport Equation models

- one-equation model of Spalart-Allmaras:
  `<model>.turbmod='spalart'`
  widely used in aircraft computations.
- 2-equation model $k - l$:
  `<model>.turbmod='smith'`
  probably one of the most robust 2-equation models in *elsA* (with $k - \omega$). It gives good results for external flows (shock locations) but suffers of inconsistencies for wakes, jets and mixing layers.
- 2-equation $k - \omega$ model: several variants are available:
  `<model>.turbmod='komega_wilcox'`
  `<model>.turbmod='komega_kok'`
  The $k-\omega$ models are often robust, but, because of physical inconsistencies, they suffer from various weaknesses. This explains the number of versions available in *elsA*. The Kok version is probably the most widely used.
- 2-equation model $k - \epsilon$ Jones-Launder:
  `<model>.turbmod='kepsjl'`
  The $k - \varepsilon$ model implemented in *elsA* corresponds to the Jones-Launder low Reynolds version. This model has been chosen mainly because it does not use the wall distance in the wall damping functions.

2.5.2.1 Wall distance

Many turbulence models have to know the distance between each cell and the nearest wall. Several options are available:

- `walldistcompute='gridline'`: this is the fastest one;
- `walldistcompute='gridline_ortho'`;
- `walldistcompute='mininterf'`;
- `walldistcompute='mininterf_ortho'`.

2.6 Numerical algorithm

Objects of class `numerics` define *how* the system of equations will be solved by *elsA*. There is an incredible number of options available to control the numerical algorithms used by *elsA* kernel to integrate the CFD equations. We may regret that situation, but it is unavoidable if *elsA* is to stay at the forefront of research. Fortunately, a large number of default values (see Chapter 5) have been set during *elsA* installation: this means that you, the beginner, can safely ignore many of the technical subtleties of CFD. In the following, we will try to present a simplified [15] process of numerical parameter selection, mostly through several typical examples.

2.6.1 *Space discretization*

2.6.1.1 *Convective (inviscid) fluxes*

Both centered schemes (with some kind of artificial dissipation) and upwind schemes are available.

- Jameson's centered scheme is second order in space; it must be combined with artificial dissipation. Main options are: `artviscosity`, `av_type`, `avcoef_k2`, `avcoef_k4`, `avcoef_sigma`, `central_type`;
- Several upwind schemes are available, notably Roe, Coquel-Liou and van Leer fluxes. To reach second order accuracy, they are combined with MUSCL extrapolation, where the *slope* computation must include a *limiter* to avoid non-physical oscillations and improve convergence.

The situation is more complex in turbulent computation with a transport equation turbulent model: in such cases, one has the option to use different spatial discretization for the mean flow system and for the system of turbulent equation. Related attributes are: `t_harten`, `turb_order`.

2.6.1.2 *Viscous fluxes*

Three options are available:

- `viscous_fluxes='3p'`;
- `viscous_fluxes='5p'`;
- `viscous_fluxes='5p_cor'`;

`viscous_fluxes='5p'`, which is the most CPU efficient, may lead to unphysical results (see figure 2.1); `viscous_fluxes='3p'` is the less CPU efficient; `viscous_fluxes='5p_cor'` is often a good compromise.

[15] hopefully not oversimplified ...

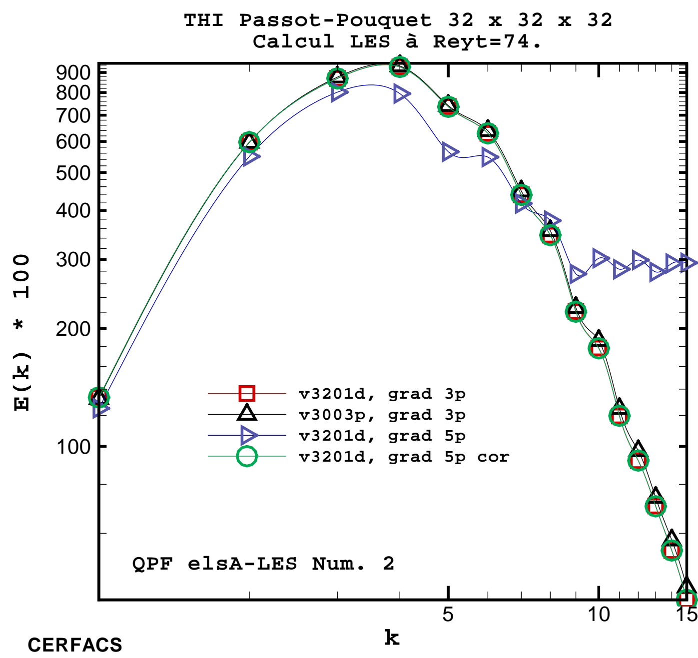


Figure 2.1: Turbulent energy (THI computation)

.

2.6.2 Time integration

The best time integration algorithms are different for *steady* and *unsteady* computations.

2.6.2.1 Local / Global time step

- Local time-stepping, where the time step is not constant across the computational domain, can be used in steady computations to speed overall convergence; in that case, the user *must* choose the CFL number: high CFL values generally increase convergence rate, but may lead to numerical instability.
- Conversely, in unsteady computations, where time accuracy is required, the user *must* select a global time step: it must be small enough so as to resolve correctly the unsteady phenomena, but not to small in order to minimize the number of time steps.

2.6.2.2 Explicit stage

In the explicit stage, the time integration is based upon either a multi-stage Runge-Kutta algorithm, or a standard backward-Euler scheme.

2.6.2.3 Implicit stage

In both steady and unsteady cases, an implicit stage is generally added to speed up the total computation time, by bypassing the time step limitation of explicit schemes. The most widely used implicit operators are:

- Implicit Residual Smoothing (IRS); it is used in association with centered Jameson's scheme, with Runge-Kutta 4-stage explicit time integration.
- LU or LUSSOR: they may be used with both centered and upwind spatial discretization schemes, with backward Euler explicit time integration.

2.6.3 Multigrid acceleration

Multigrid uses a sequence of successively coarser meshes; in some cases, it can be a very powerful tool to accelerate convergence. To use multigrid, users must provide meshes which can be coarsened in each direction: if n_g grid levels are desired, the number of points of the fine grid must be divisible by $2^{n_g} + 1$. In fact, the constraint is even stronger: each boundary condition must be "coarsen-able". Also, a minimum number of points must remain in the coarsest grid; this minimum depends on the spatial discretization scheme:

- 3 nodes (2 cells) with Jameson's scheme;
- 4 nodes (3 cells) with Upwind schemes.

2.6.4 *Other acceleration techniques*

We do not discuss here either *Low Speed Preconditioning* or *Dual Time Stepping*. Please consult the Theoretical Handbook and User's Reference Manual.

2.6.5 *Some useful examples*

In the following, we shall try to provide a limited set of useful associations; starting from these examples, it is hoped that users will tune the numerical parameters to their specific problem in far less time than by starting from scratch. To keep examples as compact as possible, we have used default values (see 5.1) in a systematic way.

2.6.5.1 *Centered scheme, steady computation*

May be used in subsonic/transonic configuration.

```
num = numerics(name='num')
# spatial discretization scheme
num.flux = 'jameson'
num.set('avcoef_k2', 0.5)
num.set('avcoef_k4', 0.032)
# temporal integration scheme
num.ode      = 'rk4'
num.implicit = 'irs'
num.cfl = 4.   # typical CFL number
```

2.6.5.2 *Centered scheme, unsteady computation*

```
num = numerics(name='num')
# spatial discretization scheme
num.flux = 'jameson'
num.set('avcoef_k2', 0.5)
num.set('avcoef_k4', 0.032)
# temporal integration scheme
num.time_algo = 'unsteady'
num.ode      = 'rk4'
num.implicit = 'irs'
num.timestep = ?    # global time step
num.itime    = ?    # simulation initial time
num.ftime    = ?    # simulation final time
```

2.6.5.3 *Unsteady computation, dual time step (DTS)*

```
num.set('ode', 'backwardeuler')
num.set('time_algo', 'dts')
num.set('cfl', 4.0)
num.set('restoreach_cons', 5.e-2)
num.set('dual_iteration', 50)
```

2.6.5.4 *Centered scheme, steady computation with multigrid acceleration*

```
num = numerics()
# spatial discretization scheme
num.flux = 'jameson'
num.set('avcoef_k2', 0.5)
num.set('avcoef_k4', 0.032)
# temporal integration scheme
num.ode      = 'rk4'
num.implicit = 'irs'

num.multigrid = ?
num.coarse = ?
num.cfl = 4.   # typical CFL number
```

2.6.6 *Upwind scheme, steady computation*

May be used in subsonic/transonic, as well as in supersonic/hypersonic configuration.

```
num = numerics()
# spatial discretization scheme
num.flux = 'roe'    #  Must be used with caution in viscous flow computation
# temporal integration scheme
num.ode      = 'backwardeuler'
num.implicit = 'lurelax'
num.cfl = 10.
```

2.7 Run the simulation

This is probably the easiest part:

```
problem.compute()
```

The current version allows users to chain several `<cfdpb>.compute` in the same run [16]:

```
init1 = init(name='init1')
init1.file = 'restart_1'
cfd.compute()

cfd.reuse = 'active'
cfd.compute()
```

2.8 Information extraction

elsA users can be interested in lots of data, during and after a simulation. We will not even try to explain all the extraction modes available. Here, our advice is: experiment yourself, and read the User's Reference Manual. Let us only give some examples.

[16] Note however that in the current version, mesh sequencing runs cannot be chained in the same script.

2.8.1 *Restart files*

Restart files may be obtained with explicit creation of extractor objects:

```
e_restart = extractor(name='e_restart)
e_restart.set('var',  'conservative')
e_restart.set('file', 'restart'
e_restart.set('loc',  'cell')
```

See section 3.1 for a faster and safer way to specify restart file management.

2.8.2 *Convergence information*

Convergence information can be sent both to standard output and to a file:

```
res_stdout     = extractor(name='res_stdout') # extraction on stdout
res_stdout.var = 'residual_ro'                # density residual (L1 and L2)

res_file = extractor(name='res_file')         # extraction in a file
res_file.var = 'residual_conservative'        # extract residual for each conservat
res_file.file= 'residual.tp'
res_file.norm= NORM_L2
```

2.8.3 *Lift and Drag information*

APROF-KL-Wl/APROF-KL-Wl.py

```
extract_lift = extractor(Some_Family, name='extract_drag')
extract_lift.set("format","fmt_tp")
extract_lift.set("var","convflux_rou convflux_row")
extract_lift.set("period",PERIOD_EXTRACT_LIFT)
extract_lift.set("loc", INTERFACE)
extract_lift.set("fluxcoeff",COEFL)

extract_drag = extractor(Some_Family, name='extract_drag')
extract_lift.set("format","fmt_tp")
extract_drag.set("var","diffflux_rou diffflux_row")
extract_drag.set("period",PERIOD_EXTRACT_DRAG)
extract_drag.set("loc", INTERFACE)
extract_drag.set("fluxcoeff",COEFD)
```

2.8.4 *Flow analysis*

Let us give an example where the mesh coordinates and the Mach number are saved in a Tecplot file, thus allowing further analysis of the computation.

```
extract_mach        = extractor(name='extract_mach')
extract_mach.var    = 'xyz mach'
extract_mach.file   = 'mach.tp'
extract_mach.format = 'bin_tp'
```

3. MULTI-ZONE COMPUTATIONS

elsA accepts multi-zone structured meshes. Each zone corresponds to one (and only one) `mesh` object. Each mesh is, in turn, attached to its corresponding block.

```
m1 = mesh()
m1.file'  = 'm1.tp'
m1.format = 'fmt_tp'
b1 = block()
b1.mesh = m1

m2 = mesh()
m2.file'  = 'm2.tp'
m2.format = 'fmt_tp'
b2 = block()
b2.mesh = m2
```

Note that a file is associated to a single zone: this is a very simple way to store mesh data. For massively parallel configurations, it is probably the safest way to obtain a fully scalable solution. However, for large configurations, the management of a large number of files, and the definition of many objects in the script file (to specify mesh and restart files) can become cumbersome. Future releases will provide access to hierarchical CGNS data base file, where a single file can store the data corresponding to every zone (and much more) [1]. In addition, *elsA* users can choose to let *elsA* generate "internally", in an automatic and safe way, block, mesh, init and extract (for restart) objects. This is described in the next section.

3.1 Automatic generation of `block`, `mesh` and `init` objects

To choose this mode, we must use the `<cfdpb>.automatic_block_gen` attribute. Mesh files, init files (if any) and restart files follow the same naming convention:

- they must belong to a single directory; for example, `Mesh_d, Flow_i_d, Flow_o_d` for mesh, init and restart files, respectively.
- File names are built with a prefix, completed with digits: `my_prefix000, my_prefix001, ...`

Most attributes admit default value (the exception is `cfd_nb_block`).

[1] Note however that if a global file system is not available, which frequently happens for low-cost cluster systems, a copy of the CGNS file must be available on all the computing nodes, which can be cumbersome.

```
naca = cfdpb(name='naca')

naca.set('automatic_block_gen','db_directory)
naca.set('cfd_nb_block',2)

DEFAULT=1
# Optional parameters
if not DEFAULT:
  naca.set('cfd_block_prefix','Block')
  naca.set('cfd_file_index0', 0)
  naca.set('cfd_file_digit',4)
  naca.set('cfd_mesh_format','fmt_tp')
  naca.set('cfd_flow_out_format','fmt_tp')
  naca.set('cfd_flow_ini_format','fmt_tp')


#--------------------
# MESH
#--------------------
naca.set('cfd_mesh__dir','Mesh') # 'Mesh' is actually default


#---------------------
# Flow initialisation
#---------------------
RESTART_FROM_FILE=1
if RESTART_FROM_FILE:
  naca.set('cfd_flow_ini_dir','Flow_ini')
else:
  naca.set('cfd_init_state', 'sta')

#---------------------
# restart file
#---------------------
naca.set('cfd_flow_out_dir','Flow_out')
```

3.2 Zone connectivity

In principle, one can think of clever geometrical algorithms which would be able to generate zone connectivity information when parts of a zone connect with parts of another zone or itself, without any additional user inputs. However, *elsA* use a different strategy, for several reasons:

- Coding of such algorithms is certainly not an easy task; we are not sure that it is even achievable in the most general case.
- Even in cases where such algorithms could be used, the associated cost may not be negligible compared with CFD computations [2]. It is thus more efficient

[2] Specially on vector computers, since these geometrical algorithms are not easily vectorisable.

to store the connectivity information once, saving us the cost of re-computing connectivity information at the beginning of every run.

There are three types of connectivity that can occur [3]: point-by-point, patched, and over-set.

- The point-by-point, or 1-to-1, type occurs when the edges of zones abut, and where grid vertices from one patch exactly correspond with grid vertices from the other, with no points missing a partner.
- The patched type occurs when the edges of zones abut, but there is not a correspondence of the points, or they are not partnered with another point.
- The over-set type occurs when zones overlap one another (or a zone overlaps itself). We do not describe mismatched (patched) or over-set connectivity information in this document: the user is referred to User's Reference Manual for details.

3.2.1 `match`: *1-to-1 connectivity definition*

The easiest way to explain how to specify 1-to-1 connectivity is, as usual, to give a simple example:

```
b1 = block(name='b1')
join1 = new_join('join1', 'b1', 'join2', f_match,   (23, 23, 1,7, 1,7))

b2 = block(name='b2')
join2 = new_join('join2', 'b2', 'join1', f_match,   ( 1,  1, 1,7, 1,7))
```

In this example, the '`i=IMAX=23`' edge of block `b1` abuts the '`i = 1`' edge of block `b2`. `f_match` is a user-chosen arbitrary integer.
Internally, *elsA* uses an algorithm to find the orientation of the abutting faces. In some cases, this algorithm fails, and users have to provide additional information, in the form of an additional Python tuple (here `(1,-2,3)`):

```
join = new_join('b1', 'join2', f_match,   (23, 23, 1,7, 1,7), (1,-2,3))
```

Remark : A good practice is to always explicitly give the orientation tuple.

3.2.2 `near_match`: *1-to-n connectivity definition*

```
new_join_nearmatch('b1E','b1','b2W', Fam, (23,23, 1, 17, 1,17), 'fine',   (2,2,2), (1
new_join_nearmatch('b2W','b2','b1E', Fam, ( 1, 1, 1,  9, 1, 9), 'coarse', (2,2,2), (1
```

Compared with `type='match'`, the only added information is a Python tuple (here `(2,2,2)`) giving the refinement ratio.

[3]Once again, readers are strongly advised to consult CGNS documentation, specially: CGNS Overview and Entry-Level Document, Appendix C.

3.2.3 nomatch

```
g1 = globborder(name='g1')
g2 = globborder(name='g2')

new_join_nomatch('Bnd0001', 'Block0000', 'g1','g2', Fam, (23,23, 1,17, 1,17))
new_join_nomatch('Bnd0006'  'Block0001', 'g2','g1', Fam, ( 1, 1, 1,17, 1,17))
```

3.2.4 nomatch_linem

```
new_join_nomatch_linem('Bnd0001',  'Block0000', 'g1','g2', Fam, (23,23, 1,17, 1,17)
```

Compared with `type='nomatch'`, the only added information is a Python tuple (here `(0,0)`) giving the internal ordering inside the `globborder` "global reference frame".

3.2.5 overlap

```
new_join('Bnd0002', 'Block0000', 'overlap', Fam, (10, 202, 1,1, 1,2))
```

4. UNITS, DIMENSIONAL AND NON-DIMENSIONAL DATA

To solve the Navier-Stokes (or Euler) equations, it is often convenient, although not mandatory, to use dimensionless quantities. In some cases, using a well-chosen normalization can improve numerical accuracy [1], specially inside geometric algorithms (metrics computation, neighbour search (chimera) ...).
Let us recall that it is equivalent to say either that the quantity x is non-dimensionalised referred to a length, L, or that the unit of length is chosen such that the length of x is unity.
Contrary to many other scientific software, *elsA* do not use a specific unit system. This means that users do not have to adapt to a unit system not suited to their needs. Of course, this freedom has a price: it is up to the user to enter all values using a coherent unit system.

Remark : An additional Python module, `adim_lib`, is available to help users in the choice of a convenient normalisation system. See "Additional Tools User's Manual", `http://elsa.onera.fr/ExternDocs/user/MU-06023.pdf`, for a complete description.

4.0.6 Example: viscous coefficients

In viscous computations, since fluid molecular viscosity is computed with Sutherland's law :

$$\mu = \mu_s \sqrt{\frac{T}{T_s}} \frac{1 + C_s/T_s}{1 + C_s/T} \tag{4.1}$$

the users must provide the 3 coefficients:

- `suth_const` : C_s constant in non-dimensional form ($110.4/T_{ref}$).
- `suth_muref` : μ_s, non-dimensional molecular viscosity corresponding to $T = T_s$.
- `suth_tref` : T_s, non-dimensional temperature to define μ_s.

```
mod1 = model(name='mod1')
mod1.suth_const = 1.
mod1.suth_muref = 1.E-4
mod1.suth_tref  = 1.0
```

All quantities must be given in accordance to the non-dimensional form chosen by the user to the equations. The μ_s value fixes the Reynolds of the computation.
In turbulent computations with transport-equation models, users must additionally supply cutoffs values (section 6.3.1).

[1] This is related to floating point arithmetic properties.

For post-processing purpose, it is often useful to express the pressure coefficient and the global aerodynamic forces with their usual definitions. In dimensional or non-dimensional quantities in coherent unit system, we have :

$$K_p = \frac{p - p_\infty}{\frac{1}{2}\rho_\infty U_\infty^2} = \frac{p - p_\infty}{\frac{1}{2}p_\infty M_\infty^2} \tag{4.2}$$

$$C_{F\Sigma w} = \frac{\int_{\Sigma w} \text{flux } d\Sigma}{\frac{1}{2}\rho_\infty U_\infty^2 S} \tag{4.3}$$

The quantity $C_{F\Sigma w}$ may be any of the forces acting on a solid wall boundary. As the integration of the fluxes is done over the boundaries, the reference surface S must be chosen in agreement with the mesh definition. The flux integral is obtained using the extraction of `convflux_rou` for the pressure forces in x-direction or `diffflux_rou` for the friction forces in x-direction (see the User Manual).
In the following, we will discuss in some details five useful examples of unit/normalization systems, and give some advice to avoid common errors, specially for viscous computations.

4.1 SI units

The user must enter every quantities using SI units: *meter* (length), *kilogram* (mass), *second* (time), *Kelvin* (temperature), from which derived units can be built:

- velocity V: m/s;
- density ρ : kg/m^{-3};
- pressure P: Pa ($kg\ m^{-1}s^{-2}$);
- specific internal energy e: $kg/m^{-1}s{-}2$;
- viscosity coefficient μ : Poiseuille (($Kg\,m^{-1}\,s^{-1}$ or $N\,s\,m^{-2}$)).

This system is very simple. However, a common error is to introduce mesh coordinates in a non-SI unit (for instance, millimeters or centimeters).

4.2 Free-stream dimensioning: free-stream velocity scaling

In this system, a reference length, L, the free-stream density, ρ_∞, free-stream velocity, U_∞, and free-stream temperature T_∞, are unity. This system is very popular, specially in external flow computations. Every other fluid quantity is then non-dimensionalised

using a reference quantity with the corresponding dimension. Introducing Mach number, $M_\infty = U_\infty/a_\infty$ (where a_∞ is the free-stream speed of sound), and specific heat ratio, γ ($a_\infty^2 = \gamma P_\infty/\rho_\infty$), we obtain:

$$a_\infty = \frac{1}{M_\infty}$$

$$P_\infty = \frac{1}{\gamma M_\infty^2}$$

$$e_\infty = \frac{1}{\gamma(\gamma-1)M_\infty^2} = Cv$$

$$R = \frac{P}{\rho T} = \frac{1}{\gamma M_\infty^2}$$

where R is the gas constant ($R = P/(\rho T)$), and Cv is the specific heat capacity ($e = CvT$).
In viscous computation, we also introduce the Reynolds number,

$$Re_\infty = \frac{\rho_\infty U_\infty L}{\mu_\infty}$$

$$\mu_\infty = \frac{1}{Re_\infty}$$

Sutherland's law:

$$\mu = \mu_s \sqrt{\frac{T}{T_s}} \frac{1 + C_s/T_s}{1 + C_s/T} \tag{4.4}$$

With `REINF`=Re_∞ and `TINFDIM`=T_∞ K, one have :

```
mod1 = model(name='mod1')
mod1.suth_const = 110.4/TINFDIM
mod1.suth_muref = 1./REINF
mod1.suth_tref  = 1.0
```

4.3 Free-stream dimensioning: free-stream pressure scaling

This system is a slight variant of the previous one [2]. Here, the free-stream pressure (instead of the free-stream velocity) is unity.

$$a_\infty = \sqrt{\gamma}$$

$$U_\infty = M_\infty \sqrt{\gamma}$$

[2] often used in hypersonics computation

$$e_\infty = \frac{1}{(\gamma - 1)}$$

$$R = 1$$

$$Cv = \frac{1}{\gamma - 1}$$

$$\mu_\infty = \frac{\rho_\infty U_\infty L}{Re_\infty} = \frac{M_\infty \sqrt{\gamma}}{Re_\infty}$$

The Sutherland law is expressed as in the previous case.

4.4 Stagnation condition dimensioning

In this system, the stagnation density ρ_i, the stagnation temperature T_i and the sound velocity a_i corresponding to T_i are taken equal to unity :

$$a_\infty = \left(1 + \frac{\gamma - 1}{2} M_\infty^2\right)^{-1} \quad (4.5)$$

$$u_\infty = M_\infty a_\infty \quad (4.6)$$

$$p_\infty = \frac{1}{\gamma}\left(\frac{p}{p_i}\right)_\infty = \left(1 + \frac{\gamma - 1}{2} M_\infty^2\right)^{\frac{-\gamma}{\gamma-1}} \quad (4.7)$$

$$\rho_\infty = \frac{1}{\gamma}\left(\frac{\rho}{\rho_i}\right)_\infty = \left(1 + \frac{\gamma - 1}{2} M_\infty^2\right)^{\frac{-1}{\gamma-1}} \quad (4.8)$$

$$R = \frac{p}{\rho T} = \frac{1}{\gamma} \quad ; \quad C_v = \frac{1}{\gamma(\gamma - 1)} \quad (4.9)$$

$$e_\infty = C_v T_\infty = \frac{1}{\gamma(\gamma - 1)}\left(1 + \frac{\gamma - 1}{2} M_\infty^2\right)^{-1} \quad (4.10)$$

$$E_\infty = C_v T_i = \frac{1}{\gamma(\gamma - 1)} \quad (4.11)$$

$$R_{e\infty} = \frac{\rho_\infty U_\infty}{\mu_\infty} \quad (4.12)$$

$$\mu_\infty = \frac{M_\infty}{R_{e\infty}}\left(\frac{\rho}{\rho_i}\right)_\infty \left(\frac{T}{T_i}\right)_\infty \quad (4.13)$$

$$K_p = \frac{\gamma p - (p/p_i)_\infty}{\frac{\rho_\infty U_\infty^2}{2 p_i}} \quad (4.14)$$

4.5 Critical state dimensioning

In this system, the critical density ρ_c, the critical temperature T_c and the sound velocity a_c corresponding to T_c are taken equal to unity :

$$a_\infty = \frac{1+\frac{\gamma-1}{2}}{1+\frac{\gamma-1}{2}M_\infty^2} \tag{4.15}$$

$$u_\infty = M_\infty a_\infty \tag{4.16}$$

$$p_\infty = \frac{1}{\gamma}\frac{(p/p_i)_\infty}{(p/p_i)_c} = \frac{1}{\gamma}\left(\frac{1+\frac{\gamma-1}{2}}{1+\frac{\gamma-1}{2}M_\infty^2}\right)^{\frac{\gamma}{\gamma-1}} \tag{4.17}$$

$$\rho_\infty = \frac{(\rho/\rho_i)_\infty}{(\rho/\rho_i)_c} = \left(\frac{1+\frac{\gamma-1}{2}}{1+\frac{\gamma-1}{2}M_\infty^2}\right)^{\frac{1}{\gamma-1}} \tag{4.18}$$

$$R = \frac{p}{\rho T} = \frac{1}{\gamma} \quad ; \quad C_v = \frac{1}{\gamma(\gamma-1)} \tag{4.19}$$

$$e_\infty = C_v T_\infty = \frac{1}{\gamma(\gamma-1)}\left(\frac{1+\frac{\gamma-1}{2}}{1+\frac{\gamma-1}{2}M_\infty^2}\right) \tag{4.20}$$

$$E_\infty = C_v T_i = \frac{\gamma+1}{2\gamma(\gamma-1)} \tag{4.21}$$

$$R_{e\infty} = \frac{\rho_\infty U_\infty}{\mu_\infty} \tag{4.22}$$

$$\mu_\infty = \frac{M_\infty}{R_{e\infty}}\left(\frac{1+\frac{\gamma-1}{2}}{1+\frac{\gamma-1}{2}M_\infty^2}\right)^{\frac{1}{\gamma-1}} \tag{4.23}$$

$$K_p = \frac{2}{M_\infty^2}\left[p\left(\frac{1+\frac{\gamma-1}{2}}{1+\frac{\gamma-1}{2}M_\infty^2}\right)^{\frac{1}{\gamma-1}} - 1\right] \tag{4.24}$$

4.6 Turbulent conservative variables and cutoff

The choice of the boundary values to impose to the turbulent conservative variables and to the corresponding cutoff is not trivial since it depends on the non-dimensionality and of the turbulence models. However, the rule of thumb is relatively simple : the user must choose the turbulence level $T_{u\infty}$ of order 10^{-4} or 10^{-3} and the turbulent Reynolds

number $(\mu_t/\mu)_\infty$ of order 10^{-2}. These quantities are only given for numerical purpose and, in particular, $T_{u\infty}$ has generally nothing to do with the turbulence level of a wind tunnel to impose for transition criteria.
From the T_u definition, one have $k_\infty = 3U_\infty^2 T_u^2/2$ and the second turbulent quantity is obtained from μ_t/μ through the μ_t formulation of each particular turbulence model. To simplify, one can take the wall damping function appearing in μ_t equal to unity Except for the Wilcox model without Zheng limiter, the solution is normally insensitive to the values at infinity providing they are small enough. One must not hesitate to check the $(\mu_t/\mu)_\infty$ (`var='viscrapp'` quantity) issued from the computation.

4.7 Summary

Let us provide a Python script example, which may make the normalization task less prone to user errors.

```
from math import *
# Some flow characteristics
MachInf = 9.86
Gamma    = 1.40
Reynolds = 1.E5
Alpha    = 0.

if FREESTREAM_NORM:
  Pinf     = 1. / (Gamma*MachInf*MachInf)
  RoInf    = 1.
  RouInf   = cos(Alpha)
  RovInf   = 0.
  RowInf   = sin(Alpha)
  RoeInf   = Pinf/(Gamma-1.) + 0.5

  Cv           = Pinf / (Gamma-1.)
  suth_const   =  110.4/TinfDim
  suth_muref   = 1./Reynolds
  suth_tref    = 1.

else if SI_UNIT:
  Cv = 717.
  R  = 8.31
```

5. DEFAULT VALUE MECHANISM

5.1 Why default values?

In many cases, *elsA* tries to simplify the problem definition by providing default values. Let us give some examples.

- Assume that the user has not provided an explicit choice for the artificial viscosity. In that case, *elsA* provides a default value, currently `artviscosity ='dissca'`.

```
num = numerics(name='num')
num.flux = 'jameson'           # flux type MUST be provided
# num.artviscosity = 'dissca' # Note the '#': this line is a comment
```

- Here, the user does not define the data format associated with the `extract` object. *elsA* provides `fmt_tp` as default value.

```
ext = extractor(name='ext')
ext.var = 'xyz mach'
ext.file = 'mach.tp'
# ext.format = 'fmt_tp' # Note the '#': this line is a comment
```

Conversely, note that some values *must* be entered by users. For instance, users must choose a `flux` type to associate with any `numerics` object. If they do not, *elsA* will return some kind of error message (see also 5.2 and 9.2.3):

```
# elsA [2114] ERROR: User Error.
# info [2114] No Key flux
```

We are convinced that default values are very convenient for most users, and specially for newcomers:

- *elsA* scripts can be more compact; the important feature of a given computation are thus not "lost" in a very large script file.
- When a new option is added to the software, without a default value mechanism, every already existing script would have to be modified, simply to say 'No, I do not want to use this option'. Clearly, this is not acceptable.
- *elsA* default values are *not* hard-coded inside compiled code; instead, they are stored in a "resource file" that can be customized to specific needs: in fact, this resource file (see 5.2) can be modified by local *elsA* experts, so that less advanced users will benefit from their experience. For instance, one can imagine that a computing site specialized in hypersonic flows may choose different default settings than a a computing site specialized in turbo-machinery computation.

However, default values have their price:

- Some users definitely wish to see in a single script file the complete problem definition; of course, these users are entirely free to avoid using any default values.

- A bigger problem, in our opinion, is that experienced users may have the unpleasant feeling that they do not know exactly which options *elsA* has chosen "behind the curtain". Two answers to this legitimate concern are given in the next sections [1].

5.2 What is the default value associated with a given attribute?

Internally, *elsA* default values are stored in a Python dictionary, `dict_def_val` , which can be consulted in Python module `EpKernelDefVal.py` [2]. For example, running the following command [3]:

```
cat $ELSAHOME/Dist/lib/py/EpKernelDefVal.py  | grep '\'format\''
```

We obtain:

```
'format'                 : 'fmt_tp',
```

Another (better) way to get default value associated with any attribute is to issue the following Python commands, either from the Python interpreter itself,

```
bash-2.03# python
...
>>> import EpKernelDefVal
>>> print EpKernelDefVal.dict_def_val['format']
fmt_tp
>>>
```

or from the *elsA* interpreter:

```
elsA(py) >>> import EpKernelDefVal
elsA(py) >>> print EpKernelDefVal.dict_def_val['format']
fmt_tp
elsA(py) >>>
```

So, you are now able to answer the question: "What is the default value associated with a given attribute?". Another question is: "Do *elsA* provide a default value for a given attribute?". As seen before (section 5.1), you can obtain an answer *a posteriori*, simply by removing attribute definition from script and running the simulation. A cleaner way is to run the same Python (or *elsA*) command:

[1] The following section, 5.2 may be safely skipped by newcomers.
[2] usually found in directory `$ELSAHOME/Dist/lib/py`
[3] or `grep '"format"'` for older versions

```
elsA(py) >>> import EpKernelDefVal
elsA(py) >>> print EpKernelDefVal.dict_def_val['flux']
Traceback (innermost last):
  File "<console>", line 1, in ?
KeyError: flux
elsA(py) >>>
```

For additional information, consult User's Reference Manual, specially `get_defaults`, `show_defaults`, `use_defaults`, `show_origin` and `view`.

6. ADVANCED PROBLEM DEFINITION

This chapter covers material not discussed in Chapter 2.

6.1 Family

It is often convenient to gather boundaries which share a common properties into `family` objects:

- in this example, all the boundaries that are or type `type='walladia'` belongs to family `F_WALL`, where `F_WALL` is a pre-defined (positive) integer.

```
F_WALL=14
bnd1 = new_boundary('bnd1','bk0','b_wall', F_WALL,  (1, 1, j1, j2, k1, k2))
...
bndn = new_boundary('bndn','bkN','b_wall', F_WALL,  (1, 1, j1, j2, k1, k2))
```

- For more complex configurations, it can be useful to divide the "wall" family into subsets, for example, when computing a complete aircraft, one family for the wing, another one for the fuselage ...

The power of the family concept appears when we have to define post-processing (extraction), specially in parallel MPI: contrary to individual boundaries, which are not invariant through block splitting arising during the load balancing algorithm, families are conserved, so that defining extraction using family is much easier and less error prone than using directly boundary (or associated window) objects (see also section 2.8.3):

```
ext_wing     = extractor(F_WING,     name='ext_wing')
...
ext_fuselage = extractor(F_FUSELAGE, name='ext_fuselage_wing')
...
```

Remark : The family concept can also be used with `boundary` objects instantiated with direct call to `boundary` constructor [1]. In that case, one must use `<boundary>.family`:

```
Bnd0000 = boundary('Block0000','E_W_Bnd0000','inj1',name='Bnd0000')
E_W_Bnd0000.set('wnd', [1, 1, 1, 17, 1, 7])
Bnd0000.set('family', 6)
```

[1] i.e. not with call to construction method `new_boundary`

6.2 Mesh sequencing

It frequently happens that we would like to perform computations with a coarsened mesh:

- It may be convenient to perform preliminary computations on a coarsened mesh, to find mistakes in the Python script(s), to identify any unforeseen problems, or to tune numeric and physical parameters, without wasting too much resources.
- Comparing computations performed on coarse and fine mesh gives very useful information concerning grid convergence. To achieve this, *elsA* provides users with an easy to use, yet powerful, mechanism:

  ```
  problem = cfdpb(name='problem')
  problem.coarsen_mesh = 2
  ```

  In this example, coarsening is uniform in the entire computational domain. Except this additional line [2], the script is unchanged, which avoids many potential errors.
- The total time to obtain converged results can sometimes be reduced through several chained computations, converging first on the coarsest grid, using the coarse solution to initialize solution on the finer grid (through any interpolation algorithm), and going towards finest mesh. The idea is very similar to standard multigrid algorithm: long-wave perturbation are dissipated much faster on coarse grids. Note that except for the coarsest level, if the coarsening factor is equal to 2, it is possible to use multigrid acceleration: association of mesh sequencing and multigrid is sometimes called Full Multi Grid (FMG).

To ease running FMG computations, *elsA* provides users with several attributes (`<cfdpb>.coarsen_mesh`, `<cfdpb>.coarsen_init`, `<cfdpb>.fromcoarse`). The following example shows how to chain three runs, going from coarse to fine grid [3]:

```
# 1st computation: 1 point over four
nozzle.set('coarsen_mesh', 4)
nozzle.set('coarsen_init', 4)

# Flow_0 contains some initialization for 1s1 mesh
nozzle.set('cfd_flow_ini_dir', 'Wksp/Flow_0')
nozzle.set('cfd_flow_out_dir', 'Wksp/Flow_1s4')
```

[2] if initialization files are used (instead of initialization from constant `state`), a second line has to been inserted:
`problem.coarsen_init = 2`

[3] Consider using `elsAsession` in `EpelsA.py` to automate this process.

```
num.set('multigrid', 'none')


# 2nd computation: 1 point over two
nozzle.set('coarsen_mesh', 2)
nozzle.set('fromcoarse',   2)

nozzle.set('cfd_flow_ini_dir', 'Wksp/Flow_1s4')
nozzle.set('cfd_flow_out_dir', 'Wksp/Flow_1s2')

num.set('multigrid', 'v_cycle')
num.set('nbcoarsegrid', 1)


# 3rd run
nozzle.set('fromcoarse',   2)

nozzle.set('cfd_flow_ini_dir', 'Wksp/Flow_1s2')
nozzle.set('cfd_flow_out_dir', 'Wksp/Flow_1s1')

num.set('multigrid', 'v_cycle')
num.set('nbcoarsegrid', 2)
```

Presently, interpolation (prolongation) from coarse to fine grid use simple linear interpolation, without inter-block communications.

6.3 Numerical cutoffs

6.3.1 Cutoffs

Cutoffs are mainly used for the turbulent computation.

- `muratiomax` : maximum authorized value of μ_t/μ during a computation. This cutoff may be needed for turbulence models in which the μ_t expression can lead to $0/0$. This is mainly the case for the $k-\varepsilon$ model. This cutoff may be used during the establishment phase of the solution and must be inactive when convergence is reached. If this is not the case, the user does not use the expected turbulence model but its own model! Depending on the Reynolds number, μ_t/μ can take very different values. If the cutoff is set to 0, a laminar computation is done.

- `t_cutvar1` and `t_cutvar2` : these cutoff on turbulent conservative variables are needed to avoid non physical negative values of these quantities. A good practice is to define these cutoffs equal to a fraction (from $1.$ to 0.001 or less) of the values at infinity (see paragraph 4.6).

6.4 Topics not discussed

Many important subjects are still not covered in this document.

- Computations involving motions, in relative or absolute reference frame.
- Chimera computation. See (EVB):
  `validation/script/CHIM-2D-01/chim-2d-01.py`
  `validation/script/RAE-KO-CHIM/rae-ko-chim-lam.py`
- Transition.
- Data associated with boundary object in specific files, for instance to prescribe a temperature field in isothermal wall boundary.

7. ADDITIONAL INFORMATION

7.1 ICEM-CFD to *elsA* translator

For complex multi-block configurations, writing manually *elsA* script files can be cumbersome, and error-prone. Fortunately, users can use ICEM2elsA, a tool to automate the translation from ICEM-CFD topological files to *elsA*.

7.2 How to reduce start-up time?

For very large configurations, script files may be quite large. In most cases, this is not a problem. However, on some platforms, specially vector computers (NEC, CRAY, FUJITSU), it has been observed that, in certain situations, the start-up time can be unbearable - more than ten minutes! Here are some guidelines to avoid such annoyance.

1. Use systematically the `new_boundary` / `new_join` syntax:

   ```
   # preferred syntax
   bnd = new_boundary('bnd', 'blk', 'b_phys', family, (i1, i2, j1, j2, k1, k2))
   ```

   instead of the equivalent syntax with involves the creation of an auxiliary `window` object:

   ```
   # "Slow" syntax
   win = window('b', name='win')
   win.set('iw1', i1)
   win.set('iw2', i2)
   win.set('jw1', j1)
   win.set('jw2', j2)
   win.set('kw1', k1)
   win.set('kw2', k2)
   bnd = boundary('blk', 'win', 'wallslip', name='bnd')
   ```

2. As soon as your script is debugged, you can switch off most of the checks performed by the *elsA* interpreter, simply by adding the `--fast` option on the command line[1]:

   ```
   elsa -f my_script.py --fast
   ```

   This can reduce markedly the start-up time (typically by a factor of 2).

[1] Caution : this option is incompatible with the "short" form, you have to use the `set` accessor.

3. You can put all the invariant part of your script (and specially boundary condition definition) in a separate Python script file, say `my_bnd.py`. Python will create a file `my_bnd.pyc` on the first interpretation; the `.pyc` files contain "compiled" code, and are interpreted much faster in subsequent runs. Python will automatically re-compile the original `.py` file if it is modified.

```
cfd = cfdpb(name='cfd')
...
import my_bnd # Please note : no extension!
...
```

4. Use the `family` concept to define post-processing, thus avoiding the trouble of potentially extremely long lines [2].

```
# preferred
Fuselage = 50  # Integer family code associated to fuselage part
bnd1 = new_boundary(..., Fuselage, ...)
bnd2 = new_boundary(..., Fuselage, ...)
...
ext = extractor(Fuselage), name='ext'
ext.var = 'psta'

# deprecated
win1 = window('blk', name='win1')
win2 = window('blk', name='win2')
...
bnd1 = boundary(..., win1, ...)
bnd2 = boundary(..., win2, ...)
...
ext  = extract_group(name='ext')
ext.windows = 'win1+win2+...' # potentially very long string
```

7.3 Control of job execution

It is sometimes useful to be able to change the planned job execution *during* the run:

1. You receive a message from the system administrator:

```
System will be shut down in 5 minutes...
```

   In such cases, you may wish to save the state of the computation, so that you can start a new computation from this state, thus sparing precious computing time.

2. During a computation, you may wish to "see" dynamically if everything goes as expected. Of course, you could have asked for periodic extractions by creating `extractor` objects in the simulation script, in a static way. However, dynamic interaction is definitely much more flexible.

[2] Most text editors cannot manage properly lines exceeding a given limit.

3. Your computation has been running for many hours, and you discover that you have forgotten to ask for restart files in your script!

4. You may wish to change some computing parameters, for instance the CFL number. This is sometimes called *Computational Steering*; presently, *elsA* does not provide such a facility.

The following two subsections (7.3.1 and 7.3.2) describe two mechanisms to deal with the first three points.

7.3.1 Restart file

When *elsA* has entered the main (pseudo-) time loop, the user can ask that restart files corresponding to the current iteration should be written. To do that, one must know the Unix process number of the computing job (probably through the Unix command `ps`). Then, the user must enter the following command [3]:

```
kill -SIGUSR2 <process_number>
```

Restart files will then be created; the file name will be constructed from the block name and the time iteration: for instance, if `blk1, blk2` are the names of the two blocks in the problem, and the signal is sent during iteration 130, two files, named `blk1.iter00130` and `blk2.iter00130` will be created. Then the process reenters the time loop, and the solution proceeds further on. Let us give an example of the printed output, when the user has enter the `kill` command during iteration 18:

```
 iteration no 17

 -----------------------------------------------------------------
#dq  1 L2 = 4.3240937e-04 Linf = 9.0833416e-03  (   3  16  16 )  0
#dq  2 L2 = 3.8816478e-04 Linf = 5.9381099e-03  (   3  16  16 )  0
#dq  3 L2 = 2.3411757e-04 Linf = 4.1046026e-03  (   3  15  16 )  0
#dq  4 L2 = 2.3411732e-04 Linf = 4.1046027e-03  (   3  16  15 )  0
#dq  5 L2 = 1.1554889e-03 Linf = 2.8076357e-02  (   3  16  16 )  0
 -----------------------------------------------------------------

*********************************************************************
 iteration no 18
Dump restart file (process pid: 9044182,  niter = 18)
.....................................................................
elsA  : Post-Processing for 'Block0000_pid0009044182_iter00018'
Write : Block0000_pid0009044182_iter00018
.....................................................................

 -----------------------------------------------------------------
#dq  1 L2 = 3.7224305e-04 Linf = 6.1108484e-03  (   4  16  16 )  0
#dq  2 L2 = 3.5497200e-04 Linf = 5.6742947e-03  (   5  16  16 )  0
```

[3] On some platforms, you may have to replace `SIGUSR2` by `USR2` .

```
#dq  3 L2 = 2.1372279e-04 Linf = 4.6443970e-03  (   3  15  16 )  0
#dq  4 L2 = 2.1372277e-04 Linf = 4.6443970e-03  (   3  16  15 )  0
#dq  5 L2 = 9.9448340e-04 Linf = 1.7954864e-02  (   3  16  16 )  0
 -------------------------------------------------------------------
```

7.3.2 *SIGTSTP signal* (Control-Z)

Another possibility to interact dynamically with a running job is to send it the SIGTSTP signal. In interactive mode, you can use 'control-Z' key combination. You are then prompted with a menu:

```
Stop.......1
Extract....2
Continue...3
Kill.......4
```

1. The job is suspended:

   ```
   [1] + Stopped (SIGSTOP)  /tools/Tempo/v2.2.10/Dist/bin/sgi/elsA.x x.py
   ```

   Execution will continue if the user enters:

   ```
   fg %1
   ```

2. The registered extract objects are scanned, and the corresponding files are written: without the user interruption, these files would have been written at the job's end, during the job.extract() command. This option is specially interesting to look at the convergence residuals. When all the extraction have been performed, the user is prompted again with the same four possible choices (Stop/Extract/Continue/Kill). Let us give an example, in which three extractor objects have been registered:

   ```
   **********************************************************************
    iteration no 7

    -------------------------------------------------------------------
   #dq  1 L2 = 2.1194850e-03 Linf = 2.5305340e-02  (  16  16  16 )  0
   #dq  2 L2 = 1.9950121e-03 Linf = 2.0783402e-02  (  17  16  16 )  0
   #dq  3 L2 = 1
   Pause......1
   Extract....2
   Continue...3
   Kill.......4
   : 2

    -------------------------------------------------------------------
   #dq  1 L2 = 1.7171855e-03 Linf = 2.3111593e-02  (   7  16  16 )  0
   #dq  2 L2 = 1.4053604e-03 Linf = 1.4030115e-02  (  15  16  16 )  0
   ```

```
#dq  3 L2 = 8.9873227e-04 Linf = 7.0547847e-03  (   5  15  16 )  0
#dq  4 L2 = 8.9873191e-04 Linf = 7.0547845e-03  (   5  16  15 )  0
#dq  5 L2 = 4.5892234e-03 Linf = 6.6441164e-02  (   7  16  16 )  0
 -------------------------------------------------------------------
....................................................................
elsA  : Post-Processing for 'debam_1s1'
Write : debam_1s1
....................................................................
....................................................................
elsA  : Post-Processing for 'debav_1s1'
Write : debav_1s1
....................................................................
....................................................................
elsA  : Post-Processing for 'Wksp/Flow_1s1/flow0000'
Write : Wksp/Flow_1s1/flow0000
....................................................................

Pause......1
Extract....2
Continue...3
Kill.......4
: 3

********************************************************************
 iteration no 9
...
```

3. Execution continues.

4. The job is killed immediately.

7.4 Script files and new releases

For each *elsA* release, the Python–*elsA* interface defines all the documented features coherently with the User's Reference Manual (URM), /ELSA/MU-98057 attached to this release.
The URM details the various debugging procedures, including dealing with Python–*elsA* scripts which are no more coherent with the current release (or conversely using current scripts with older releases, if need be).
A global means of interface definitions comparison between two *elsA* versions is to invoke, for each version, the `man()` function as :

```
man('elsA')
```

and to re-direct the output to a file.
Ex. :

```
<using ''old'' environment>
elsa --pycmds "man('elsA') ; close()" > old.out
<using ''new'' environment>
```

```
elsa --pycmds "man('elsA') ; close()" > new.out
diff old.out new.out | more
```

For a given script, the following command-line options (definitions extracted from the URM) may be useful (please mind that option order is significant) :

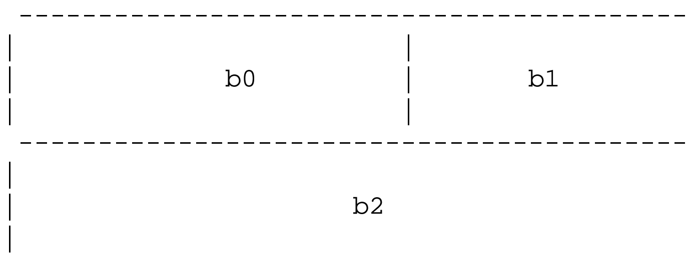
```
    --validate          : check script coherency (see --warn below)
                             implies  --noexecution --check  --noraise --nowarn
                                      --noshow --nostats
                             disables --allow_obsolete
                             keeps a memory of all errors (not final state only)
    --strict            : warnings are treated as errors
    --warn              : (re-)enable warnings (useful after --validate)
    --allow_obsolete    : accept automatic replacement of obsolete features
```

So that `--validate --warn` will check a script (not performing the computation) with all warnings enabled, while `--validate --strict` will also perform only a check, but treating warnings as errors.
Using `--strict`, specified without `--validate`, will abort the computation only if any error or warning was found during the global check.

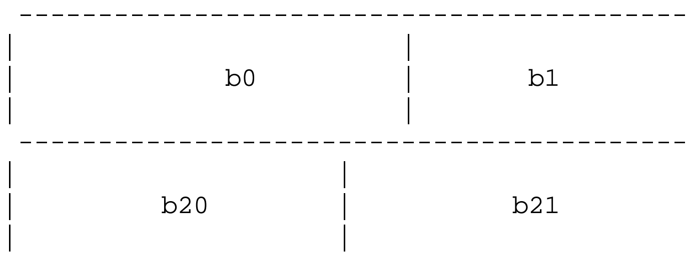
Remark : The `--allow_obsolete` option should *not* be used after `--validate`, because it defeats the purpose of catching inadequate specifications ; also, it is only meant to be an aid in performing computations with old scripts, but may not perform all necessary conversions in all cases.

8. PARALLEL MODE

elsA implements coarse-grained block-based parallelism, based on MPI [1]. It is the user's responsibility to allocate blocks on each processor. Depending on the number of processor and the individual block sizes, achieving good load balancing may require that some blocks have to be split in several sub-blocks. Presently, this task must be done by users *before* actually submitting their parallel job to *elsA*. Let us give a simple example.
Before splitting:



After splitting:



Once this pre-processing step is over, using *elsA* in MPI parallel mode is straightforward:

1. Script files are nearly identical in serial and parallel mode; the only additional data to be specified is the mapping of blocks to processors. Two options are available to define this mapping:

   (a) use of attribute `<block>.proc`, that must be set for `block` [2].

   ```
   blk0 =  block(name='blk0')
   blk0.node = 0
   blk1 =  block(name='blk1')
   blk1.node = 1
   ```

[1] Future *elsA* releases may provide in addition OpenMP shared memory parallel processing (OpenMP is the *de facto* standard for directive-based shared memory parallel processing); although some experiments have already been done to parallelize *elsA* with OpenMP, OpenMP version is still not officially supported.

[2] And *not* for `mesh` or `extract` objects.

(b) use of attribute `<cfdpb>.mpi_block2proc`:

```
my_cfdpb.set('mpi_block2proc', 'script_load_balance')
```

Here, `script_load_balance.py` is a very simple Python script, containing a Python dictionary providing the mapping of blocks to processors. The dictionary keys and associated values are the block numbers and the processor numbers.

```
cat script_load_balance.py
# Splitted configuration : 5 blocks

# Number of processors   : 4

nproc = 1

dict_block2proc = {
   0 : 0,
   1 : 1,
   2 : 1,
   3 : 2,
   4 : 3
}
```

2. At run time, launching *elsA* MPI executable is platform dependent; in many situations, the following will work:

```
mpirun -np <nb_of_Proc> parallel_script.py
```

9. TROUBLESHOOTING

Since *elsA* is a complex system, user errors are unavoidable. Also, unfortunately, internal errors may arise inside *elsA* kernel. This chapter presents the basics of error treatment provided by *elsA*: it is hoped that a careful classification of error messages, as well as a description of the most frequent ones, will help users to understand by themselves what is going wrong, thus saving a lot of precious time.
It is useful to classify errors in three broad categories:

1. environment errors ;
2. interface errors ;
3. kernel errors.

9.1 Environment error

Let us give examples of errors resulting from incorrect environment; this should help you to recognize what's going on [1]. In case of trouble, please look carefully the first few lines printed on the standard output after you enter the `elsa` command with `-v` option:

```
$ elsa -v
elsA interface : Message : displaying (selected) control parameters :
  verbose=echo use_import=off
  platform nickname     = GNU/Linux
  ELSAPROD              = intelIA32em
  ELSAHOME              = /tmp_user/eos010/gazaix/v3301
  ELSA_EXE              = /tmp_user/eos010/gazaix/v3301/Dist/bin/intelIA32em/elsA.x
  PYTHONPATH            = /tmp_user/eos010/gazaix/v3301/Dist/lib/py
  LD_LIBRARY_PATH       = /opt/intel/fce/9.0/lib:/opt/intel/cce/9.0/lib
```

9.1.1 Incorrect `PYTHONPATH`

```
Traceback (innermost last):
  File "<string>", line 1, in ?
ImportError: No module named EpelsA_loader
```

9.1.2 Incorrect `LD_LIBRARY_PATH`

An example of message issued by Unix system with an incorrect `LD_LIBRARY_PATH`:

[1] Depending on your platform and the version used, messages may be somewhat different.

```
12700720:/tools/Tempo/v2.2.10/Dist/bin/sgi/elsA.x:
rld: Fatal Error: Cannot map soname 'libeDescp.so' under any of:
/tools/gnome/lib/libeDescp.so:/usr/lib64/libeDescp.so
```

Check carefully your spelling: did you define LD_LIBARY_PATH?

9.1.3 Incorrect PYTHONHOME

Example of message written by the Python interpreter:

```
Could not find platform independent libraries <prefix>
Could not find platform dependent libraries <exec_prefix>
Consider setting $PYTHONHOME to <prefix>[:<exec_prefix>]
'import exceptions' failed; use -v for traceback
Warning!  Falling back to string-based exceptions
'import site' failed; use -v for traceback
```

See 1.5 for a possible value of PYTHONHOME.

9.2 Interface errors

Users interact with the computational CFD kernel through a software layer, which we will call here the *elsA* interface. The interface is written itself in Python; one can view this layer as a "wrapper", providing users with a high-level CFD interpreter. The interface layer provides many convenient mechanisms to check user inputs as soon as possible, and so to be able to give users reliable information, and even in some cases suggestions to correct the error (see also 7.4, *p. 54*). See User's Reference Manual for complete information. The interface cannot identify all the possible errors that can arise during a computation. This may happen because of incomplete coherence checks, or because of truly internal errors, such as failure of numerical algorithm: in such cases, it will be the kernel's job to implement the error treatment (see 9.3.1).

9.2.1 Syntax error

As in any language, users may enter invalid commands. Since the *elsA* interpreter is built on top of Python, most syntax errors are reported by the Python interpreter itself [2]:

```
elsA(py) >>> mmm =
  File "<console>", line 1
    mmm =
         ^
SyntaxError: invalid syntax
```

[2] in fact, this is one of the many advantages brought by extending an existing interpreter, instead of writing yet another one by ourselves

9.2.2 Invalid attribute

9.2.2.1 Unknown attribute

The user tries to give a value to an attribute which does not exist in the class to which belongs the object (in the following example, note the spurious 'h' in gahmma):

```
elsA(py) >>> mod1 = model(name='mod1')
elsA(py) >>> mod1.gahmma = 1.4   # Note the spurious 'h'

 elsA interface : ERROR : Name error :
 unknown (macro-)attribute `gahmma' for class `model'
     (macro-)attribute name should be in :
['baldwin_model', 'constke', 'constke1', 'constke2', 'constke3', 'constke4',
 'cv', 'fluid', 'gamma', 'michel_model', 'models', 'phymod', 'phys_props',
 'prandtl', 'prandtltb', 'specrad_s_mean', 'sst_cor', 'suth_const',
 'suth_muref', 'suth_tref', 'tblx_ckleb', 'tblx_distlim', 'tblx_ibalditx',
 'tblx_preslim', 'tblx_vortrlim', 'tmic_cfg', 'tmic_ctipleak', 'tmic_delta',
 'tmic_deltamx', 'tmic_itpf', 'tmic_vortcrit', 'tmic_vortlim', 'tmic_vortrlim',
 'turbmod', 'turbmod_variants', 'type_asm', 'type_keps', 'visclaw',
 'viscosity', 'walldistcompute', 'zhenglim']
... message is : unknown attribute `gahmma' for class `model'
```

9.2.2.2 Invalid type

Here, the attribute exists, but the type of the associated value is wrong:

```
>>> from elsA_user import *
>>> cfd1 = cfdpb(name='cfd1')
>>> mod1 = model(name='mod1')
>>> mod1.set('gamma', 1)

elsA interface : ERROR   : Type error : wrong type for value : 1
 ... types : <type 'int'> vs <type 'float'>
 ... for 'gamma' attribute of <model instance 'mod1'>
```

9.2.2.3 Invalid range

```
elsA(py) >>> mod1.gamma=-.5

 elsA interface : ERROR : Value error : wrong value `-0.5'
      for attribute `gamma' of object : <model instance 'mod1'>
     value(s) should be in :
      ]0,...,inf[
```

9.2.3 Attribute value required

A value is required but the user did not provide one and no default value exists : *elsA* raises an error.

```
# elsA [2114] ERROR: User Error.
# info [2114] No Key flux
```

Note that the previous message is provided at runtime by *elsA* kernel, not the (Python) interface on a `check()` call.
Useful information about default value can also be obtained through `check()` :

```
elsA >>> num1 = numerics(name='num1')
elsA >>> num1.check()
elsA interface : Warning : using default value 2.9387360491e-39
                 for num1.convergence_level
 ... static default value, context-dependent one failed
elsA interface : Warning : using default value           'none' for num1.multigrid
 ... static default value, context-dependent one failed
elsA interface : Warning : using default value           'none' for num1.precond
 ... static default value
elsA interface : Warning : using default value           'none' for num1.artviscosity
 ... static default value, context-dependent one failed
elsA interface : Warning : using default value            'rk4' for num1.ode
 ... static default value, context-dependent one failed
elsA interface : Warning : using default value         'steady' for num1.time_algo
 ... static default value, context-dependent one failed
elsA interface : Warning : using default value           'none' for num1.implicit
 ... static default value, context-dependent one failed

elsA interface : ERROR   : Coherency error : missing value for num1.flux
 ... and no default value found or allowed for <numerics>.flux attribute
 ... <numerics>.flux attribute value is always required
```

9.3 Kernel errors

The separation between interface and kernel errors is not absolute. Being pragmatic, we may define kernel errors as "every error which is not an interface error"! In fact, it is not an easy task to design a clean error system, because the *elsA* kernel is used in two different contexts :

- it is used through the *elsA* interface by *elsA* end users to perform CFD computations;
- it provides CFD scientists with a powerful Object-Oriented CFD toolkit [3]: they can build their specific applications by combining kernel classes, deriving new classes from existing ones, and adding their own classes. In this context, error messages are sent to programmers, not to end users. We acknowledge that such kernel error messages, intended for programmers, can be quite intimidating for end users. Let us give an example:

[3] an OO toolkit is equivalent to a Unix library.

```
# elsA : Internal Error
         Please check your script file,
         and look carefully to warning/errors;
         Then, Please submit a full bug report.
         See <URL:http://elsa.onera.fr/elsA/query/PRsub.html>
# elsA [ File : .Obj/sgi/Base/BlkMesh.C (line no : 951)]
# elsA [9920] FATAL: Internal Error.
```

The "philosophy" corresponding to these two contexts is quite different : to be useful, the toolkit must be very extensible, letting programmers do numerical experiments, at their own risk. On the contrary, end users, and specially newcomers, must be provided with as much safety guards as possible. Let us hope that a good compromise can be found between these two conflicting requirements.

9.3.1 The three kernel error levels

Kernel errors are classified in three categories, according to the error severity :

1. *WARNING*: there is some inconsistency in the user input; *elsA* tries to do its best to continue. Example 1:

   ```
   E_ERRENTRY(2232, E_WARNING, "Rotation with null angle.",
              "JoinBaseP.C", "No text")
   ```

   Example 2: Boundary interface re-defined

   ```
   # elsA [2350] ERROR: User Error.
   # info [2350]  Boundary Interface already defined :
   blk1 : bnd111 : 1  1  2  3  1  2
   ........................................
   ```

2. *ERROR*: an error is detected. Processing continues, but garbage will almost surely being produced. Example: Boundary interface not defined

   ```
   # elsA [2361] ERROR: User Error.
   # info [2361]  Boundary Interface never defined :
   blk : 69  69  63  64  1  2
   ........................................
   ```

3. *FATAL*: There is no way to continue: processing immediately stops. Example: failure of memory allocation

   ```
   Dynamic memory allocation algorithm has failed.
   Please try increasing the process datasize limit
   (ulimit in ksh, limit in csh).
   If submitted with qsub, check '-lm' argument.
   Note that the problem you try to solve may be too big for your machine...
   ```

```
 Detailed Memory Information:
   Process asked for 1345294332 bytes
   Current Total     count = 1345298532

--------------------------------------------------------------------------------
# elsA [9110] FATAL: Out of Memory

Leaving error, code is 9110
# elsA : exit forced
```

9.4 Parallel errors

In MPI parallel mode, if something goes wrong, look carefully to each logfile produced by each processor (`elsA_MPI_Pid_xxxxxxx_N_0`, `elsA_MPI_Pid_xxxxxxx_N_1` ...), paying special attention to any error messages.
It is sometimes useful to run in sequential mode: in this case [4], `proc` is simply ignored, so that it is not necessary to remove definition of `proc` attributes. If the configuration is too big to be run on a single processor, consider using `<cfdpb>.coarsen_mesh` and `<cfdpb>.coarsen_init` [5].

9.5 Stack overflow

In some rare cases, *elsA* might fail at runtime (probably with a "segmentation violation") due to overflowing the stack. Try to increase the stack size (typically using `limit stacksize` (in `csh` and derivatives) or `ulimit -s` (in `sh` and derivatives).

9.6 What should you do in case of trouble?

9.6.1 Do not ignore warning messages

Warning / Error messages often provide a clue that something is going wrong. Please, do not ignore them. Also, please read carefully log messages printed on `stdout` and `stderr`. Look with special care the banner which is printed at the beginning of each run; many information are provided, which can help you to perform many checks:

- *elsA* release, production date and mode:

```
# elsA v3.1.06 - Copyright (c) 1997-2003 by ONERA
#
# Production: Linux_japhet_2.2.13 - linux - Feb_16,_2002_-_16:44:08
# C++ Compiler Option: -Wall_-march=i686_-mcpu=i686_-O_-DNDEBUG_-D_E_FORTRAN_LOO
# Fortran Compiler Option: -O_-Wall_-O3_-march=i686_-mcpu=i686
```

[4]either running *elsA* sequential executable, or the parallel one, with $NPROC = 1$
[5]This is usable only if the configuration allows multigrid.

- Information about single/double precision:

```
Size of Float   : 4 Bytes
Size of Integer : 4 Bytes
```

9.6.1.1 Special case: parallel mode

In parallel mode, each computing node writes to standard output its own messages. Unfortunately, on some platforms, one can obtain scrambled outputs, quite difficult to interpret. Future versions will avoid this annoying behaviour.

9.6.2 Some of the most frequent errors

Frequent user errors have already been discussed in section 9.2.1, 9.2.2, 9.2.3, 9.2.3. Let us describe other common errors.

9.6.2.1 Use of reserved keywords

elsA scripts are really just Python scripts: so they must respect Python naming rules [6]. Moreover, A limited set of keywords are used by the *elsA* interpreter [7]: it is forbidden to name user-created objects with these keywords.

List of reserved *elsA* keywords:

`cfdpb, mesh, block, numerics, model, init, extractor, extract, extract_group, boundary, group, family, window, globwindow, globborder.`

Python has also its own list of reserved keywords, for example: `if, else, ...`.

9.6.2.2 Duplicated object name

In order to distinguish between objects created by users, it is strictly forbidden to use the same name for two objects, even if they belong to different classes.

```
w1 = window()
...
w1 = window()
 Error : duplicated object name!
 The duplicated name is : w1
 You must choose non-ambiguous object name.
 Sorry -- cannot continue.
# elsA [2111] FATAL: User Error.
```

[6] For example, an identifier must not contain a . (dot) character.

[7] These names are injected in the current scope through the `from elsA_user import *`.

9.6.2.3 *Memory problem*

If you run out of memory, it is sometimes possible to increase the memory allowed by the (Unix) system:

```
# give maximum size of data segment or heap (in kbytes)
ulimit -d
3906250
```

You may try:

```
ulimit -d unlimited
```

9.6.2.4 *Arithmetic exception: NaN (Not a Number)*

When a floating point exception is encountered, depending on the production, two cases are possible:

- Computation stops immediately;
- Computation continues, until the next occurrence of convergence residual computation [8].

Suggestion: it may help to reduce CFL, maybe starting from a relatively low value, and increasing towards larger values :

```
f_cfl = function('linear')
f_cfl.set('linear',[2., 30.0, 500, 3000])
num.attach(f_cfl)
```

9.6.2.5 *Turbulence does not develop*

In case of Navier-Stokes computation with transport equation models, check that the turbulence develops correctly. To this end, look at the residual of ρk. It must increase at the beginning of the computation. Use `<init>.coeffmutinit` and `iter_ini_tur` if needed, in particular for Spalart-Allmaras and $k - \varepsilon$.

9.6.2.6 *File error*

```
Mesh m1 :  file  ='very_bidulic_file_name'
     m1 :  format='fmt_tp'
# elsA [4011] FATAL: Fortran OPEN error
```

Suggestion: check file name and file permission. Please note that *elsA* is currently too "laxist" about file ownership and permission; some checks should be added (so that, for instance, re-start files cannot be inadvertently overwritten).

[8] *elsA* test the residuals: if a `NaN` is found, computation is stopped.

9.6.3 *When all else fails*

- Look at known bugs in the appropriate section of the *elsA* Web site (http://elsa.onera.fr/elsA/use/refbugs.html).
- Search for interface changes, also in the appropriate section of the *elsA* Web site. It may happen that some attributes have been changed, so that your python script does not mean what you think. Look carefully to `EpAttrDefs.py`, and/or use the `man` and `check` [9] interface commands:

```
elsA >>> man('vel_formulation')
Attribute name   : vel_formulation
Class(es)        : numerics
Description      : velocity formulation for mobile grids
Allowed values   : 'relative', 'absolute'
Default value(s) : 'absolute'
Rules            :
 dependency rules :
    vel_formulation is meaningful only IF :
      block.motion = 'mobile'
```

- Send an e-mail to `elsA-info@onera.fr`.
  See `http://elsa.onera.fr/elsA/query/PRsub.html`.

[9] `man('elsA')` prints synthetic information for each attribute

10. FREQUENTLY ASKED QUESTIONS

10.1 How to convert *elsA* files from a format to another one

It occurs frequently that one has to convert a file from a given format, say formatted Tecplot to another one, say binary VOIR3D. Instead of writing a conversion utility, it is much better to let *elsA* do the work for us:

```
my_cfdpb = cfdpb(name='my_cfdpb')


m        = mesh(name='m')
m.file   = 'm.tp'
m.format = 'fmt_tp'
...
blk      = block(name='blk')
blk.mesh = m
...
e        = extractor('blk', name='e')
e.var    = 'xyz'
e.file   = 'm.v3d'
e.format = 'bin_v3d'
e.loc    = 'node'

num      = numerics()
num.iter = 0

# 0 iteration : no actual computation
my_cfdpb.compute()
my_cfdpb.extract()
```

Using `automatic_block_gen='db_directory'`, the whole configuration can be converted very easily:

```
my_cfdpb = cfdpb(name='my_cfdpb')
my_cfdpb.set('cfd_mesh_format', 'fmt_tp')
...
# extractor without additional argument
#  --> Applies to the whole configuration
e        = extractor(name='e')
e.var    = 'xyz'
e.file   = 'm.v3d'
e.loc    = 'node'

num      = numerics()
num.iter = 0

# 0 iteration : no actual computation
my_cfdpb.compute()
my_cfdpb.extract()
```

At run time, for each block, a mesh file with `format='bin_v3d'` will be created: `m.v3d0000, m.v3d0001 ....`
A similar trick can be used to extract a coarsened grid from the fine one:

```
m          = mesh()
m.file     = 'm_fine'
m.coarse_i = 2
m.coarse_j = 3
m.coarse_k = 1
...
e        = extractor(name='e')
e.var    = 'xyz'
e.file   = 'm_coarse'
e.loc    = 'node'
```

This will create a file corresponding to a mesh with one point over two in the i direction, one over three in j, and every point in k.

10.2 Can I exchange VOIR3D binary files between different computing platforms?

The answer is *YES*; this is done through `<cfdpb>.set_binv3d`; see *elsA* User's Reference Manual for a complete discussion. For instance, binary files created by *elsA* executables on COMPAQ (DEC-ALPHA) machines can be used by SGI, PC running Linux [1], and NEC computers.
Binary Tecplot files can be exchanged freely; note however that Tecplot binary files are not available on all platforms.

[1] An experimental version of *elsA* is available for PC running Windows ; this version requires that Cygwin has been installed.

Appendix A. FORTRAN EXAMPLE CREATING A TECPLOT MESH FILE

```
      PROGRAM WRITE_GRID_TP
      IMPLICIT NONE
      INTEGER UNIT
      INTEGER IMAX, JMAX, KMAX
      INTEGER i,j,k
      CHARACTER*8 cform
      PARAMETER (UNIT=10)
      PARAMETER (IMAX=12, JMAX=7, KMAX=7)
      REAL x(IMAX,JMAX,KMAX), y(IMAX,JMAX,KMAX),z(IMAX,JMAX,KMAX)
C     Create Grid Points
      DO i=1,IMAX
      DO j=1,JMAX
      DO k=1,KMAX
        x(i,j,k) = float(i-1)
        y(i,j,k) = float(j-1)
        z(i,j,k) = float(k-1)
      END DO
      END DO
      END DO
      cform = '(6E15.7)'
      OPEN(UNIT, FILE='./m1.tp')
C     See Tecplot User's Guide
      WRITE(UNIT,'A') 'TITLE = "First mesh example"'
      WRITE(UNIT,'A') 'VARIABLES = "x" "y" "z"'
      WRITE(UNIT,'A') 'ZONE T="grid 1 ",  I=12,  J=7,  K=7, F=BLOCK'
      WRITE(UNIT,cform) (((x(i,j,k), i=1,IMAX),j=1,JMAX),k=1,KMAX)
      WRITE(UNIT,cform) (((y(i,j,k), i=1,IMAX),j=1,JMAX),k=1,KMAX)
      WRITE(UNIT,cform) (((z(i,j,k), i=1,IMAX),j=1,JMAX),k=1,KMAX)
      CLOSE(UNIT)
      END
```

Appendix B. HOW TO RUN BENCHMARKS

B.1 CPU efficiency

It is sometimes useful to know *elsA* CPU efficiency on a given platform [1]. A convenient way to measure CPU efficiency is to divide the total CPU time by the time iterations and the number of mesh points. The computed value will of course depend somewhat upon the specific test case; however, if the problem size is large enough, since the cost associated with boundary treatment can be neglected, the efficiency will be nearly entirely determined by the numerical scheme (spatial discretization and temporal integration). To give an easy way to measure *elsA* performance, with complete freedom to specify the number of blocks, and the number of mesh points inside each block, we have provided an "automatic" way to build `mesh` objects, without the burden to create new mesh files each time the problem size changes:

```
# Example of automatic cartesian mesh generation
# (avoid use of external mesh files)
# 2 block configuration
# This script can be used to run \sigle{MPI} benchmark, with 2 computing nodes

from elsA_user import *

bench = cfdpb(name='bench')

cartesian_delta = 1. # Cell size

# Parallelepiped size
IM = 25
JM = 10
KM =  5
NPOINT = 2 * IM*JM*KM

# MESH CREATION
m0 = mesh(name='m0')
m0.set('generator', 'cartesian')
m0.set('im', IM)
m0.set('jm', JM)
m0.set('km', KM)


m1 = mesh(name='m1')
m1.set('generator', 'cartesian')
m1.set('im', IM)
m1.set('jm', JM)
m1.set('km', KM)
```

[1] We may have to compare *elsA* with other CFD codes, or we have to check the efficiency of a a new implementation (for example, quality of vectorization).

```
# Offset of mesh 2
m1.set('cartesian_orig_x', (IM-1)*cartesian_delta)

# BLOCK CREATION
b0 = block(name='b0')
b0.set('mesh', 'm0')
b0.set('proc', 0)

b1 = block(name='b1')
b1.set('mesh', 'm1')
b1.set('proc', 1)


...
import time
t1=time.clock()
bench.compute()
t2=time.clock()

print '#############################'
print 'T CPU = ',t2-t1
print 'T CPU = %6f',(t2-t1)/NITER/NPOINT
print '#############################'
```

B.2 Memory usage

The Unix Operating System, as well as standard queuing systems, provide utilities, such as `ps`, `top`, `acctjob` to measure the memory used by a process. However, we have found useful to provide our own internal measure of the *dynamic* [2] memory allocated inside *elsA* kernel. We restrict the memory allocation diagnostic to `FldField` objects, which are the basic containers of numerical values manipulated by *elsA*.

```
problem = cfdpb(name='problem')
..
problem.compute()
problem.statistics()
```

An example of output from `<cfdpb>.statistics` call:

```
------------- Heap Memory Usage Summary -------------
=====================================================
Total Number of new calls =         7836
          new [E_Float  ] =         6182
          new [E_Int    ] =         1614
          new [E_Boolean] =           40
=====================================================
Maximum total allocated memory    :     15454328 bytes
Maximum allocated memory (float) :     13097992 bytes
```

[2] i.e. obtained from the Operating System through `new` operator

```
Maximum allocated memory (int)   :      2398728 bytes
Maximum allocated memory (bool)  :       148208 bytes
------------------------------------------------------
------------------------------------------------------
------------------------------------------------------
```

Another way to get memory information, without inserting a call to `<cfdpb>.statistics`, is to set environment variable `ELSA_MEMORY_VERBOSE` to `TRUE`: a detailed memory usage summary will be printed at the end of the logfile.

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