A User’s Guide to CGNS

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1 INTRODUCTION

This User’s Guide has been written to aid users in the implementation of CGNS (CFD General Notation System). It is intended as a tutorial: light in content, but heavy in examples, advice, and guidelines. Readers interested in additional details are referred to other documents, listed in the references, which are available from the CGNS website www.cgns.org.

1.1 What is CGNS?

CGNS (CFD General Notation System) originated in 1994 as a joint effort between Boeing and NASA, and has since grown to include many other contributing organizations worldwide. It is an effort to **standardize** CFD input and output, including grid (both structured and unstructured), flow solution, connectivity, BCs, and auxiliary information. CGNS is also easily extensible, and allows for file-stamping and user-inserted-commenting. It employs ADF (Advanced Data Format), a system which creates binary files that are portable across computer platforms. CGNS also includes a second layer of software known as the mid-level library, or API (Application Programming Interface), which eases the implementation of CGNS into existing CFD codes.

In 1999, control of CGNS was completely transferred to a public forum known as the CGNS Steering Committee. This Steering Committee is made up of international representatives from government and private industry. All CGNS software is completely free and open to anyone (open source). The CGNS standard is also the object of an ISO standardization effort for fluid dynamics data [6], for release some time in the early to mid-2000’s.

1.2 Why CGNS?

CGNS will eventually eliminate most of the translator programs now necessary when working between machines and between CFD codes. Also, it eventually may allow for the results from one code to be easily restarted using another code. It will hopefully therefore save a lot of time and money. In particular, it is hoped that future grid-generation software will generate grids with all connectivity and BC information included as part of a CGNS database, saving time and avoiding potential costly errors in setting up this information after-the-fact.

1.3 What is a CGNS File?

A CGNS file is an entity that is organized (inside the file itself) into a set of “nodes” in a tree-like structure, in much the same way as directories are organized in the UNIX
The top-most node is referred to as the “root node.” Each node below the root node is defined by both a name and a label, and may or may not contain information or data. Each node can also be a “parent” to one or more “child” nodes. A node can also have as a child node a link to a node elsewhere in the file or to a node in a separate CONS file altogether. Links are transparent to the user: the user “sees” linked children nodes as if they truly exist in the current tree. An example of a CONS tree-like structure is shown in Fig. 1.

Figure 1: Example CONS tree-like structure.

In order for any user to be able to interpret a CONS file, its nodes must be assembled according to particular rules. For example, Fig. 2 shows a simple example of a tree-like structure that organizes some animals into categories according to rules that most of us are very familiar with. (Note that this figure is different from Fig. 1 in that no “Labels” or “Data” are used, only “Names.”) The categories get narrower and narrower in their scope as you traverse lower in the tree. The broadest category here is “Animals,” and the tree narrows all the way down to particular dogs (two “Fido”s, a “Spot,” and a “Ginger”). Knowing ahead of time how this tree is organized allows you to quickly and easily access whatever particular information from the tree that you may be interested in. If someone else were to organize these same animals in a completely different way, according to different rules, then it would be difficult for you to access the desired information without spending a lot of time searching and studying the tree.

The particular rules for organizing CONS files for aerodynamic data, which allow users to easily access desired information, are described in the Standard Interface Data Structures (SIDS) document [1]. Because CONS files are binary files, they cannot be

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1 Strictly speaking, because links may be used to store information in multiple files, there is no notion of a CONS file, only of a CONS database implemented within one or more files. However, throughout this document the two phrases are used interchangeably.
Figure 2: Simple tree-like structure that categorizes some animals.

viewed by the user with standard UNIX ASCII-editing tools. The utility adfedit was created to allow users to easily view CGNS files. It is briefly described in Appendix A.

1.4 How this User’s Guide is Organized

The main content in this User’s Guide is located in section 2, where several simple examples are given for both structured and unstructured grids. This section covers the basics that most users want or need to learn in order to get started using CGNS. It is recommended that the section on structured grids be read first, in its entirety, even if the user is only interested in unstructured grid applications. Some additional information is covered in section 3; these issues are felt to be important (i.e., most users will want to eventually include them), but they are not as crucial as the basic items covered in section 2. Finally, sections 4 and 5 briefly cover troubleshooting and frequently asked questions, respectively.

Note that all of the codes and code segments given in this document are available as complete codes from the CGNS website www.cgns.org (in the User’s Guide section). The names of these codes and their functions are listed in Appendix B. Also note that not all CGNS capabilities are covered in this document. It is meant to be a fairly simple introductory guide only.
## 2 GETTING STARTED

The rules and conventions governing how the nodes in a CGNS file are organized, including their names and labels, are specified in the SIDS document [1], with additional details in [2] [3]. These documents also specify in detail how CFD information is to be stored within the nodes in a standardized fashion so that other users can easily access and read it. When a CGNS file strictly adheres to the rules given in the SIDS document, it is said to be “SIDS-compliant.” A CGNS file must be SIDS-compliant in order for other users to be able to properly interpret it. A brief overview of the most commonly used aspects of the SIDS is given in Appendix C.

However, to get started with CGNS, it is not necessary for the user to fully understand the SIDS document or Appendix C. The mid-level, or API calls have been created to aid users in writing and reading CGNS files that are SIDS-compliant. Using the API, most CFD data of interest to the majority of users can be written into or read from a CGNS file very easily with only an elementary understanding of the SIDS.

In the following sections, we give detailed instructions on how to create typical CGNS files or portions of files. These instructions are given in the form of simple examples. They make use of the mid-level API calls, although not all API calls are covered in this document (a complete list of available API calls can be found in [5]). We recommend that the user read through the examples in this section in order, because some information in the later sections depends on being familiar with information given in the earlier ones. Hopefully, users should be able to easily extend these simple examples to their own applications. Additional applications are covered in section 3. For those users already familiar with the PLOT3D format for CFD data [7], we include a detailed description on reading and writing PLOT3D-type variables in a CGNS file in Appendix D.

Also note that we have delayed the discussion of units and nondimensionalization until section 3. For now, all examples simply store and retrieve pure numbers, and it is assumed that the user knows what the dimensions or nondimensionalizations of each variable are.

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2 There are currently two levels of programming access to CGNS. The lowest level consists of ADF-level calls. These calls perform the most basic functions, such as creating a child node, writing data, reading data, etc. These functions always begin with the characters “ADF.” However, these low-level calls know nothing at all about the SIDS, so the user is responsible for putting data in the correct place, to make the CGNS file SIDS-compliant. The mid-level, or API calls, which always begin with the characters “cg_,” were written with knowledge of the SIDS. Therefore, it is easier to adhere to the SIDS standards when writing a CGNS file using the API calls, and some checks for SIDS-compliance are also made by the API calls when accessing a CGNS file (SIDS compliance is not guaranteed, but the API calls go a long way toward facilitating it). The API calls also drastically shorten the calling sequences necessary to perform many of the functions needed to create and read CGNS files.
2.1 Structured Grid

This first section gives several structured grid examples, whereas section 2.2 gives unstructured grid examples. However, we recommend that section 2.1 be read first, in its entirety, even if the user is only interested in unstructured grid applications. This is because much of the organization of the CGNS files is identical for both grid types, and later sections of this document assume that the user is familiar with information given in earlier sections.

2.1.1 Single-Zone Structured Grid

This first example is for a very simple 3-D Cartesian grid of size $21 \times 17 \times 9$. The grid points themselves are created using the following FORTRAN code snippet:

```fortran
  do k=1,nk
    do j=1,nj
      do i=1,ni
        x(i,j,k)=float(i-1)
        y(i,j,k)=float(j-1)
        z(i,j,k)=float(k-1)
      enddo
    enddo
  enddo
```

where $ni=21$, $nj=17$, and $nk=9$. A picture of the grid is shown in Fig. 3.

![Figure 3: Simple Cartesian structured grid.](image)
A complete FORTRAN code that creates this grid and uses API calls to write it to a CGNS file called grid.cgns is shown here (note that a FORTRAN line continuation is denoted by a +). This (and all later) coded examples are available from the CGNS website www.cgns.org (in the User’s Guide section). See Appendix B.

```fortran
program write_grid_str

! This program uses the fortran convention that all variables beginning with the letters i-n are integers, by default, and all others are real

! UNIX compilation (IRIX 5.3 or higher with mips4_64 option) for this program is:
! f90 -r8 -64 write_grid_str.f CGNSLib/lib/libcgns.mips4_64.a (Note it is compiled double precision because RealDouble is used below)
!

! must include path to cgnslib_f.h file:
! include 'CGNSLib/cgnslib_f.h'

! dimension statements (note that tri-dimensional arrays must be dimensioned exactly as (21,17,N) (N>=9) for this particular case or else they will be written to the CGNS file incorrectly! Other options are to use 1-D arrays, use dynamic memory, or pass index values to a subroutine and dimension exactly there):
! dimension x(21,17,9),y(21,17,9),z(21,17,9)
! dimension isize(3,3)
! character basename*32,zonename*32

! create gridpoints for simple example:
! ni=21
! nj=17
! nk=9
! do k=1,nk
! do j=1,nj
! do i=1,ni
! x(i,j,k)=float(i-1)
! y(i,j,k)=float(j-1)
! z(i,j,k)=float(k-1)
```
enddo
enddo
enddo
write(6, '( '' created simple 3-D grid points' ')')
c
WRITE X, Y, Z GRID POINTS TO CGNS FILE
c open CGNS file for write
call cg.open.f('grid.cgns',MODE_WRITE,index_file,ier)
c create base (user can give any name)
basename='Base'
icelldim=3
iphysdim=3
call cg.base.write.f(index_file,basename,icelldim,iphysdim,
+ index_base,ier)
c define zone name (user can give any name)
zonename = 'Zone 1'
c vertex size
isize(l,i)=21
isize(2,1)=17
isize(3,1)=9
c cell size
isize(1,2)=isize(1,1)-1
isize(2,2)=isize(2,1)-1
isize(3,2)=isize(3,1)-1
c boundary vertex size (always zero for structured grids)
isize(1,3)=0
isize(2,3)=0
isize(3,3)=0
c create zone
call cg.zone.write.f(index_file,index_base,zonename,isize,
+ Structured,index_zone,ier)
c write grid coordinates (user must use SIDS-standard names here)
call cg.coord.write.f(index_file,index_base,index_zone,RealDouble,
+ 'CoordinateX',x,index_coord,ier)
call cg.coord.write.f(index_file,index_base,index_zone,RealDouble,
+ 'CoordinateY',y,index_coord,ier)
call cg.coord.write.f(index_file,index_base,index_zone,RealDouble,
+ 'CoordinateZ',z,index_coord,ier)
c close CGNS file
call cg.close.f(index_file,ier)
write(6,('( '' Successfully wrote grid to file grid.cgns' ')'))
stop
end
There are several items to note regarding this code. Whenever a new entity is created using the API, an integer index is returned. This index is used in subsequent API calls to refer to the entity. For example, the above call to `cg_open_f`, which opens the file `grid.cgns`, assigns to this entity the index `index_file`. This same `index_file` is used to identify this entity in subsequent calls. Similarly, `cg_base_write_f` assigns an index `index_base` to the base, `cg_zone_write_f` assigns an index `index_zone` to the zone, and `cg_coord_write_f` assigns an index `index_coord` to each coordinate.

For FORTRAN code, an include statement pointing to `cgnslib_f.h` must be present. (The `cgnslib_f.h` file comes with the CGNS software.) Also, it is imperative that the `x`, `y`, and `z` arrays be dimensioned exactly as `(21,17,N)`, where \( N \geq 9 \) (or else as a one-dimensional array of at least size \( 21 \times 17 \times 9 \)) for this particular example; this is because the `cg_coord_write_f` routine writes the first \( 21 \times 17 \times 9 \) values contained in the array as it is stored in memory. If `x`, `y`, and `z` are tri-dimensional arrays and the first two indices are dimensioned larger than 21 and 17, respectively, then incorrect values will be placed in the CGNS file. In a real working code, one would probably either (a) use one-dimensional arrays, (b) dynamically allocate appropriate memory for `x`, `y`, and `z`, or else (c) pass the index values to a subroutine and write via an appropriately dimensioned work array.

In this case, the cell dimension (`icelldim`) is 3 (because the grid is made up of volume cells), and the physical dimension (`iphysdim`) is 3 (because 3 coordinates define 3-D). (Refer to Appendix C for a more detailed description.) The `isize` array contains the vertex size, cell size, and boundary vertex size for each index direction. For a 3-D structured grid, the index dimension is always the same as the cell dimension, so this means there are 3 vertex sizes, 3 cell sizes, and 3 boundary vertex sizes (one each for the \( i \), \( j \), and \( k \) directions). For structured grids, the cell size is always one less than the corresponding vertex size, and the boundary vertex size has no meaning and is always zero. When writing the grid coordinates, the user must use SIDS-standard names. For example, `x`, `y`, and `z` coordinates must be named `CoordinateX`, `CoordinateY`, and `CoordinateZ`, respectively. Other standard names exist for other possible choices (see [1]). Finally, `basename` and `zonename` must be declared as character strings, and the integer array `isize` must be dimensioned appropriately.

The grid coordinate arrays can be written in single or double precision. The desired data type is communicated to the API using the keywords `RealSingle` or `RealDouble`. The user must insure that the data type transmitted to the API is consistent with the one used in declaring the coordinates arrays. When it is compiled, the code must also link to the compiled CGNS library `libcgns.xxx.a`, where `xxx` is set depending on the computer system on which it is implemented. Instructions for compiling the CGNS library are given in README files that come with the CGNS software, or a pre-compiled `libcgns.xxx.a` library appropriate for a given system can be downloaded from the CGNS website.

A complete code written in C that performs the same task of creating grid coordinates and writing them to a CGNS file is given here.
/* Creates simple 3-D structured grid and writes it to a CGNS file. */ UNIX compilation (IRIX 5.3 or higher with mips4.64 option) for this program is: cc -r8 -64 write_grid_str.c CGNSLib/lib/libcgns.mips4.64.a (CGNSLib/lib/ is the location where the compiled library libcgns.mips4.64.a is located) (Note it is compiled double precision because RealDouble is used below) */ #include <stdio.h> /* must include path to cgnslib.h file: */ #include "CGNSLib/cgnslib.h" main() { /* dimension statements (note that tri-dimensional arrays x,y,z must be dimensioned exactly as [N][17][21] (N>=9) for this particular case or else they will be written to the CGNS file incorrectly! Other options are to use 1-D arrays, use dynamic memory, or pass index values to a subroutine and dimension exactly there): */ double x[9][17][21],y[9][17][21],z[9][17][21]; int isize[3][3]; int ni,nj,nk,i,j,k; int index_file,icelldim,iphysdim,index_base; int index_zone,index_coord; char *basename,*zonename; /* create gridpoints for simple example: */ ni=21; nj=17; nk=9; for (k=0; k < nk; ++k) { for (j=0; j < nj; ++j) { for (i=0; i < ni; ++i) { x[k][j][i]=i; y[k][j][i]=j; z[k][j][i]=k; } } }
printf("\ncreated simple 3-D grid points");

/* WRITE X, Y, Z GRID POINTS TO CGNS FILE */
/* open CGNS file for write */
cg_open("grid_c.cgns", MODE_WRITE, _index_file);
/* create base (user can give any name) */
basename="Base";
icelldim=3;
iphysdim=3;
cg_base_write(index_file, basename, icelldim, iphysdim, &index_base);
/* define zone name (user can give any name) */
zonename="Zone 1";
/* vertex size */
isize[0][0]=21;
isize[0][1]=17;
isize[0][2]=9;
/* cell size */
isize[1][0]=size[0][0]-1;
isize[1][1]=size[0][1]-1;
isize[1][2]=size[0][2]-1;
/* boundary vertex size (always zero for structured grids) */
isize[2][0]=0;
isize[2][1]=0;
isize[2][2]=0;
/* create zone */
cg_zone_write(index_file, index_base, zonename, *isize, Structured, 
&index_zone);
/* write grid coordinates (user must use SIDS-standard names here) */
cg_coord_write(index_file, index_base, index_zone, RealDouble, "CoordinateX", 
x, _index_coord);
cg_coord_write(index_file, index_base, index_zone, RealDouble, "CoordinateY", 
y, _index_coord);
cg_coord_write(index_file, index_base, index_zone, RealDouble, "CoordinateZ", 
z, _index_coord);
/* close CGNS file */
cg_close(index_file);
printf("\nSuccessfully wrote grid to file grid_c.cgns\n");
}

Note that in the C-code, the "h" file that must be included is called cgnslib.h. From now on, all codes will be given in FORTRAN only. The C-equivalent calls are similar, as demonstrated above. Also, from now on, complete code will not be shown, but rather
only code segments, in order to save space. However, complete codes can be accessed from the CGNS website www.cgns.org (in the User’s Guide section).

The CGNS file grid.cgns that is created by the code above is a binary file that, internally, possesses the tree-like structure shown in Fig. 4. As mentioned in the Introduction, each node has a name, a label, and may or may not contain data. In the example in the figure, all the nodes contain data except for the GridCoordinates node, for which MT indicates no data.

Figure 4: Layout of CGNS file for simple Cartesian structured grid.

However, the user really does not need to know the full details of the tree-like structure in this case. The API has automatically created a SIDS-compliant CGNS file! Now, the user can just as easily read the CGNS file using the API. The FORTRAN code segment used to read the CGNS file grid.cgns that we just created is given here:

```fortran
  c READ X, Y, Z GRID POINTS FROM CGNS FILE
  include 'cgnslib_f.h'
  c open CGNS file for read
  call cg_open_f('grid.cgns',MODE_READ,index_file,ier)
  c we know there is only one base (real working code would check!)
  index_base=1
```
c we know there is only one zone (real working code would check!)
   index_zone=1

c get zone size (and name - although not needed here)
   call cg_zone_read_f(index_file,index_base,index_zone,zonename,
   + isize,ier)

c lower range index
   irmin(1)=1
   irmin(2)=1
   irmin(3)=1

c upper range index of vertices
   irmax(1)=isize(1,1)
   irmax(2)=isize(2,1)
   irmax(3)=isize(3,1)

c read grid coordinates
   call cg_coord_read_f(index_file,index_base,index_zone,
   + 'CoordinateX',RealSingle,irmin,irmax,x,ier)
   call cg_coord_read_f(index_file,index_base,index_zone,
   + 'CoordinateY',RealSingle,irmin,irmax,y,ier)
   call cg_coord_read_f(index_file,index_base,index_zone,
   + 'CoordinateZ',RealSingle,irmin,irmax,z,ier)

c close CGNS file
   call cg_close_f(index_file,ier)

Note that this FORTRAN coding is very rudimentary. It assumes that we know that
there is only one base and one zone. In a real working code, one should check the
numbers in the file, and either allow for the possibility of multiple bases or zones, or
explicitly disallow it. Also, this coding implicitly assumes that the grid.cgns file is a
3-D structured grid (cell dimension = physical dimension = 3). In a real working code,
one should check to make sure that this is true, or else allow for other possibilities. One
should also check to make sure the zone type is **Structured** if this is the type expected.

As before, the x, y, and z arrays in this case *must* be dimensioned correctly: for a tri-
dimensional array, (21,17,N), where \(N \geq 9\). (In a real working code, one would probably
either (a) use one-dimensional arrays, (b) dynamically allocate appropriate memory for x,
y, and z after reading isize, or else (c) pass the isize values to a subroutine and dimension
a work array appropriately prior to reading.) Also note that, regardless of the precision
in which the grid coordinates were written to the CGNS file (single or double), one can
read them either way; the API automatically performs the translation. (The arrays x,
y, and z in the code above must be declared as single precision if **RealSingle** is used
and as double precision if **RealDouble** is used.) Finally, isize should be dimensioned
appropriately, zonename should be declared as a character variable, and irmin and irmax
should be dimensioned appropriately.
2.1.2 Single-Zone Structured Grid and Flow Solution

In this section, we now write a flow solution associated with the grid from section 2.1.1. We assume that we have two flow solution arrays available: static density and static pressure. To illustrate three important options, we will show how to write the flow solution (a) at vertices, (b) at cell centers, and (c) at cell centers plus rind cells.

(a) Flow Solution at Vertices

The first option is illustrated schematically in 2-D in Fig. 5. Simply stated, a Vertex flow solution is located at the same location as the grid points. Assuming that the grid points have already been written to a CGNS file, the following FORTRAN code segment adds the flow solution at vertices:

![Figure 5: Schematic showing location (circles) of Vertex flow solution relative to grid.](image)

c WRITE FLOW SOLUTION TO EXISTING CGNS FILE
   include 'cgnslib_f.h'
c open CGNS file for modify
   call cg.open_f('grid.cgns',MODE.MODIFY,index_file,ier)
c we know there is only one base (real working code would check!)
   index_base=1
   we know there is only one zone (real working code would check!)
   index_zone=1
   define flow solution node name (user can give any name)
   solname = 'FlowSolution'
c create flow solution node
   call cg.sol_write_f(index_file,index_base,index_zone,solname,
                     + Vertex,index_flow,ier)
c write flow solution (user must use SIDS-standard names here)
In this code, the density ($r$) and pressure ($p$) variables *must* be dimensioned correctly for this particular case: for a tri-dimensional array, $(21,17,N)$, where $N \geq 9$ (see discussion in section 2.1.1). Note that the API, knowing that the flow solution type is Vertex, automatically writes out the correct index range, corresponding with the zone’s grid index range. Also note that we opened the existing CGNS file and modified it (MODE_MODIFY) - we knew ahead of time that only one base and only one zone exist; a real working code would make appropriate checks. Finally, solname should be declared as a character variable and $r$ and $p$ must be declared as double precision variables when RealDouble type is used.

The layout of the CGNS file with the flow solution at vertices included is shown in Fig. 6. The three nodes under GridCoordinates_t have been left out to conserve space in the figure, but they exist as indicated by the three unconnected lines.

The vertex flow solution can be read in using the following FORTRAN code segment (can read in as single or double precision – see discussion in section 2.1.1):
Figure 6: Layout of CGNS file for simple Cartesian structured grid with flow solution at vertices. (Note: because GridLocation = Vertex is the default, it is not necessary to specify it. In fact, the latest API software does not include this node in the file.)
+ solname, loc, ier)
   if (loc .ne. Vertex) then
      write(6, _ ( _ _ Error, GridLocation must be Vertex!’’))
      stop
   end if
   irmax(1) = isize(1, 1)
   irmax(2) = isize(2, 1)
   irmax(3) = isize(3, 1)

   c read flow solution
   call cg_field_read_f(index_file, index_base, index_zone, index_flow,
   + ’Density’, RealSingle, irmin, irmax, r, ier)
   call cg_field_read_f(index_file, index_base, index_zone, index_flow,
   + ’Pressure’, RealSingle, irmin, irmax, p, ier)
   c close CGNS file
   call cg_close_f(index_file, ier)

Note that this code segment assumes that it is known that the flow solution contains
no rind data (to be covered in detail below). If rind data does exist, but the user does
not account for it, then the flow solution information will be read incorrectly. Hence, a
real working code would check for rind cells, and adjust the dimensions and index ranges
appropriately. Other similar cautions as those mentioned earlier regarding dimensioning
of variables, real working code checks, etc., apply here as well. These cautions will not
always be repeated from this point forward.

(b) Flow Solution at Cell Centers

The option for outputting the flow solution at cell centers is illustrated schematically
in 2-D in Fig. 7. The flow solutions are defined at the centers of the cells defined by the
four surrounding grid points. In 3-D, the cell centers are defined by eight surrounding
grid points. The code segment to write to cell centers is identical to that given above for
vertices, except that the call to cg_sol_write_f is replaced by:

   c create flow solution node (NOTE USE OF CellCenter HERE)
   call cg_sol_write_f(index_file, index_base, index_zone, solname, CellCenter,
   + index_flow, ier)

Also, now the density (r) and pressure (p) variables must be dimensioned correctly for
this particular case: for a tri-dimensional array, (20,16,N), where N ≥ 8 (i.e., one less in
each index dimension than the grid itself). Again, the API, knowing that the flow solution
type is CellCenter, automatically writes out the correct index range, corresponding with
the zone’s grid index range minus 1 in each index direction.

The layout of the CGNS file with the flow solution at cell centers is shown (below the
Figure 7: Schematic showing location (circles) of CellCenter flow solution relative to grid.

FlowSolution_t node only) in Fig. 8. Note that the indices over which the flow solutions are written are now from (1, 1, 1) to (20, 16, 8) (contrast with the FlowSolution part of Fig. 6).

Figure 8: Layout of CGNS file (under FlowSolution_t node) for simple Cartesian structured grid with flow solution at cell centers.

The FORTRAN code segment to read in the solution at cell centers is the same as that given above for vertices, except that the section that defines irmax is replaced by:

c upper range index - use cell dimensions
c checking GridLocation first (real working code would check
c to make sure there are no Rind cells also!):
call cg_sol_info_f(index_file, index_base, index_zone, index_flow, 
+    solname, loc, ier)
if (loc .ne. CellCenter) then
    write(6,'('' Error, GridLocation must be CellCenter!'')')
    stop
end if
irmax(1)=isize(1,2)
irmax(2)=isize(2,2)
irmax(3)=isize(3,2)

and, as usual, the r and p arrays must be dimensioned appropriately.

(c) Flow Solution at Cell Centers With Additional Rind Data

Rind data is additional flow solution data exterior to a structured grid, at “ghost cell” locations. Rind data can be associated with other GridLocation values beside CellCenter, although we only show an example using CellCenter here. The option for outputting the flow solution at cell centers with additional rind data is illustrated schematically in 2-D in Fig. 9. In this diagram, we show one layer of rind cell data in the row below the grid itself. There could be rind data at other sides of the grid, or there could be more than one row at a given side.

![Figure 9: Schematic showing location (circles) of CellCenter flow solution, including rind cells, relative to grid.](image)

In CGNS, the flow solution at rind cells is not stored as separate entities, but rather the flow solution range is extended to include the rind cells. For example, in the 2-D schematic of Fig. 9, instead of an index range of p(3,2) for pressures stored at the cell centers, the flow solution would now have an index range of p(3,0:2) or p(3,3). See [1]
For details.

For our 3-D example, we assume that we have one row of rind data at 4 faces of the zone (ilo, ihi, jlo, jhi, where these represent the low and high ends of the i and j directions, respectively), and no rind cells at klo or khi (at either end of the k direction). The code segment to write the flow solution and rind data is as follows:

```fortran
  c WRITE FLOW SOLUTION TO EXISTING CGNS FILE
  include 'cgnslib_f.h'
  c open CGNS file for modify
    call cg_open_f('grid.cgns',MODE_MODIFY,index_file,ier)
  c we know there is only one base (real working code would check!)
    index_base=1
  c we know there is only one zone (real working code would check!)
    index_zone=1
  c define flow solution node name (user can give any name)
    solname = 'FlowSolution'
  c create flow solution node
    call cg_sol_write_f(index_file,index_base,index_zone,solname,CellCenter,
                          index_flow,ier)
  c go to position within tree at FlowSolution_t node
    call cg_goto_f(index_file,index_base,ier,' Zone_t ',index_zone,
                   'FlowSolution_t',index_flow,'end')
  c write rind information under FlowSolution_t node (ilo,ihi,jlo,jhi,klo,khi)
    irinddata(1)=ilo
    irinddata(2)=ihi
    irinddata(3)=jlo
    irinddata(4)=jhi
    irinddata(5)=klo
    irinddata(6)=khi
    call cg_rind_write_f(irinddata,ier)
  c write flow solution (user must use SIDS-standard names here)
    call cg_field_write_f(index_file,index_base,index_zone,index_flow,
                           RealDouble,' Density ',r,index_field,ier)
    call cg_field_write_f(index_file,index_base,index_zone,index_flow,
                           RealDouble,' Pressure ',p,index_field,ier)
  c close CGNS file
    call cg_close_f(index_file,ier)
```

Note that in the case of rind data, the user must position the Rind_t node appropriately, using the cg_goto_f call. In this case, the Rind_t node belongs under the FlowSolution_t node.

For this case of cell center flow solution with rind data, the density (r) and pressure (p) are written to the CGNS file with the following index ranges: from $i = 0$ to $i = 20 + 1 = 21$
(or a total $i$ length of 22), from $j = 0$ to $j = 16 + 1 = 17$ (or a total $j$ length of 18), and from $k = 1$ to $k = 8$. The variables $r$ and $p$ must be dimensioned appropriately to reflect these index ranges modified by the rind values.

The layout of the CGNS file for this example (below the FlowSolution.t node only) is shown in Fig. 10. Compare this figure with Figs. 6 and 8.

![Diagram of CGNS file structure]

Figure 10: Layout of CGNS file (under FlowSolution.t node) for simple Cartesian structured grid with flow solution at cell centers plus rind data.

A FORTRAN code segment to read the flow solution for this example is:

```fortran
! READ FLOW SOLUTION FROM CGNS FILE
include 'cgnslib_f.h'
open CGNS file for read
  call cg_open_f('grid.cgns',MODE_READ,index_file,ier)
we know there is only one base (real working code would check!)
  index_base=1
we know there is only one zone (real working code would check!)
  index_zone=1
we know there is only one FlowSolution.t (real working code would check!)
  index_flow=1
get zone size (and name - although not needed here)
  call cg_zone_read_f(index_file,index_base,index_zone,zonename,isize,ier)
go to position within tree at FlowSolution.t node
  call cg_goto_f(index_file,index_base,ier,'Zone_t',index_zone,
    'FlowSolution.t',index_flow,'end')
read rind data
  call cg_rind_read_f(irinddata,ier)
lower range index
  irmin(1)=1
```
2.1.3 Single-Zone Structured Grid with Boundary Conditions

To illustrate the use of boundary conditions, we again use the same single-zone Cartesian grid from section 2.1.1. Referring back to Fig. 3, we wish to apply the following:

\[
\begin{align*}
\text{ilo} & \quad \text{BCTunnelInflow} \\
\text{ihi} & \quad \text{BCExtrapolate} \\
\text{jlo} & \quad \text{BCWallInviscid} \\
\text{jhi} & \quad \text{etc.} \\
\text{klo} & \quad \text{etc.} \\
\text{khi} & \quad \text{etc.}
\end{align*}
\]

where BCTunnelInflow, BCExtrapolate, and BCWallInviscid are data-name identifiers for boundary conditions. The complete list of boundary condition identifiers is found in [1]. In this example, we take the approach of using the lowest-level BC implementation allowed – see Fig. 24 and the discussion in Appendix C.

In this section, we show two different approaches for defining the region over which each boundary condition acts. The first is with type \texttt{PointRange}, meaning that we define the minimum and maximum points on a face that define a logically rectangular region (this method is usable only for faces that are capable of being defined in this way). The second is with type \texttt{PointList}, which gives the list of all the points for which the boundary condition applies. This latter method is generally used for unstructured zones or for any zone whose defined region is not logically rectangular.
(a) Boundary Conditions Specifying Range

A FORTRAN code segment to write the boundary condition information of type PointRange to the existing CGNS file from section 2.1.1 or 2.1.2 is given here:

```fortran
! WRITE BOUNDARY CONDITIONS TO EXISTING CGNS FILE
include 'cgnslib.f.h'
!
!
! open CGNS file for modify
! call cg.open('grid.cgns',MODE.MODIFY,index_file,ier)
!
! we know there is only one base (real working code would check!)
index_base=1
!
! we know there is only one zone (real working code would check!)
index_zone=1
!
! get zone size (and name - although not needed here)
! call cg.zone_read(index_file,index_base,index_zone,zonename,
+ isize,ier)
ilo=1
ihi=isize(1,1)
jlo=1
jhi=isize(2,1)
klo=1
khi=isize(3,1)
!
! write boundary conditions for ilo face, defining range first
! (user can give any name)
!
! lower point of range
ipnts(1,1)=ilo
ipnts(2,1)=jlo
ipnts(3,1)=klo
!
! upper point of range
ipnts(1,2)=ilo
ipnts(2,2)=jhi
ipnts(3,2)=khi
! call cg.boco_write(index_file,index_base,index_zone,'Ilo',
+ 'BCTunnelInflow',PointRange,2,ipnts,index_bc,ier)
!
! write boundary conditions for ihi face, defining range first
! (user can give any name)
!
! lower point of range
ipnts(1,1)=ihi
ipnts(2,1)=jlo
ipnts(3,1)=klo
!
! upper point of range
ipnts(1,2)=ihi
ipnts(2,2)=jhi
```

22
ipnts(3,2)=khi
        call cg.boco.write.f(index_file,index_base,index_zone,'Ihi',
                           + BCExtrapolate,PointRange,2,ipnts,index_bc,ier)
c write boundary conditions for jlo face, defining range first
c (user can give any name)
c lower point of range
        ipnts(1,1)=ilo
        ipnts(2,1)=jlo
        ipnts(3,1)=klo
c upper point of range
        ipnts(1,2)=ihi
        ipnts(2,2)=jlo
        ipnts(3,2)=khi
        call cg.boco.write.f(index_file,index_base,index_zone,'Jlo',
                           + BCWallInviscid,PointRange,2,ipnts,index_bc,ier)
          etc...
c close CGNS file
        call cg.close.f(index_file,ier)

The zone names (e.g., Ilo) are arbitrary. Note that the variable zonename must be
declared as a character variable, and isize and ipnts must be dimensioned appropriately.
The layout of the CGNS file for this example is shown in Fig. 11. Four of the children
nodes of ZoneBC.t are left off for clarity.

Reading the boundary conditions can also be easily accomplished using API calls, but
we do not show an example of this here. Because there are multiple BC.t children nodes
under the ZoneBC.t node, the user must first read in the number of children nodes that
exist, then loop through them and retrieve the information from each.

(b) Boundary Conditions Specifying Points

The FORTRAN code segment to write the boundary conditions using PointList is
the same as that for PointRange except that the following segment, for example,

        c write boundary conditions for ilo face, defining range first
        c (user can give any name)
        ipnts(1,1)=ilo
        ipnts(2,1)=jlo
        ipnts(3,1)=klo
        ipnts(1,2)=ilo
        ipnts(2,2)=jhi
        ipnts(3,2)=khi
        call cg.boco.write.f(index_file,index_base,index_zone,'Ilo',
                           + BCTunnelInflow,PointRange,2,ipnts,index_bc,ier)
Figure 11: Layout of CGNS file for simple Cartesian structured grid with flow solution and boundary conditions using PointRange.
is replaced by:

```c
write boundary conditions for ilo face, defining pointlist first
(c user can give any name)
  icount=0
  do j=jlo,jhi
    do k=klo,khi
      icount=icount+1
      ipnts(1,icount)=ilo
      ipnts(2,icount)=j
      ipnts(3,icount)=k
    enddo
  enddo
  call cg_boco_write_f(index_file,index_base,index_zone,'Ilo',
                       BCTunnelInflow,PointList,icount,ipnts,index_bc,ier)
```

The layout of the CGNS file in this case is the same as Fig. 11, except that `PointRange (IndexRange_t)` becomes `PointList (IndexArray_t)` and there is `icount` data in the `PointList` nodes.

### 2.1.4 Multi-Zone Structured Grid with 1-to-1 Connectivity

For the case of a multi-zone structured grid, each zone is handled individually in the same way as the examples in the preceding sections. However, multi-zone grids also require additional information about how the zones are connected to one another. A discussion of different types of zone-to-zone connectivity can be found in Appendix C. For the example in this section, we show only a simple 1-to-1 connectivity example. We assume that we have a two-zone grid, each identical to the one showed in Fig. 3 (21 x 17 x 9), except that zone 2 is offset in the x-direction by 20 units. Thus, the ilo face of zone 2 abuts the ihi face of zone 1, and each abutting point in the two zones touches a point from the neighboring zone. A picture of the grid is shown in Fig. 12.

The overall layout of this two-zone CGNS file is not shown here. It is similar to those shown earlier, except now there are two zones rather than one. See Appendix C for an additional example.

Now, 1-to-1 connectivity information must be written into each of the zones. There are two ways to record this 1-to-1 information. The first (specific) method is valid only for 1-to-1 interfaces, and the regions must be logically rectangular (because they are recorded via `PointRange` and `PointRangeDonor` nodes, for which only two points define the entire region). The second way is more general. It uses `PointList` nodes in combination with `PointListDonor`. (A third method, used to describe interfaces that are not point-matched – such as mismatched or overset zones – employs `CellListDonor`
and InterpolantsDonor.) Refer to the SIDS document [1] for details on the various methods for describing connectivity.

(a) Connectivity Using Specific 1-to-1 Method

The 1-to-1 connectivity information for the current example can be written to a CGNS file using the following FORTRAN code segment (assuming that all grid information has already been written):

```fortran
C WRITE 1-TO-1 CONNECTIVITY INFORMATION TO EXISTING CGNS FILE
include 'cgnslib.f.h'
c open CGNS file for modify
   call cg_open_f('grid.cgns',MODE_MODIFY,index_file,ier)
c we know there is only one base (real working code would check!)
   index_base=1

c get number of zones (should be 2 for our case)
   call cg_nzones_f(index_file,index_base,nzone,ier)
c loop over zones to get zone sizes and names
   do index_zone=1,nzone
      call cg_zone_read_f(index_file,index_base,index_zone,
      +   zonename(index_zone),isize,ier)
      ilo(index_zone)=1
      ihi(index_zone)=isize(1,1)
```

Figure 12: 2-Zone Cartesian structured grid with 1-to-1 connectivity.
jlo(index_zone)=1
jhi(index_zone)=isize(2,1)
klo(index_zone)=1
khi(index_zone)=isize(3,1)
enddo
c loop over zones again
do index_zone=1,nzone
c set up index ranges
  if (index_zone .eq. 1) then
donorname=zonename(2)
c lower point of receiver range
  ipnts(1,1)=ihi(1)
  ipnts(2,1)=jlo(1)
  ipnts(3,1)=klo(1)
c upper point of receiver range
  ipnts(1,2)=ihi(1)
  ipnts(2,2)=jhi(1)
  ipnts(3,2)=khi(1)
c lower point of donor range
  ipntsdonor(1,1)=ilo(2)
  ipntsdonor(2,1)=jlo(2)
  ipntsdonor(3,1)=klo(2)
c upper point of donor range
  ipntsdonor(1,2)=ilo(2)
  ipntsdonor(2,2)=jhi(2)
  ipntsdonor(3,2)=khi(2)
else
  donorname=zonename(1)
c lower point of receiver range
  ipnts(1,1)=ilo(2)
  ipnts(2,1)=jlo(2)
  ipnts(3,1)=klo(2)
c upper point of receiver range
  ipnts(1,2)=ilo(2)
  ipnts(2,2)=jhi(2)
  ipnts(3,2)=khi(2)
c lower point of donor range
  ipntsdonor(1,1)=ihi(1)
  ipntsdonor(2,1)=jlo(1)
  ipntsdonor(3,1)=klo(1)
c upper point of donor range
  ipntsdonor(1,2)=ihi(1)
  ipntsdonor(2,2)=jhi(1)
  ipntsdonor(3,2)=khi(1)
end if
c set up Transform
   itranfrm(1)=1
   itranfrm(2)=2
   itranfrm(3)=3

c write 1-to-1 info (user can give any name)
   call cg_itol_write_f(index_file,index_base,index_zone,
                        + 'Interface',donorname,ipnts,ipntsdonor,itranfrm,
                        + index.conn,ier)
enddo

c close CGNS file
   call cg_close_f(index_file,ier)

Note that this code segment is geared very specifically toward our 2-zone example, i.e., it relies on our knowledge of this particular case. Transform defines the relative orientation of the i, j, and k indices of the abutting zones. Details concerning the values of Transform are not given here; they can be found in [1]. However, note that Transform values of (1,2,3) indicate that the i, j, k axes of both zones are oriented in the same directions. Reading the connectivity information can also be easily accomplished using API calls, but we do not show an example of this here. And finally, we do not show the layout of the nodes associated with the connectivity here. The interested user is referred to Appendix C for an example figure.

(b) Connectivity Using General Method

Using a more general method, for which each connectivity pair is listed (rather than ranges), the connectivity information for the current example can be written to a CGNS file using the following FORTRAN code segment:

c WRITE GENERAL CONNECTIVITY INFORMATION TO EXISTING CGNS FILE
   include 'cgnslib_f.h'

c open CGNS file for modify
   call cg_open_f('grid.cgns',MODE_MODIFY,index_file,ier)

c we know there is only one base (real working code would check!)
   index_base=1

c get number of zones (should be 2 for our case)
   call cg_nzones_f(index_file,index_base,nzone,ier)

c loop over zones to get zone sizes and names
   do index_zone=1,nzone
      call cg_zone_read_f(index_file,index_base,index_zone,
                          + zonename(index_zone),isize,ier)
      ilo(index_zone)=1
      ihi(index_zone)=isize(1,1)
      jlo(index_zone)=1
jhi(index_zone)=isize(2,1)
klo(index_zone)=1
khi(index_zone)=isize(3,1)
enddo

c loop over zones again
do index_zone=1,nzone

c set up point lists
  if (index_zone .eq. 1) then
    icount=0
    do j=jlo(index_zone),jhi(index_zone)
      do k=klo(index_zone),khi(index_zone)
        icount=icount+1
        ipnts(1,icount)=ihi(1)
        ipnts(2,icount)=j
        ipnts(3,icount)=k
        ipntsdonor(1,icount)=ilo(2)
        ipntsdonor(2,icount)=j
        ipntsdonor(3,icount)=k
      enddo
    enddo
  else
    donorname=zonename(2)
  end if
  icount=0
  do j=jlo(index_zone),jhi(index_zone)
    do k=klo(index_zone),khi(index_zone)
      icount=icount+1
      ipnts(1,icount)=ilo(2)
      ipnts(2,icount)=j
      ipnts(3,icount)=k
      ipntsdonor(1,icount)=ihi(1)
      ipntsdonor(2,icount)=j
      ipntsdonor(3,icount)=k
    enddo
  enddo
  donorname=zonename(1)
end if

c write integer connectivity info (user can give any name)
call cg_conn_write_f(index_file,index_base,index_zone,  
  'GenInterface',Vertex,AbuttingItol1,PointList,icount,ipnts,  
  donorname,Structured,PointListDonor,Integer,icount,  
  ipntsdonor,index_conn,ier)
enddo

c close CGNS file

call cg_close_f(index_file,ier)
We do not describe the method for recording mismatched (patched) or overset connectivity information in this document; the user is referred to [1] for details. However, note that in such cases the use of CellListDonor (along with InterpolantsDonor) implies the specification of cell center indices on the donor side (these would correspond to element numbers in unstructured zones). The InterpolantsDonor information consists of real-valued interpolants.
2.2 Unstructured Grid

This section gives several unstructured grid examples. The user should already be fam-
iliar with the information covered in section 2.1, which gives structured grid examples.
Because much of the organization of the CGNS files is identical for both grid types, many
of the ideas covered in the structured grid section are not repeated again here.

2.2.1 Single-Zone Unstructured Grid

This example uses the exact same grid shown earlier in Fig. 3. However, it is now written
as an unstructured grid, which is made up of a series of 6-sided elements (cubes in this
case). A FORTRAN code segment that uses API calls to write this grid to a CGNS file
called grid.cgns is shown here (note that it does not matter how the nodes are ordered
in an unstructured zone, but in this example they are ordered sequentially for simplicity
of presentation):

c WRITE X, Y, Z GRID POINTS TO CGNS FILE
   include 'cgnslib_f.h'
c open CGNS file for write
   call cg_open_f('grid.cgns',MODE_WRITE,index_file,ier)
c create base (user can give any name)
   basename='Base'
   icelldim=3
   iphysdim=3
   call cg_base_write_f(index_file,basename,icelldim,iphysdim,index_base,ier)
c define zone name (user can give any name)
   zonename = 'Zone 1'
c We use the same grid as for the structured example with ni=21,
c nj=17, nk=9. The variables ni, nj, and nk are still used later,
c for convenience when numbering the unstructured grid elements.
   ni=21
   nj=17
   nk=9
   c vertex size (21*17*9 = 3213)
   isize(1,1)=3213
   c cell size (20*16*8 = 2560)
   isize(1,2)=2560
   c boundary vertex size (zero if elements not sorted)
   isize(1,3)=0
   c create zone
   call cg_zone_write_f(index_file,index_base,zonename,isize,
   + Unstructured,index_zone,ier)
c write grid coordinates (user must use SIDS-standard names here)
   call cg_coord_write_f(index_file,index_base,index_zone,RealDouble,
+ 'CoordinateX',x,index_coord,ier)
call cg.coord.write.f(index_file,index_base,index_zone,RealDouble,
+ 'CoordinateY',y,index_coord,ier)
call cg.coord.write.f(index_file,index_base,index_zone,RealDouble,
+ 'CoordinateZ',z,index_coord,ier)
c set element connectivity:
c do all the HEXA_8 elements (this part is mandatory):
c maintain SIDS-standard ordering
  ielem_no=0
c index no of first element
  nelem_start=1
do k=1,nk-1
do j=1,nj-1
do i=1,ni-1
    ielem_no=ielem_no+1
c in this example, due to the order in the node numbering, the
c hexahedral elements can be reconstructed using the following
c relationships:
    ifirstnode=i+(j-1)*ni+(k-1)*ni_nj
    ielem(1,ielem_no)=ifirstnode
    ielem(2,ielem_no)=ifirstnode+1
    ielem(3,ielem_no)=ifirstnode+1+ni
    ielem(4,ielem_no)=ifirstnode+ni
    ielem(5,ielem_no)=ifirstnode+ni*nj
    ielem(6,ielem_no)=ifirstnode+ni*nj+1
    ielem(7,ielem_no)=ifirstnode+ni*nj+1+ni
    ielem(8,ielem_no)=ifirstnode+ni*nj+ni
  enddo
  enddo
c index no of last element (=2560)
  nelem_end=ielem_no
c unsorted boundary elements
  nbdyelem=0
c write HEXA_8 element connectivity (user can give any name)
call cg.section.write.f(index_file,index_base,index_zone,
+ 'Elem',HEXA_8,nelem_start,nelem_end,nbdyelem,ielem,
+ index_section,ier)
c close CGNS file
call cg.close.f(index_file,ier)

Note that for unstructured zones, the index dimension is always 1 (because only one
index value is required to identify a position in the mesh), so the isize array contains
the total vertex size, cell size, and boundary vertex size for the zone. In this example, the
The node points that lie in the lower left corner of Fig. 3 are shown schematically for two elements in Fig. 13. Here it can be seen, for example, that node numbers 1, 2, 23, 22, 358, 359, 380, and 379 make up element 1.

Figure 13: Schematic representation of nodes and elements of unstructured grid.

The overall layout of the CGNS file created by the above code segment is shown in Fig. 14. The nodes for y and z are left off due to lack of space. Compare this figure with the layout for the structured version of this grid in Fig. 4.

For unstructured zones, the user may also wish to separately list the boundary elements in the CGNS file. This may be useful for assigning boundary conditions, as we will show in section 2.2.3 below. In the current example, assume that the user wishes to assign three different types of boundary conditions: inflow at one end, outflow at the other end, and side walls on the four faces in-between. To accomplish this, it would be helpful to have three additional Elements_t nodes in the CGNS file, each of which lists the corresponding faces as elements (QUAD_4 in this case).

A FORTRAN code segment that accomplishes a part of this is given here. It may be a part of the same code (above) that defined the grid and HEXA_8 connectivity.

c do boundary (QUAD) elements (this part is optional,
c but you must do it if you eventually want to define BCs
 c at element faces rather than at nodes):
c INFLOW:
ielem_no=0
 c index no of first element
 nelem_start=nelem_end+1
Figure 14: Layout of CGNS file for unstructured grid.
i=1
do k=1,nk-1
  do j=1,nj-1
    ielem_no=ielem_no+1
    ifirstnode=i+(j-1)*ni+(k-1)*ni*nj
    jelem(1,ielem_no)=ifirstnode
    jelem(2,ielem_no)=ifirstnode+ni*nj
    jelem(3,ielem_no)=ifirstnode+ni*nj+ni
    jelem(4,ielem_no)=ifirstnode+ni
  enddo
enddo

c index no of last element
nelem_end=nelem_start+ielem_no-1

c write QUAD element connectivity for inflow face (user can give any name)
call cg_section_write_f(index_file,index_base,index_zone,
+  'InflowElem',QUAD_4,nelem_start,nelem_end,nbdyelem,
+  jelem,index_section,ier)

c OUTFLOW:
  ... etc...

In this example, the jelem array must be dimensioned exactly as (4,N), where N is
greater than or equal to the total number of elements. Note that the nelem_start and
range is defined subsequent to the range of any other elements (i.e., the HEXA_8
elements) already defined in this zone. In other words, all elements in a given zone must
have a different number.

The layout of the CGNS file in this case is exactly the same as that shown in Fig. 14,
except that there are now three additional Elements_t nodes under Zone_t. These are
shown separately in Fig. 15.

2.2.2 Single-Zone Unstructured Grid and Flow Solution

To add a flow solution to an unstructured zone, the procedure is identical to that for
a structured zone. However, rind cells are not valid for unstructured zones and should
not be used. In other words, the code segments given in section 2.1.2 for vertex and
cell-center flow solutions (subsections (a) and (b)) are valid for unstructured zones as
well, but the code segments that use rind cells (subsection (c)) are not. For the vertex
and cell-center examples, the only difference for unstructured zones is that all arrays are
one-dimensional (there is only one index), as opposed to three indices for 3-D structured
arrays. A vertex solution indicates that the solution is stored at vertices or nodes. In
the above example, there would be lists of 3213 data array items per solution variable.
A cell center solution implies that the solution is stored at the center of each element. In
the above example, there would be lists of 2560 data array items per solution variable.

The overall layout of the CGNS file is the same as that shown in Fig. 14, except that
there would also be a `FlowSolution_t` node under `Zone 1`, and this node would have the children nodes `GridLocation`, `Density`, and `Pressure`.

### 2.2.3 Single-Zone Unstructured Grid with Boundary Conditions

When writing boundary conditions to a CGNS file for an unstructured zone, one follows the same general procedure outlined in section 2.1.3 for a structured zone. In other words, the boundary conditions are defined for point ranges or for individual points, where the points refer to nodes (vertices) of the grid. Coding would be essentially the same as that presented in section 2.1.3, except that the points and/or ranges are now one-dimensional (there is only one index), as opposed to three indices for 3-D structured arrays.

However, one also has other options for unstructured zones. For example, if one wishes to apply boundary conditions at face centers rather than at vertices, one can create additional `Elements_t` nodes that define the boundary face elements, and then point to these elements rather than to the nodes. By default, boundary conditions are assumed to apply at vertices (nodes). But when `GridLocation` is something other than `Vertex`, then the boundary conditions for an unstructured zone no longer refer to nodes, but to elements.

Because this concept is quite different from what was done with the structured zone earlier, we illustrate it with an example. At the end of section 2.2.1, we showed how to create the additional `Elements_t` nodes defining the boundary faces. The face-center boundary conditions now can be written using the following code segment.
c WRITE BOUNDARY CONDITIONS TO EXISTING CGNS FILE
   include 'cgnslib.f.h'
c open CGNS file for modify
   call cg_open_f('grid.cgns',MODE_MODIFY,index_file,ier)
c we know there is only one base (real working code would check!)
   index_base=1
c we know there is only one zone (real working code would check!)
   index_zone=1
c we know that for the unstructured zone, the following face elements
c have been defined as inflow (real working code would check!):
   nelem_start=2561
   nelem_end=2688
   icount=0
   do n=nelem_start,nelem_end
      icount=icount+1
      ipnts(icount)=n
   enddo
c write boundary conditions for ilo face
   call cg_boco_write_f(index_file,index_base,index_zone,'Ilo',
   + BC TunnelInflow,PointList,icount,ipnts,index_bc,ier)
c we know that for the unstructured zone, the following face elements
c have been defined as outflow (real working code would check!):
   nelem_start=2689
   nelem_end=2816
   icount=0
   do n=nelem_start,nelem_end
      icount=icount+1
      ipnts(icount)=n
   enddo
c write boundary conditions for ihi face
   call cg_boco_write_f(index_file,index_base,index_zone,'Ihi',
   + BCExtrapolate,PointList,icount,ipnts,index_bc,ier)
c we know that for the unstructured zone, the following face elements
c have been defined as walls (real working code would check!):
   nelem_start=2817
   nelem_end=3776
   icount=0
   do n=nelem_start,nelem_end
      icount=icount+1
      ipnts(icount)=n
   enddo
c write boundary conditions for wall faces
   call cg_boco_write_f(index_file,index_base,index_zone,'Walls',
   + BCWallInviscid,PointList,icount,ipnts,index_bc,ier)
c
c the above are all face-center locations for the BCs - must indicate this, 
c otherwise Vertices will be assumed!
do iibc=1,index_bc
  c (the following call positions you in BC.t - it assumes there
  c is only one Zone.t and one ZoneBC.t - real working code would check!)
    call cg.goto.f(index_file,index_base,ier,'Zone.t',1,
        'ZoneBC.t',1,'BC.t',ibc,'end')
    call cg.gridlocation.write.f(FaceCenter,ier)
  enddo
  c close CGNS file
  call cg.close.f(index_file,ier)

Note that we assume here that we know in advance the element numbers associated 
with each of the boundaries. We have written these element numbers as a PointList, 
but, because they are in order, we could just as easily have used PointRange instead. In 
that case, only two ipnts values would be needed, equal to nelem_start and nelem_end, 
and icount would be 2. Finally, note that the GridLocation_t node under BC.t must be 
written using the API call cg.goto.f (which positions you correctly in the tree) followed 
by cg.gridlocation.write.f.

A portion of the layout of the CGNS file for the ZoneBC.t node and its children is 
shown in Fig. 16. The ZoneBC.t node lies directly under Zone.t. The three figures, 
Figs. 14, 15, and 16 taken together, constitute the entire layout of the file.

![Figure 16: Layout of part of CGNS file for an unstructured zone with boundary conditions defined at face-center elements.](image-url)
3 ADDITIONAL INFORMATION

This section introduces several additional types of data in CGNS. These items are by no means necessary to include when getting started, but it is likely that most users will eventually want to implement some of them into their CGNS files at some point in the future. The section ends with a discussion on the usage of links.

3.1 Convergence History

The ConvergenceHistory_t node can be used to store data associated with the convergence of a CFD solution. For example, one may wish to store the global coefficient of lift as a function of iterations. In this case, this variable should be stored at the CGNSBase_t level of the CGNS file. This is achieved using the API in the following FORTRAN code segment:

```fortran
! WRITE CONVERGENCE HISTORY INFORMATION TO EXISTING CGNS FILE
include 'cgnslib_f.h'
!
c open CGNS file for modify
   call cg_open_f(grid.cgns,MODE_MODIFY,index_file,ier)
!
c we know there is only one base (real working code would check!)
   index_base=1
!
c go to base node
   call cg_goto_f(index_file,index_base,ier,'end')
!
c ntt is the number of recorded iterations
   call cg_convergence_write_f(ntt,'',ier)
!
c go to new history node
   call cg_goto_f(index_file,index_base,ier,'ConvergenceHistory_t',
   +   1,'end')
!
c write lift coefficient array (user must use SIDS-standard name here)
   call cg_array_write_f('CoefLift',RealDouble,1,ntt,cl,ier)
!
c close CGNS file
   call cg_close_f(index_file,ier)
```

In this example, the array `cl` must be declared as an array of size `ntt` or larger. Additional arrays of the same size may also be written under the ConvergenceHistory_t node. Note that the call to `cg_convergence_write_f` includes a blank string in this case, because we are not recording norm definitions.
3.2 Descriptor Nodes

Descriptor nodes, which record character strings and can be inserted nearly everywhere in a CGNS file, have many possible uses. Users can insert comments or descriptions to help clarify the content of some data in the CGNS file. In Appendix C, we mention a possible use for descriptor nodes to describe data that is UserDefined. Another potentially desirable use of the descriptor node is to maintain copies of the entire *input* file(s) from the CFD application code. Because descriptor nodes can include carriage returns, entire ASCII files can be “swallowed” into the CGNS file. In this way, a future user can see and retrieve the exact input file(s) used by the CFD code to generate the data contained in the CGNS file. The only ambiguity possible would be whether the CFD code itself has changed since that time; but if the CFD code has strict version control, then complete recoverability should be possible.

An example that writes a descriptor node at the CGNSBase_t level is given here:

```c
#include 'cgnslib_f.h'

call cg_open_f('grid.cgns',MODE_MODIFY,index_file,ier)
index_base=1

call cg_goto_f(index_file,index_base,ier,'end')
call cg_descriptor_write_f('Information',textstring,ier)

call cg_close_f(index_file,ier)
```

In this example, the Descriptor_t node is named Information and the character string textstring (which is made up of text1 and text2 with a line feed - char(10) - in-between) is written there. All character strings must be declared appropriately.

3.3 Dimensional Data

The node DataClass_t denotes the class of the data. When data is dimensional, then DataClass_t = Dimensional. The DataClass_t node can appear at many levels in the CGNS hierarchy; precedence rules dictate that a DataClass_t lower in the hierarchy supersedes any higher up.

For dimensional data, one generally is expected to indicate the dimensionality of
each particular variable through the use of DataClass_t, DimensionalUnits_t, and DimensionalExponents_t. An example of this is shown in the following code segment in which units are added to the structured grid and cell center flow solution from sections 2.1.1 and 2.1.2.

```fortran
C WRITE DIMENSIONAL INFO FOR GRID AND FLOW SOLN
include 'CGNSLib/cgnslib_f.h'
C open CGNS file for modify
   call cg.open_f('grid.cgns',MODE.MODIFY,index_file,ier)
C we know there is only one base (real working code would check!)
   index_base=1
C we know there is only one zone (real working code would check!)
   index_zone=1
C we know there is only one FlowSolution_t (real working code would check!)
   index_flow=1
C we know there is only one GridCoordinates_t (real working code would check!)
   index_grid=1
C put DataClass and DimensionalUnits under Base
   call cg.goto_f(index_file,index_base,ier,'end')
   call cg.dataclass_write_f(Dimensional,ier)
   call cg.units_write_f(Kilogram,Meter,Second,Kelvin,Degree,ier)
C read fields
   call cg.nfields_f(index_file,index_base,index_zone,index_flow,
   + nfields,ier)
   do i=1,nfields
      call cg.field_info_f(index_file,index_base,index_zone,
   + index_flow,i,datatype,fieldname,ier)
      if (fieldname .eq. 'Density') then
         exponents(1)=1.
         exponents(2)=-3.
         exponents(3)=0.
         exponents(4)=0.
         exponents(5)=0.
      else if (fieldname .eq. 'Pressure') then
         exponents(1)=1.
         exponents(2)=-1.
         exponents(3)=-2.
         exponents(4)=0.
         exponents(5)=0.
      else
         write(6,'(” Error! this fieldname not expected: ”,a32)')
      end if
      fieldname
   stop
end if
```

41
c write DimensionalExponents
    call cg_goto_f(index_file,index_base,ier,'Zone.t',1,
    'FlowSolution.t',1,'DataArray.t',if,'end')
    call cg_exponents_write_f(RealSingle,exponents,ier)
enddo
c read grid
    call cg_ncoords_f(index_file,index_base,index_zone,ncoords,ier)
exponents(1)=0.
exponents(2)=1.
exponents(3)=0.
exponents(4)=0.
exponents(5)=0.
do ic=1,ncoords
c write DimensionalExponents
    call cg_goto_f(index_file,index_base,ier,'Zone.t',1,
    'GridCoordinates.t',1,'DataArray.t',ic,'end')
    call cg_exponents_write_f(RealSingle,exponents,ier)
enddo
c close CGNS file
    call cg_close_f(index_file,ier)

Notice in this example that a DataClass_t node and a DimensionalUnits_t node
are placed near the top of the hierarchy, under CGNSBase_t. DataClass_t is specified
as Dimensional, and DimensionalUnits_t are specified as (Kilogram, Meter, Second,
Kelvin, Degree). These specify that, by and large, the entire database is dimensional
with MKS units (anything that is not dimensional or not MKS units could be su-
perseded at lower levels). Then, for each variable locally, one need only specify the
DimensionalExponents, where one exponent is defined for each unit.

The layout of part of the resulting CGNS file from the above example is shown
in Fig. 17. The density has units of kilogram/meter$^3$, and the pressure has units of
kilogram/(meter-second$^2$). The grid coordinates (not shown in the figure) have units of
meters.

3.4 Nondimensional Data

This example is for the relatively common occurrence of CFD data that is purely nondi-
dimensional, for which the reference state is arbitrary (unknown). This type is referred to
as NormalizedByUnknownDimensional. Another nondimensional type, NormalizedBy-
Dimensional, for which the data is nondimensional but the reference state is specifically
known, is not covered here.

For a NormalizedByUnknownDimensional database, the DataClass is recorded as
such, but also a ReferenceState_t node is necessary to define the nondimensionalizations used.
(A ReferenceState_t node can be used for any dataset to indicate the global reference
Figure 17: Layout of part of a CGNS file for flow solution at cell centers with dimensional data.
state (such as free stream), as well as quantities such as the reference Mach number and Reynolds number. A ReferenceState_t node was not included in section 3.3, but it could have been.)

For the current example, we do not go into detail regarding the choices of the items which should populate the reference state for a NormalizedByUnknownDimensional database. We simply show in the example some typical choices which very often would likely be included. A detailed discussion of how the data in ReferenceState_t defines the nondimensionalizations is given in the SIDS document [1].

```c
WRITE NONDIMENSIONAL INFO
  include 'CGNSLib/cgnslib.h'
  open CGNS file for modify
    call cg_open_f(grid.cgns_,MODE_MODIFY,index_file,ier)
  we know there is only one base (real working code would check!)
  index_base=1
  put DataClass under Base
    call cg_goto_f(index_file,index_base,ier,'end')
    call cg_dataclass_write_f(NormalizedByUnknownDimensional,ier)
  put ReferenceState under Base
    call cg_state_write_f(ReferenceQuantities,ier)
  Go to ReferenceState node, write Mach array and its dataclass
    call cg_goto_f(index_file,index_base,ier,'ReferenceState_t',1,
      'end')
    call cg_array_write_f('Mach',RealSingle,1,1,xmach,ier)
    call cg_goto_f(index_file,index_base,ier,'ReferenceState_t',1,
      'DataArray_t',1,'end')
    call cg_dataclass_write_f(NondimensionalParameter,ier)
  Go to ReferenceState node, write Reynolds array and its dataclass
    call cg_goto_f(index_file,index_base,ier,'ReferenceState_t',1,
      'end')
    call cg_array_write_f('Reynolds',RealSingle,1,1,reue,ier)
    call cg_goto_f(index_file,index_base,ier,'ReferenceState_t',1,
      'DataArray_t',2,'end')
    call cg_dataclass_write_f(NondimensionalParameter,ier)
  Go to ReferenceState node to write reference quantities:
    call cg_goto_f(index_file,index_base,ier,'ReferenceState_t',1,
      'end')
    c First, write reference quantities that make up Mach and Reynolds:
      c Mach_Velocity
        call cg_array_write_f('Mach_Velocity',RealSingle,1,1,xmv,ier)
      c Mach_VelocitySound
        call cg_array_write_f('Mach_VelocitySound',RealSingle,
          1,1,xmc,ier)
      c Reynolds_Velocity
```
call cg_array_write_f(‘Reynolds_Velocity’, RealSingle,
    + 1,1,rev,ier)
c Reynolds_Length
call cg_array_write_f(‘Reynolds_Length’, RealSingle,
    + 1,1,rel,ier)
c Reynolds_ViscosityKinematic
call cg_array_write_f(‘Reynolds_ViscosityKinematic’, RealSingle,
    + 1,1,renu,ier)
c Next, write flow field reference quantities:
c Density
call cg_array_write_f(‘Density’, RealSingle, 1,1, rho0, ier)
c Pressure
call cg_array_write_f(‘Pressure’, RealSingle, 1,1, p0, ier)
c VelocitySound
call cg_array_write_f(‘VelocitySound’, RealSingle, 1,1, c0, ier)
c ViscosityMolecular
call cg_array_write_f(‘ViscosityMolecular’, RealSingle,
    + 1,1, vm0, ier)
c LengthReference
call cg_array_write_f(‘LengthReference’, RealSingle,
    + 1,1, xlength0, ier)
c VelocityX
call cg_array_write_f(‘VelocityX’, RealSingle, 1,1, vx, ier)
c VelocityY
call cg_array_write_f(‘VelocityY’, RealSingle, 1,1, vy, ier)
c VelocityZ
call cg_array_write_f(‘VelocityZ’, RealSingle, 1,1, vz, ier)
c close CGNS file
call cg_close_f(index_file, ier)

In this case, the only information added to the CGNS file is at the CGNSBase_t level. Note that Mach and Reynolds (which are stored under ReferenceState) are variables that are known as “NondimensionalParameter”s, so they must each contain a DataClass child node stating this (the local DataClass nodes supersede the overall NormalizedByUnknownDimensional data class that holds for everything else).

The layout of the relevant portion of the resulting CGNS file from the above example is shown in Fig. 18. Many of the reference quantities that appear under ReferenceState_t have been left out of the figure to conserve space.
3.5 Flow Equation Sets

The FlowEquationSet_t node is useful for describing how a flow solution was generated. This is one of the useful self-descriptive aspects of CGNS that may improve the usefulness and longevity of a CFD dataset. For example, under this node, information such as the following may be recorded: the flow field was obtained by solving the thin-layer Navier-Stokes equations (with diffusion only in the \( j \)-coordinate direction); the Spalart-Allmaras turbulence model was employed, and an ideal gas assumption was made with \( \gamma = 1.4 \).

The following FORTRAN code segment writes some of the above example flow equation set information under the Zone_t node from our earlier single-zone structured grid example from section 2.1. (Note that a FlowEquationSet_t node can also be placed at a higher level, under the CGNSBase_t node. The usual precedence rules apply).

```fortran
C WRITE FLOW EQUATION SET INFO
   include 'CGNSLib/cgnslib_f.h'
C open CGNS file for modify
   call cg_open_f('grid.cgns',MODE_MODIFY,index_file,ier)
C we know there is only one base (real working code would check!)
   index_base=1
C we know there is only one zone (real working code would check!)
   index_zone=1
C existing file must be 3D structured (real working code would check!)
```
This particular example is specific to a 3-D structured zone. In an unstructured zone, the use of `DiffusionModel` is not valid. The layout of the relevant portion of the resulting CGNS file from the above example is shown in Fig. 19.
Figure 19: Layout of part of a CGNS file with flow equation set information.
3.6 Time-Dependent Data

Time-dependent data (data with multiple flow solutions) can also be stored in a CGNS file. Different circumstances may produce data with multiple flow solutions; for example:

1. Non-moving grid
2. Rigidly-moving grid
3. Deforming or changing grid

Each of these may either be the result of a time-accurate run, or else may simply be multiple snapshots of a non-time-accurate run as it iterates toward convergence.

This section gives an example for type 1 only. Readers interested in the two other types should refer to the SIDS document [1]. For a non-moving grid, the method for storing the multiple flow solutions is relatively simple: multiple FlowSolution_t nodes, each with a different name, are placed under each Zone_t node. However, there also needs to be a mechanism for associating each FlowSolution_t with a particular time and/or iteration. This is accomplished through the use of BaseIterativeData_t (under CGNSBase_t) and ZoneIterativeData_t (under each Zone_t). BaseIterativeData_t contains NumberOfSteps, the number of times and/or iterations stored, and their values. ZoneIterativeData_t contains FlowSolutionPointers as a character data array. FlowSolutionPointers is dimensioned to be of size NumberOfSteps, and contains the names of the FlowSolution_t nodes within the current zone that correspond with the respective times and/or iterations. Finally, a SimulationType_t node is placed under CGNSBase_t to designate what type of simulation (e.g., TimeAccurate, NonTimeAccurate) produced the data. (Note: the SimulationType_t node is not restricted for use with time-dependent data; any CGNS dataset can employ it!)

The following FORTRAN code segment writes some of the above information, using our earlier single-zone structured grid example from section 2.1. For the purposes of this example, it is assumed that there are 3 flow solutions from a time-accurate simulation, to be output as a function of time to the CGNS file. The variables r1 and p1 represent the density and pressure at time 1, r2 and p2 are at time 2, and r3 and p3 are at time 3.

c WRITE FLOW SOLUTION TO EXISTING CGNS FILE
  include 'CGNSLib/cgnslib_f.h'
c open CGNS file for modify
    call cg_open_f('grid.cgns',MODE_MODIFY,index_file,ier)
c we know there is only one base (real working code would check!)
    index_base=1
c we know there is only one zone (real working code would check!)
    index_zone=1
c set up the times corresponding to the 3 solutions to be
  c stored:
time(1)=10.
time(2)=20.
time(3)=50.
c define 3 different solution names (user can give any names)
solname(1) = 'FlowSolution1'
solname(2) = 'FlowSolution2'
solname(3) = 'FlowSolution3'
c do loop for the 3 solutions:
do n=1,3
c create flow solution node
call cg.sol.write_f(index_file,index_base,index_zone,solname(n),
+ Vertex,index_flow,ier)
c write flow solution (user must use SIDS-standard names here)
if (n .eq. 1) then
call cg.field.write_f(index_file,index_base,index_zone,index_flow,
+ RealDouble,'Density',r1,index_field,ier)
call cg.field.write_f(index_file,index_base,index_zone,index_flow,
+ RealDouble,'Pressure',p1,index_field,ier)
else if (n .eq. 2) then
call cg.field.write_f(index_file,index_base,index_zone,index_flow,
+ RealDouble,'Density',r2,index_field,ier)
call cg.field.write_f(index_file,index_base,index_zone,index_flow,
+ RealDouble,'Pressure',p2,index_field,ier)
else
call cg.field.write_f(index_file,index_base,index_zone,index_flow,
+ RealDouble,'Density',r3,index_field,ier)
call cg.field.write_f(index_file,index_base,index_zone,index_flow,
+ RealDouble,'Pressure',p3,index_field,ier)
end if
enddo
c create BaseIterativeData
nsteps=3
call cg.biter.write_f(index_file,index_base,'TimeIterValues',
+ nsteps,ier)
c go to BaseIterativeData level and write time values
call cg.goto.f(index_file,index_base,ier,'BaseIterativeData_t',
+ 1,'end')
call cg.array.write_f('TimeValues',RealDouble,1,3,time,ier)
c create ZoneIterativeData
call cg.ziter.write_f(index_file,index_base,index_zone,
+ 'ZoneIterativeData',ier)
c go to ZoneIterativeData level and give info telling which
flow solution corresponds with which time (solname(1) corresponds
c with time(1), solname(2) with time(2), and solname(3) with time(3))
call cg.goto.f(index_file,index_base,ier,'Zone_t',
+ 1,ier)
50
index_zone,'ZoneIterativeData_t',1,'end')
idata(1)=32
idata(2)=3
call cg_array_write_f('FlowSolutionPointers', Character, 2, idata,
+ solname, ier)
c add SimulationType
call cg_simulation_type_write_f(index_file, index_base,
+ TimeAccurate, ier)
c close CGNS file
call cg_close_f(index_file, ier)

As cautioned for earlier coding snippets, dimensions must be set appropriately for all variables. The variable time (which is an array dimensioned size 3 in this case) contains the time values stored under BaseIterativeData_t. The layout of the resulting CGNS file from the above example is shown in Fig. 20. Compare this figure with Fig. 6. To conserve space, the GridCoordinates_t, ZoneType_t, and all nodes underneath FlowSolution_t have been left off.

Figure 20: Layout of CGNS file for simple Cartesian structured grid with multiple time-accurate flow solutions (non-moving grid coordinates).
3.7 Using Links

A link associates one node to another within a CGNS tree, or even one node to another in a separate CGNS file altogether. This can be useful when there is repeated data; rather than write the same data multiple times, links can point to the data written only once.

One very important use of links that may be required by many users is to point to grid coordinates. This usage comes about in the following way. Suppose a user is planning to use a particular grid for multiple cases. There are several options for how to store the data. Among these are:

1. Keep a copy of the grid with each flow solution in separate CGNS files.
2. Keep just one CGNS file, with the grid and multiple FlowSolution_t nodes; each FlowSolution_t node corresponds with a different case.
3. Keep just one CGNS file, with multiple CGNSBase_t nodes. The grid and one flow solution would be stored under one base. Other bases would each contain a separate flow solution, plus a link to the grid coordinates in the first base.
4. Keep one CGNS file with the grid coordinates defined, and store the flow solution for each case in its own separate CGNS file, with a link to the grid coordinates.

Item 1 is conceptually the most direct, and is certainly the recommended method in general (this is the way all example CGNS files have been portrayed so far in this document). However, if the grid is very large, then this method causes a lot of storage space to be unnecessarily used to store the same grid points multiple times. Item 2 may or may not be a viable option. If the user is striving to have the CGNS file be completely self-descriptive, with ReferenceState and FlowEquationSet describing the relevant conditions, then this method cannot be used if the ReferenceState or FlowEquationSet is different between the cases (for example, different Mach numbers, Reynolds numbers, or angles of attack). Item 3 removes this restriction. It uses links to the grid coordinates within the same file. Item 4 is similar to item 3, except that the grid coordinates and each flow solution are stored in separate files altogether.

A sample layout showing the relevant portions of two separate CGNS files for an example of item 4 is shown in Fig. 21. Note that for multiple-zone grids, each zone in FILE 1 in this example would have a separate link to the appropriate zone’s grid coordinates in FILE 2.

At the time of this publication, there is currently no capability in the API for creating links within a CGNS file; instead, a user must employ the ADF core library software (specifically ADFLINK). However, reading a linked CGNS file presents no difficulties for the API, because links are “transparent.” As long as any separate linked files keep their name unchanged, and maintain the same position (within the Unix-directory) relative to the parent file, opening the parent file will automatically access the linked ones.

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Figure 21: Layout of part of two CGNS files with a link from one to the grid coordinates of the other.
4 TROUBLESHOOTING

4.1 Handling Errors

The API has an extensive number of checks for errors, relating both to illegal usage of ADF as well as relating to SIDS-noncompliance. However, it is not guaranteed that the API will catch all problems prior to reaching the core level. The list of errors that can arise in the ADF core routines themselves are not listed here; they can be found in the file ADF_interface.c under “Error strings,” and in the ADF User’s Guide [2].

If an error occurs, the message given by the ADF or the API routine should hopefully be descriptive enough to point to the source of the error.

4.2 Known Problems

One known problem that can occur, which is not so much a problem as it is a restriction, relates to links. If a user makes a link from one CGNS file to another, then the linked file must have write permission if the user wishes to open the linking file in MODE_MODIFY or MODE_WRITE mode. In other words, opening a CGNS file in MODE_MODIFY or MODE_WRITE mode implies that the entire CGNS hierarchy, including links (since they are transparent), is accessible in that mode.
5 FREQUENTLY ASKED QUESTIONS

Q: Does CGNS support solution array names that are not listed in the SIDS?
A: You can use any data-name that you want for solution arrays. However, if you create a new name not listed in the SIDS, it may not be understood by other applications reading your file.

Q: What is a Family in CGNS?
A: The families are used to link the mesh to the geometry. The data structure Family_t is optional and can be used to define the geometry of boundary patches by referencing CAD entities. In turn, mesh patches can reference family, so we get: mesh -> family -> geometry.

Q: What are DiscreteData_t and IntegralData_t used for?
A: DiscreteData_t can be used to store field data that is not typically considered part of the flow solution FlowSolution_t. IntegralData_t can be used to store generic global or integral data (a single integer or floating point number is allowed in each DataArray_t node under IntegralData_t).

Q: What are some good programming practices that will help me avoid problems when implementing CGNS in my code?
A: The usual good programming standards apply: use plenty of comments, use logical indentation to make the code more readable, etc. In addition, the API returns an error code from each of its calls; it is a good idea to check this regularly and gracefully exit the program with an error message when it is not zero. In FORTRAN, you can use:

```fortran
if (ier .ne. 0) call cg_error_exit_f
```

Q: How can I look at what is in a CONS file?
A: At the time of this publication, the utility adfedit is the best way to look at a CONS file. This utility allows you to view the entire tree structure, or look at individual nodes of data. A brief summary of adfedit is given in Appendix A.

Q: How can I tell if I have created a truly SIDS-compliant CONS file?
A: It is currently very difficult to guarantee that a user has created a SIDS-compliant CONS file, that others can read and understand. But because the API (mid-level-library) has many checks for non-compliance, it is much more difficult for you to make a mistake when using it than if you utilize ADF (core-level) calls.
Appendix A. THE ADFEDIT UTILITY

The utility adfedit can be used to view (and edit) CGNS files. It is currently included with the CGNS software, although it is possible that in the future it may be superseded by a more advanced utility.

The following is a brief description of the most basic capabilities of the adfedit utility. A typical adfedit session might go like this:

```
adfedit
ADFmain> br  go to “browse”
ADFbrowse> o cgns.file open file cgns.file
ADFbrowse> t  go to “tools”
ADFtools> pt print out entire directory tree structure
ADFtools> pt -l same, but include node label info
ADFtools> br go to “browse”
ADFbrowse> ls list children (sub-nodes) of current node
ADFbrowse> cd Base go down one level to the node named “Base”
ADFbrowse> dd give description of node data
ADFbrowse> pd print node data
ADFbrowse> cd .. go up one level in the tree
ADFbrowse> cd go to the top of the tree (to root node)
ADFbrowse> ? help
ADFbrowse> quit exits program
```
Appendix B. EXAMPLE COMPUTER CODES

The following computer codes are complete, workable versions of the codes mentioned in the text of this User’s Guide (plus some that are not mentioned). They can be obtained from the CGNS website www.cgns.org (in the User’s Guide section). They read and write very simple example CGNS files, in order to help the user understand the CGNS concepts as well as the usage of the API calls. Instructions for compiling them on UNIX systems is contained in comment lines in each program. These assume that the user has obtained the CGNS libraries (from the same website) and placed it locally as subdirectory /CGNSLib. Most of the following codes are written in FORTRAN.

Note that these programs are very unsophisticated, purposefully for ease of readability. Real working codes would be written more generally, with more checks, and would not be as hardwired for particular cases. The codes are listed here by corresponding section.

### STRUCTURED GRID

**Section 2.1.1:**

| write_grid_str.f | writes grid |
| write_grid_str.c | writes grid (C-program example) |
| read_grid_str.f  | reads grid |

**Section 2.1.2:**

| write_flowvert_str.f | writes vertex-based flow solution |
| read_flowvert_str.f  | reads vertex-based flow solution |
| write_flowcent_str.f | writes cell centered flow solution |
| read_flowcent_str.f  | reads cell centered flow solution |
| write_flowcentrind_str.f | writes cell centered flow solution with rind cells |
| read_flowcentrind_str.f | reads cell centered flow solution with rind cells |

**Section 2.1.3:**

| write_bc_str.f | writes PointRange boundary condition patches |
| read_bc_str.f  | reads PointRange boundary condition patches |
| write_bcpnts_str.f | writes PointList boundary condition patches |
| read_bcpnts_str.f | reads PointList boundary condition patches |

**Section 2.1.4:**

| write_grid2zn_str.f | writes 2-zone grid |
| read_grid2zn_str.f  | reads 2-zone grid |
| write_con2zn_str.f  | writes 1-to-1 connectivity for 2-zone example |
| read_con2zn_str.f   | reads 1-to-1 connectivity for 2-zone example |
| write_con2zn_genrl_str.f | writes general 1-to-1 connectivity for 2-zone example |
| read_con2zn_genrl_str.f | reads general 1-to-1 connectivity for 2-zone example |
**UNSTRUCTURED GRID**

Section 2.2.1:

| write_grid_unst.f | writes grid |
| read_grid_unst.f | reads grid |

Section 2.2.2:

| write_flowvert_unst.f | writes vertex-based flow solution |
| read_flowvert_unst.f | reads vertex-based flow solution |

Section 2.2.3:

| write_bcpnts_unst.f | writes PointList boundary condition patches (FaceCenter) |
| read_bcpnts_unst.f | reads PointList boundary condition patches (FaceCenter) |

**GENERAL**

Section 3.1:

| write_convergence.f | writes convergence history |
| read_convergence.f | reads convergence history |

Section 3.2:

| write_descriptor.f | writes descriptor node under CGNSBase_t |
| read_descriptor.f | reads descriptor node under CGNSBase_t |

Section 3.3:

| write_dimensional.f | writes dimensional data to an existing grid + flow solution |
| read_dimensional.f | reads dimensional data from an existing grid + flow solution |

Section 3.4:

| write_nondimensional.f | writes nondimensional data to an existing CGNS file |
| read_nondimensional.f | reads nondimensional data from an existing CGNS file |

Section 3.5:

| write_floweqn_str.f | writes flow equation information for structured example |
| read_floweqn_str.f | reads flow equation information for structured example |

Section 3.6:

| write_timevert_str.f | writes time-dependent flow soln (as Vertex) for structured example |
| read_timevert_str.f | reads time-dependent flow soln (as Vertex) for structured example |
Appendix C. OVERVIEW OF THE SIDS

C.1 The Big Picture

As mentioned in the Introduction, a CGNS file is organized into a set of “nodes” in a tree-like structure, in much the same way as directories are organized in the UNIX environment. Each node is identified by both a label and a name. Most node labels are given by a series of characters followed by “.t”. There are generally very strict rules governing the labeling conventions in a CGNS file. Node names are sometimes user-defined, but sometimes must also follow strict naming conventions. The label identifies a “type.” For example, Zone.t identifies a Zone-type node, and DataArray.t identifies a type of node that contains a data array. The name identifies a specific instance of the particular node type. For example, Density is the name of a node of type DataArray.t that contains an array of densities.

As you become more familiar with how CGNS files are organized, you will notice that, generally, the higher you are in the CGNS hierarchy, the more important the label is (names tend to be user-defined); whereas the lower you are in the hierarchy, the more important the name is. This convention arises because at the higher levels, the broader categories are established, and are used to determine “where to go” in the hierarchy. At the lower levels, the category becomes less important because this is the region where you are searching for specific items.

Throughout the remainder of this first section, we will primarily be referring to the nodes by their label, because we are focusing on the “big picture.” In later sections, as we get into specific examples, both names and labels will be referred to.

It is important to note at this point that the SIDS document specifies the layout of the CGNS file, in terms of parents and children. However, when a given piece of information is listed as being “under” a node, there are actually two possibilities: the information can be stored as data in the current node, or it can be stored as data in or under a separate child node. This distinction is illustrated in Fig. 22. The SIDS-to-ADF mapping document [3] determines which of the two possibilities are used for each situation, and must always be consulted along with the SIDS document. Throughout the remainder of this appendix, the location of information (whether as data or as a separate child node) will always be explicitly specified, according to the SIDS-to-ADF mapping document.

The remainder of this appendix attempts to summarize the most important and most commonly-used aspects of the SIDS. It does not cover all possible nodes or situations. It is intended as a general overview only. It is also likely that future extensions to the SIDS will add additional capabilities beyond what we cover here.

The top, or entry-level, of the CGNS file is always what is referred to as the “root node.” Children to be found directly under this node are the node CGNSLibraryVersion.t and one or more CGNSBase.t nodes. The CGNSLibraryVersion.t node has, as its data, the library version (release) number. The CGNSBase.t node represents the top level.
Figure 22: Two possible treatments of a parent node with sets of data “under” it.

for a given database, or “case.” Most CGNS files will only have one \texttt{CGNSBase.t} node, although the SIDS allows for any number in order to remain extensible and to allow for the possibility of having more than one “case” in a single file. Here, the definition of “case” is left open. For the remainder of this appendix, we assume that there is only one \texttt{CGNSBase.t} node within a given CGNS file.

The \texttt{CGNSBase.t} node may have, as its children, the following nodes: Zone\_t, ConvergenceHistory\_t, BaseIterativeData\_t, SimulationType\_t, Family\_t, IntegralData\_t, DataClass\_t, FlowEquationSet\_t, DimensionalUnits\_t, ReferenceState\_t, and Descriptor\_t.

The Zone\_t node gives information about a particular zone of the grid; most of the data in the CGNS file is usually found under this node. Any number of Zone\_t nodes is allowed at this level. Its children will be described in greater detail below. ConvergenceHistory\_t contains solution history information typically output by many CFD codes, such as residual, lift, drag, etc. as a function of iteration number. By convention, its name is GlobalConvergenceHistory. A ConvergenceHistory\_t node can exist under the Zone\_t node as well, but there, its name is by convention ZoneConvergenceHistory. BaseIterativeData\_t stores information relating to the times and/or iteration numbers for a database in which flow solutions and/or grids at multiple times are stored. SimulationType\_t describes the type of simulation stored (i.e., TimeAccurate or NonTimeAccurate). Family\_t is generally used to tie the grid to geometric CAD data, or to link certain entities together as a common part (e.g., “wing,” “strut,” etc.). Any number of Family\_t nodes is allowed.

The remaining nodes allowed under \texttt{CGNSBase.t} are somewhat more generic, and
can exist at other levels in the hierarchy beside this one. They are briefly described here. **IntegralData_t** is a “catch-all” node for storing any desired sets of generic data. Any number of **IntegralData_t** nodes is allowed at this level. **DataClass_t** (which, by convention, has the name DataClass) indicates the form that the data in the **CGNSBase_t** is stored, for example: **Dimensional**, **NormalizedByDimensional**, or **NormalizedByUnknownDimensional**. **FlowEquationSet_t** (which, by convention, has the name FlowEquationSet) defines the equations used in the CFD simulation. **DimensionalUnits_t** (which, by convention, has the name DimensionalUnits) defines the dimensional units used (if any). **ReferenceState_t** (which, by convention, has the name ReferenceState) defines a reference state. This node is where quantities such as Reynolds number, Mach number, and other reference quantities that define the flow field conditions and/or the nondimensionalizations are stored. Finally, **Descriptor_t** is used to store descriptor strings. Any number of **Descriptor_t** nodes is allowed at this level.

The data stored within the **CGNSBase_t** node itself are the **CellDimension** and the **PhysicalDimension**. The **CellDimension** is the dimensionality of the cells in the mesh (e.g., 3 for volume cell, 2 for face cell). The **PhysicalDimension** is the number of coordinates required to define a node position (e.g., 1 for 1-D, 2 for 2-D, 3 for 3-D). The index dimension, which is the number of different indices required to reference a node (e.g., 1=i, 2=i,j, 3=i,j,k), is not stored, but can be determined for each zone based on its type (Structured or Unstructured). If Structured, the index dimension is the same as **CellDimension**. If Unstructured, the index dimension is 1.

Much information can be stored under **Zone_t**. Because this is an overview, we do not go through it all here. Instead, we only highlight the features that most users are likely to use. **ZoneType_t** (which, by convention, has the name ZoneType) stores the name Structured or Unstructured. **GridCoordinates_t** is the parent node of the grid coordinates arrays, such as CoordinateX, CoordinateY, and CoordinateZ. Any number of **GridCoordinates_t** nodes are allowed at this level (to handle the case of deforming grids). By convention, the original grid coordinates has the name GridCoordinates. **FlowSolution_t** stores under it nodes which contain the flow solution; for example, Density, VelocityX, VelocityY, VelocityZ, and Pressure. It also gives the location at which the solution is stored (e.g., CellCenter, Vertex), and includes the possibility for including Rind (ghost cell) information. Any number of **FlowSolution_t** nodes are allowed at this level. The **Elements_t** data structure holds unstructured element data such as connectivity, neighbors, etc. Any number of **Elements_t** nodes are allowed at this level. **ZoneIterativeData_t** stores information necessary for a database in which flow solutions at multiple times are stored. Other important nodes under **Zone_t** are **ZoneBC_t** (which, by convention, has the name ZoneBC) and **ZoneGridConnectivity_t** (which, by convention, has the name ZoneGridConnectivity). These store the boundary conditions and the grid connectivity information, respectively. More will be said about these nodes later.

The data stored within the **Zone_t** node itself are the **VertexSize**, the **CellSize**, and the **VertexSizeBoundary**. These are dimensioned by the index dimension, and give the number of vertices, the number of cells, and the number of boundary vertices (used for sorted elements in unstructured zones only), respectively.
Figure 23: Hierarchical structure of a typical CGNS file (structured grid type).
An important point to note here is that the API sorts the Zone_t nodes alphanumerically according to their name when it reads them. This was deemed necessary because most CFD codes currently perform operations on the zones of multiple-zone grids in a certain order. To duplicate existing non-CGNS applications, it is necessary to insure that zones can be read in the desired sequence. (ADF does not necessarily retrieve data in the same order in which it was stored, so the API reader for zones was built to do this.) Hence, when naming zones, the user should make sure they are named alphanumerically (if an ordering is desired).

For example, the naming convention ZoneN, where N is the zone number, is alphanumerically only up to Zone9. Zone10 through Zone19 would get sorted between Zone1 and Zone2, and so on. Spaces are allowed in names, so Zone_N, with two spaces, (e.g., Zone_1, Zone_2,... Zone_99, Zone100,...) is alphanumerical up to Zone999. Other zone naming conventions are certainly possible, and are completely up to the user to define appropriately.

A summary graphic of the overall layout of a typical CGNS file is given in Fig. 23. This figure shows the hierarchical data structure, and the relative locations of the nodes. It also indicates (informally) what data, if any, is stored within each node. Note that all possible nodes are not included here. In particular, note that Elements_t nodes are not shown under Zone_t; the Elements_t nodes would be present for an unstructured zone. Also note that nodes that occur under ZoneBC_t and ZoneGridConnectivity_t have been omitted; these will also be covered below. The optional node SimulationType_t (under CGNSBase_t) is not included. And finally, note that multiple GridCoordinates_t and FlowSolution_t nodes are allowed, but we show in the figure only one of each. Multiple FlowSolution_t nodes are usually only used in the situation when multiple times of time-accurate data are stored, and multiple GridCoordinates_t nodes are used for deforming grids.

C.2 Implementation at the Lower Levels of the Hierarchy

Most of the actual data is at the lower levels of the CGNS hierarchy. We do not go into great detail here; the examples in the main body of this document serve as instruction for this. However, there are several general items of importance related to the storage of data that are appropriate to mention here.

Many specific items, variables, and conditions that relate to CFD data are specified in the SIDS. These are standardized names that must be used in order that other users will understand what is in your CGNS file. For example, the static density must be called Density. Any other name may not be recognized by other users. In fact, if another application code expects “Density,” but you name it “density” (lower case “d”), then chances are the other code’s search will fail.

Naturally, the items listed in the SIDS cannot cover all possible items required by users. Hence, the SIDS allows for the use of the type UserDefined for any special type
not covered. For example, there are currently only a limited number of defined names for turbulence models in the SIDS (e.g., OneEquation_SpalartAllmaras). As everyone knows, there are a huge number of turbulence models and turbulence model variants that exist, so that the SIDS cannot hope to define standardized names for all of them. The type UserDefined covers this situation.

When UserDefined is used, however, the user runs the risk that others will be unable to interpret the CGNS file. We therefore recommend that whenever a UserDefined type is unavoidable, the user also include a companion Descriptor.t node to specify what was done.

It is possible that, if certain items are found to be used more heavily as time goes on, that standardized names may be created and added to the SIDS in the future.

### C.3 Boundary Conditions

The boundary conditions hierarchical structure in CGNS can appear to be somewhat daunting at first. Because the CGNS team decided to make the boundary condition information as descriptive as possible and easily extensible to complex situations, there are many layers possible in the hierarchy, and the usage rules can become complex.

However, the SIDS allows for use of simplified versions of the ZoneBC.t node, which are easier to understand and adopt. Essentially, the simplified versions “cut off” the hierarchy at a higher level than the full-blown SIDS boundary condition description. The implication of this is that application codes that use a simplified version must interpret what is meant by each particular boundary condition type, without the help of the CGNS file.

For example, the boundary condition type BCFarfield indicates a boundary condition applied to a far field boundary. Most CFD codes have this type, which performs different functions depending upon whether the local flow field is inflow or outflow, subsonic or supersonic. The full-blown SIDS description of BCFarfield attempts to describe in some detail the methodology involved in this boundary condition. However, if the user chooses to use the minimal “cut off” version, the only information regarding the function of the boundary condition that is stored in the CGNS file is the name BCFarfield. An application code must determine from this name alone what is meant.

Example hierarchical structures for both the simplest implementation as well as the full-blown implementation of the ZoneBC.t node are shown in Fig. 24. (These hierarchies make use of an IndexRange.t node. It is also possible to use an IndexArray.t, which gives a complete list of boundary indices or elements, rather than a range.) Note that an intermediate structure, where BCDataset.t and TypeSimple.t are both given but DirichletData and NeumannData are not, is also allowed.

Many boundary condition types are currently defined in the SIDS, but they by no means cover all possible boundary conditions. The type UserDefined can be used for
ZoneBC_t

BC_t (data=BCType)

IndexRange_t (data=index range)

IndexRange_t (data=index range)

BCDataSet_t (data=BCTypeSimple)

BCDataSet_t (data=BCTypeSimple)

DirichletData (BCData_t)

NeumannData (BCData_t)

DataArray_t (data=BC quantities)

DataArray_t (data=BC quantities)

(a) lowest-level BC implementation
allowed (application code interprets meaning of BCType)

(b) fully SIDS-compliant BC implementation

Figure 24: General hierarchical structure of ZoneBC_t.

any special type not covered that the user finds impossible to describe using the existing SIDS. When UserDefined is used, a companion descriptor node is helpful to describe what was done.

C.4 Zone Connectivity

It is often desirable to specify zone connectivity information when parts of a zone connect with parts of another zone or itself. The connectivity information tells how zones fit together or how a zone twists to reconnect with itself; the information is needed by most CFD flow solvers.

There are three types of connectivity that can occur: point-by-point, patched, and overset. The point-by-point, or 1-to-1, type occurs when the edges of zones abut, and 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 overset type occurs when zones overlap one another (or a zone overlaps itself).

The SIDS allows for the specification of each of these types of zone connectivity under the ZoneGridConnectivity_t node. All three types can be implemented through the
general GridConnectivity_t subnode (overset also requires the use of OversetHoles_t nodes). However, the 1-to-1 type can also utilize, in certain circumstances, the more specific GridConnectivity1to1_t subnode.

Fig. 25 shows a sample hierarchy starting at the ZoneGridConnectivity_t node, for a 1-to-1 type of interface using a GridConnectivity1to1_t subnode. Note in this figure that we now list the name, label, and data within each node. For this structure, the naming convention at the bottom level is particularly important, and is actually more descriptive than the labels. In fact, the label for the Transform node is very strange, and does not even follow the usual “_t” convention. As can be seen in the figure, multiple nodes are allowed under the ZoneGridConnectivity_t node. These can be any combination of GridConnectivity1to1_t, GridConnectivity_t, OversetHoles_t, or Descriptor_t nodes.

Figure 25: Hierarchical structure of ZoneGridConnectivity_t for a 1-to-1 interface.

A sample hierarchy (again starting at the ZoneGridConnectivity_t node) is shown in Fig. 26 for an overset interface using a GridConnectivity_t subnode. The case for a patched interface would look the same, except there would be no OversetHoles_t node or its children and GridConnectivityType would be Abutting. Note that CellListDonor and InterpolantsDonor are used for patched or overset interfaces. (PointListDonor can be used in their place if the interface is 1-to-1.) See [1] [3] for details.)
C.5 Structured Zone Example

The following is an example for a structured grid. It corresponds with example 8-A in the SIDS document [1]. It is a 3-D two-zone case, where the two zones are connected in a 1-to-1 fashion at one of each of their faces. Zone 1 is $9 \times 17 \times 11$ and zone 2 is $9 \times 17 \times 21$. The $k$-max face of zone 1 abuts the $k$-min face of zone 2.

The hierarchy is shown in Figs. 27 through 30. Only directly relevant parts of the hierarchy are shown here for clarity. For example, DataClass_t, ReferenceState_t, ConvergenceHistory_t, FlowEquationSet_t, and ZoneBC_t have all been left off. However, these (and other) items are not required, and the figure still represents a valid SIDS-compliant CGNS file. Note that a data type of MT indicates that there is no data stored in the node.

In this example, the flow solution in zone 1 is given at cell centers, whereas the flow solution in zone 2 is given at the vertices (see Fig. 29). In other words, the zone 1 solution points do not correspond with the grid points (as they do in zone 2). They are defined within the volumes surrounded by the grid points. This example is constructed this way for the purpose of illustration, but it is unusual; typically one would use only a single flow solution data location for the entire file.

This example also illustrates the use of the Rind_t node, and how it affects the data arrays under a FlowSolution_t. A rind node under FlowSolution_t is used to indicate that the flow solution is outputting additional rind or "ghost" data outside one or more
Figure 27: CGNS top levels for a case composed of 2 structured zones.

Figure 28: GridCoordinate_t nodes of structured zone example.
Figure 29: FlowSolution_t nodes of structured zone example.

Figure 30: ZoneGridConnectivity_t nodes of structured zone example.
boundaries of the zone. (A rind node can also be used under GridCoordinates.t and DiscreteData.t.) It is only applicable for use with structured zones. See the SIDS document [1] for a more complete description. In zone 1 in this example, there are no additional ghost cell data in the $i$-direction, there is one ghost cell next to each of $j$-min and $j$-max, and there are 3 ghost cells next to $k$-min and 2 next to $k$-max. (Admittedly, this example is very contrived - most applications would be more consistent in their use of rind cells.) Because of the rind cells, the $i$, $j$, and $k$ ranges of all flow solution data arrays in zone 1 are extended appropriately.

It is very important for the user to realize that including rind cells affects how the data is stored in the DataArray.t’s. In other words, when reading a CGNS file one cannot ignore Rind.t nodes if they are present, and attempting to read the DataArray.t’s using unmodified VertexSize or CellSize dimensions will result in the retrieval of nonsensical data.

Note that the SIDS specifies many defaults. For example, the default Transform values are $(1,2,3)$, and the default GridLocation is Vertex. Hence, the nodes that contain these particular values in the example are not strictly necessary. The API sometimes leaves out default information.

Another important fact is illustrated in this example. When the names of a type of node (of given label) are user defined, the names must be different if they have the same parent node. For example, the two Zone.t nodes in this example must have different names (recall the earlier discussion of zone naming). However, if they are located in different places in the hierarchy, two nodes with the same label can have the same name. For example, both of the FlowSolution.t nodes, located in two different zones, have been given the same user-defined name: “My Soln” in the example.

Finally, although the ZoneBC.t nodes were not included in this example, note that if they were, they should describe the boundary conditions on all boundary faces except the $k$-max face of zone 1 and the $k$-min face of zone 2. These two faces would not be included in the boundary conditions because they are already defined as connectivity interfaces.
Appendix D. GUIDELINE FOR PLOT3D VARIABLES

The broad scope of CGNS allows users to essentially put *anything* into a CGNS file. While this is useful from the perspective of extensibility, it also makes it more difficult to read someone else’s CGNS file without an elaborate array of checks and translators. This is true not only because of the many choices of variables to output, but also because CGNS allows many forms of dimensional and nondimensional data.

Many people in the CFD community currently output flow field data in PLOT3D format [7], particularly for use in postprocessing visualization programs. It has, in some sense, become a *de facto* standard for sharing CFD data. Because this format is so widely used, we give a guideline in this appendix for outputting and reading this type of data in a CGNS file. If you follow this guideline, then it is more likely that other users will be able to easily read and interpret your CGNS files.

The PLOT3D standard grid variables are (in 3-D) $x$, $y$, and $z$. These coordinates may be dimensional or nondimensional. To follow this guideline, the three coordinates CoordinateX, CoordinateY, and CoordinateZ (either dimensional or nondimensional) must be given. There also may be “iblank” information, associated with overset grids. If used, the list of overset holes is stored under OversetHoles_t nodes (see the SIDS document [1]). This appendix does not cover the various dimensionalization and nondimensionalization options for the grid coordinates. By and large, from the point of view of portability, the issue of units and/or nondimensionalization for grid coordinates is not as crucial as it is for the “Q” variables, which is covered in great detail below. However, one should follow the SIDS standard and appropriately define within the CGNS file the grid’s units or nondimensionalizations used.

The PLOT3D standard “Q” variables are (in 3-D):

- $\rho/\rho_{ref} =$ nondimensional density
- $\rho u/(\rho_{ref} a_{ref}) =$ nondimensional $x$-momentum
- $\rho v/(\rho_{ref} a_{ref}) =$ nondimensional $y$-momentum
- $\rho w/(\rho_{ref} a_{ref}) =$ nondimensional $z$-momentum
- $\rho e_0/(\rho_{ref} a_{ref}^2) =$ nondimensional total energy per unit volume

where $a$ is the speed of sound and $\text{ref}$ indicates a reference state. Standard PLOT3D Q files also specify a reference Mach number, Reynolds number, angle of attack, and time value. For the purposes of this discussion, the time value will not be addressed. CGNS does have the capability for storing time-accurate data if needed (see section 3.6), but time-accurate data is not covered in this PLOT3D guideline. We include below the CGNS convention for storing Mach number, Reynolds number, and (indirectly) angle of attack.

Each of the 5 flow field variables above has a standard name, defined in the SIDS. They are, respectively: *Density*, *MomentumX*, *MomentumY*, *MomentumZ*, and *EnergyStagnationDensity*. To follow this guideline, these are the 5 variables that should be output to your CGNS file (in 3-D), and are also the ones that you should expect to read, given someone else’s
CGNS file, if they are following this guideline.

Multiple bases are allowed in CGNS, but, to further enhance portability of PLOT3D-like datasets, only one CGNSBase.t node is recommended under this guideline. In other words, multiple cases (such as different angles of attack) should be stored in separate CGNS files with single bases, rather than in a single file with multiple bases.

The three most common types of data that one may output in a CGNS file are:

DataClass = Dimensional
DataClass = NormalizedByDimensional
DataClass = NormalizedByUnknownDimensional

The first category indicates that the data has dimensional units. The second category indicates that the data has been nondimensionalized by known reference values, which are specified in the CGNS file. The third category indicates that the data is nondimensional, but the reference values are unspecified or unknown. Because CGNS deals with each of these in a slightly different way, we will give the guideline for each of these three classes in separate subsections.

D.1 Dimensional Data

To output dimensional data:

1. Under CGNSBase.t, set DataClass = Dimensional.

2. Under CGNSBase.t, put a ReferenceState, and under ReferenceState, put the dimensional reference values of Density and VelocitySound. Under this guideline, the units of these must be consistent with one another and with the units of Density, MomentumX, MomentumY, MomentumZ, and EnergyStagnationDensity given under FlowSolution (e.g., all MKS units). Also under ReferenceState, put Mach, Reynolds, VelocityX, VelocityY, and VelocityZ.

3. Under FlowSolution, put the dimensional variables Density, MomentumX, MomentumY, MomentumZ, and EnergyStagnationDensity. Under this guideline, the units of these 5 variables must be consistent with one another and with the units of Density and VelocitySound in ReferenceState.

To read dimensional data (i.e., if DataClass = Dimensional under CGNSBase.t):

1. Under ReferenceState (directly under CGNSBase.t), read Density, VelocitySound, Mach, and Reynolds. Also read VelocityX, VelocityY, and VelocityZ if an angle of attack of the reference state is needed.

3. To obtain the PLOT3D Q variables, do the following:

\[
\begin{align*}
\frac{\rho}{\rho_{\text{ref}}} &= \frac{\text{Density}}{\text{Density}(\text{ref})} \\
\frac{\rho u}{(\rho_{\text{ref}} a_{\text{ref}})} &= \frac{\text{MomentumX}}{(\text{Density}(\text{ref})*\text{VelocitySound}(\text{ref}))} \\
\frac{\rho v}{(\rho_{\text{ref}} a_{\text{ref}})} &= \frac{\text{MomentumY}}{(\text{Density}(\text{ref})*\text{VelocitySound}(\text{ref}))} \\
\frac{\rho w}{(\rho_{\text{ref}} a_{\text{ref}})} &= \frac{\text{MomentumZ}}{(\text{Density}(\text{ref})*\text{VelocitySound}(\text{ref}))} \\
\frac{\rho e_0}{(\rho_{\text{ref}} a_{\text{ref}}^2)} &= \frac{\text{EnergyStagnationDensity}}{(\text{Density}(\text{ref})*\text{VelocitySound}(\text{ref})^2)}
\end{align*}
\]

D.2 NormalizedByDimensional Data

To output nondimensional data with known normalizations:

1. Under CGNSBase_t, set DataClass = NormalizedByDimensional.

2. Under CGNSBase_t, put a ReferenceState; and under ReferenceState, put Mach, Reynolds, VelocityX, VelocityY, and VelocityZ. Then put either:

   - The \textit{dimensional} reference values of Density and VelocitySound. Under this guideline, the units of these must be consistent with one another and with the units of the \textit{raw} (dimensional) data Density, MomentumX, MomentumY, MomentumZ, and EnergyStagnationDensity given under FlowSolution, prior to normalization.
   - The \textit{nondimensional} reference values of Density and VelocitySound, along with their corresponding ConversionScale and ConversionOffset values. Under this guideline, the units of the \textit{raw} (dimensional) Density and VelocitySound, prior to normalization using ConversionScale and ConversionOffset, must be consistent with one another and with the units of the \textit{raw} (dimensional) data Density, MomentumX, MomentumY, MomentumZ, and EnergyStagnationDensity given under FlowSolution, prior to normalization.

3. Under FlowSolution, put the nondimensional variables Density, MomentumX, MomentumY, MomentumZ, and EnergyStagnationDensity, along with their corresponding ConversionScale and ConversionOffset values. Under this guideline, the units of the \textit{raw} (dimensional) variables, prior to normalization using ConversionScale and ConversionOffset, must be consistent with one another and with the units of the \textit{raw} (dimensional) Density and VelocitySound in ReferenceState.

To read nondimensional data with known normalizations (i.e., if DataClass = NormalizedByDimensional under CGNSBase_t):

1. Under ReferenceState (directly under CGNSBase_t), read Density and VelocitySound. Also read their ConversionScale and ConversionOffset values if they are present. Additionally, read Mach and Reynolds. Also read VelocityX, VelocityY, and VelocityZ if an angle of attack of the reference state is needed.

3. To obtain the PLOT3D Q variables, do the following. First, only if they were given as nondimensional quantities (indicated by a ^ below), recover the raw (dimensional) reference values of Density and VelocitySound, via:

\[
\text{Density}(\text{ref}) = \text{Density}'(\text{ref}) \times \text{ConversionScale} + \text{ConversionOffset}
\]

\[
\text{VelocitySound}(\text{ref}) = \text{VelocitySound}'(\text{ref}) \times \text{ConversionScale} + \text{ConversionOffset}
\]

Then do:

\[
\rho / \rho_{\text{ref}} = (\text{Density} \times \text{ConversionScale} + \text{ConversionOffset}) / \text{Density}(\text{ref})
\]

\[
\rho u / (\rho_{\text{ref}} a_{\text{ref}}) = (\text{MomentumX} \times \text{ConversionScale} + \text{ConversionOffset}) / (\text{Density}(\text{ref}) \times \text{VelocitySound}(\text{ref}))
\]

\[
\rho v / (\rho_{\text{ref}} a_{\text{ref}}) = (\text{MomentumY} \times \text{ConversionScale} + \text{ConversionOffset}) / (\text{Density}(\text{ref}) \times \text{VelocitySound}(\text{ref}))
\]

\[
\rho w / (\rho_{\text{ref}} a_{\text{ref}}) = (\text{MomentumZ} \times \text{ConversionScale} + \text{ConversionOffset}) / (\text{Density}(\text{ref}) \times \text{VelocitySound}(\text{ref}))
\]

\[
\rho e_0 / (\rho_{\text{ref}} a_{\text{ref}}^2) = (\text{EnergyStagnationDensity} \times \text{ConversionScale} + \text{ConversionOffset}) / (\text{Density}(\text{ref}) \times \text{VelocitySound}(\text{ref})^2)
\]

Note that it is possible that the conversion scale and offset for the PLOT3D Q variables may correspond to the reference conditions. This would imply that the variables could be directly output, without the above conversions needed. However, CGNS allows the variables to be normalized by properties independent of the reference conditions, so the above procedure is recommended to avoid ambiguity.

### D.3 NormalizedByUnknownDimensional Data

To output nondimensional data with unknown normalizations:

1. Under CGNSBase_t, set DataClass = NormalizedByUnknownDimensional.

2. Under CGNSBase_t, put a ReferenceState; and under ReferenceState, put Density = 1 and VelocitySound = 1. Also, put Mach, Reynolds, VelocityX, VelocityY, and VelocityZ.

3. Under FlowSolution, put the nondimensional variables Density, MomentumX, MomentumY, MomentumZ, and EnergyStagnationDensity. These must be nondimensionalized as: \(\rho / \rho_{\text{ref}}, \rho u / (\rho_{\text{ref}} a_{\text{ref}}), \rho v / (\rho_{\text{ref}} a_{\text{ref}}), \rho w / (\rho_{\text{ref}} a_{\text{ref}}), \rho e_0 / (\rho_{\text{ref}} a_{\text{ref}}^2)\).

(Setting Density = 1 and VelocitySound = 1 in the ReferenceState defines the particular nondimensionalization defined above for the PLOT3D variables; see the SIDS
document [1] for details and other examples.) To read nondimensional data with unknown normalizations (i.e., if DataClass = NormalizedByUnknownDimensional under CGNSBase.t):

1. Check under ReferenceState (directly under CGNSBase.t), to be sure that Density = 1 and VelocitySound = 1. Then, read Mach and Reynolds. Also read VelocityX, VelocityY, and VelocityZ if an angle of attack of the reference state is needed.


Nothing needs to be done in this case to obtain the PLOT3D Q variables. They are already in the correct form.

D.4 Notes

1. In addition to the flow field variables Density, MomentumX, MomentumY, MomentumZ, and EnergyStagnationDensity (under FlowSolution), you may also output additional variables if desired, but be sure these 5 are present.

2. Other reference values may also be placed under ReferenceState (for example, LengthReference may be needed to define the reference length associated with the grid coordinates), but the use of Density and VelocitySound is sufficient to define the nondimensionalizations of the PLOT3D Q variables.

3. The quantities Mach, Reynolds, VelocityX, VelocityY, VelocityZ, Density, and VelocitySound (plus anything else) under ReferenceState must all represent the same reference state of the flow. For external aerodynamics, this is usually taken to be the free stream, but it does not have to be.

4. The velocity components are used, in the PLOT3D sense, solely to provide an angle of attack of the flow field at the reference state. The definition of angle of attack itself is non-unique in 3-D, so there is therefore no SIDS standard for it. For example, one possible set of angle definitions assumes that the z-direction is “up,” and uses:

   \[ u = V \cos \beta \cos \alpha \]
   \[ v = -V \sin \beta \]
   \[ w = V \cos \beta \sin \alpha \]

   where \( V = \sqrt{u^2 + v^2 + w^2} \), \( \alpha \) is angle of attack, and \( \beta \) is angle of sideslip. Thus, an angle of attack can be obtained using \( \alpha = \tan^{-1}(w/u) \), where \( u = \text{VelocityX} \) and \( w = \text{VelocityZ} \).
5. When reading someone else’s CGNS file, a low-level approach to interpret and/or use it appropriately would be the following. First, check to see that there is only one CGNSBase_t node. (As discussed above, multiple bases are allowed in general, but under this guideline only one base should exist.) Second, insure that the variables CoordinateX, CoordinateY, and CoordinateZ exist under each zone’s GridCoordinates_t node, and that the variables Density, MomentumX, MomentumY, MomentumZ, and EnergyStagnationDensity exist under each zone’s FlowSolution_t node. (Note: for time-accurate datasets there may be multiple GridCoordinates_t and FlowSolution_t nodes under each zone – see section 3.6 – but this situation is not covered under the current PLOT3D guideline.) Then, search for the following characteristics in the file:

- If DataClass = Dimensional, then ReferenceState (directly under CGNSBase.t) must contain Density, VelocitySound, Mach, and Reynolds. VelocityX, VelocityY, and VelocityZ are needed under ReferenceState only if a reference angle of attack is required.

- If DataClass = NormalizedByDimensional, then ReferenceState (directly under CGNSBase_t) must contain Density, VelocitySound, Mach, and Reynolds. VelocityX, VelocityY, and VelocityZ are needed under ReferenceState only if a reference angle of attack is required. Furthermore, a ConversionScale and ConversionOffset must exist for each of the 5 flow field variables under FlowSolution. ConversionScale and ConversionOffset may or may not exist for the variables under ReferenceState.

- If DataClass = NormalizedByUnknownDimensional, then ReferenceState (directly under CGNSBase_t) must contain Density = 1, VelocitySound = 1, as well as Mach, and Reynolds. VelocityX, VelocityY, and VelocityZ are needed under ReferenceState only if a reference angle of attack is required.

If these conditions are met, then a low-level reader could assume that the guidelines outlined in the above subsections were followed, and the PLOT3D variables could easily be obtained using the procedures given. A more advanced reader would probably check for consistency in the dimensions and conversion scales, to ensure compliance with the guidelines.

References


The CFD General Notation System (CGNS) was developed to be a self-descriptive, machine-independent standard for storing CFD aerodynamic data. This guide aids users in the implementation of CGNS. It is intended as a tutorial on the usage of the CGNS mid-level library routines for reading and writing grid and flow solution datasets for both structured and unstructured methodologies.