CGNS Tutorial

Introduction

CFD General Notation System (CGNS)

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Outline

- Introduction
- Overview of CGNS
  - What it is
  - History
  - How it works, and how it can help
  - The future
- Basic usage
  - Getting it and making it work for you
  - Simple example
  - Aspects for data longevity

Introduction

- CGNS provides a general, portable, and extensible standard for the description, storage, and retrieval of CFD analysis data
- Principal target is data normally associated with computed solutions of the Navier-Stokes equations & its derivatives
- But applicable to computational field physics in general (with augmentation of data definitions and storage conventions)

What is CGNS?

- Standard for defining & storing CFD data
  - Self-descriptive
  - Machine-independent
  - Very general and extendable
  - Administered by international steering committee
- AIAA recommended practice (AIAA R-101A-2005)
- Free and open software
- Well-documented
- Discussion forum: cgnstalk@lists.nasa.gov
- Website: http://www.cgns.org

History

- CGNS was started in the mid-1990s as a joint effort between NASA, Boeing, and McDonnell Douglas
  - Under NASA’s Advanced Subsonic Technology (AST) program
- Arose from need for common CFD data format for improved collaborative analyses between multiple organizations
  - Existing formats, such as PLOT3D, were incomplete, cumbersome to share between different platforms, and not self-descriptive (poor for archival purposes)
- Initial development was heavily influenced by McDonnell Douglas’ “Common File Format”, which had been in use since 1989
- Version 1.0 of CGNS released in May 1998

History, cont'd

- After AST funding ended in 1999, CGNS steering committee was formed
  - Voluntary public forum
  - International members from government, industry, academia
  - Formally became a sub-committee of AIAA Committee on Standards in 2000
- Initial efforts by Boeing to make CGNS an international ISO-STEP standard (1999-2002)
  - Stalled due to lack of funding
  - Instead, the existing ISO standard AP209 (finite element solid mechanics) is being rewritten to include CGNS as well as an integrated engineering analysis framework (headed by Lockheed-Martin)

Steering committee

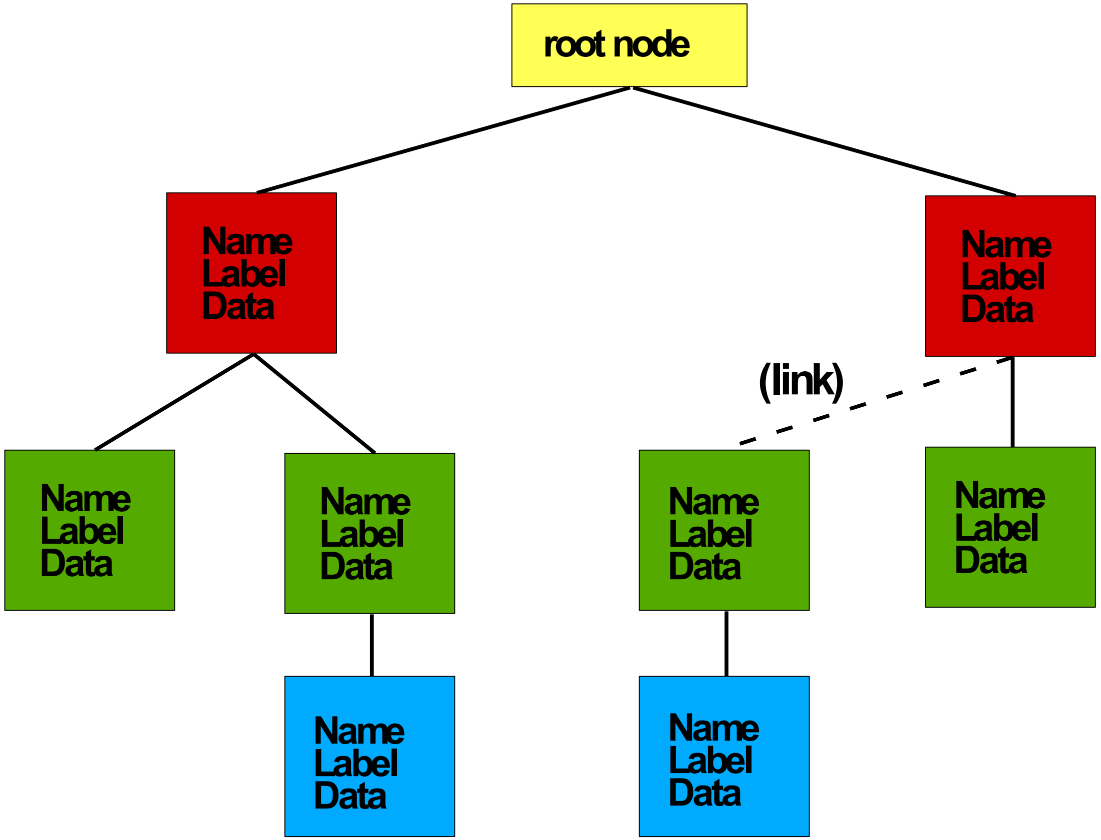
- CGNS Steering committee is a public forum
- Responsibilities include (1) maintaining software, documentation, and website, (2) ensuring free distribution, and (3) promoting acceptance
- Current steering committee make-up (22 members):

ADAPCO
ANSYS-CFX
ANSYS-ICEM CFD
Airbus
Boeing – IDS/PW
Boeing Commercial
Boeing IDS
Concepts NREC
Intelligent Light
NASA Glenn
NASA Langley
ONERA
Pointwise
Pratt & Whitney
Pratt & Whitney – Rocketdyne
Rolls-Royce Allison
Stanford University
Stony Brook University
Tecplot
TTC Technologies
U.S. Air Force / AEDC
Utah State University

CGNS main features

- Standard Interface Data Structures (SIDS) is the core of CGNS – defines the intellectual content
- Hierarchical data structure : quickly traversed and sorted, no need to process irrelevant data
- Layered so that many of the data structures are optional
- HDF5 (or ADF) database: universal and self-describing
- Data may encompass multiple files through the use of symbolic links
- Portable ANSI C software, with complete Fortran, C, Python, and Matlab interfaces
- Architecture-independent application programming interface (API) – written as a mid-level library (MLL)

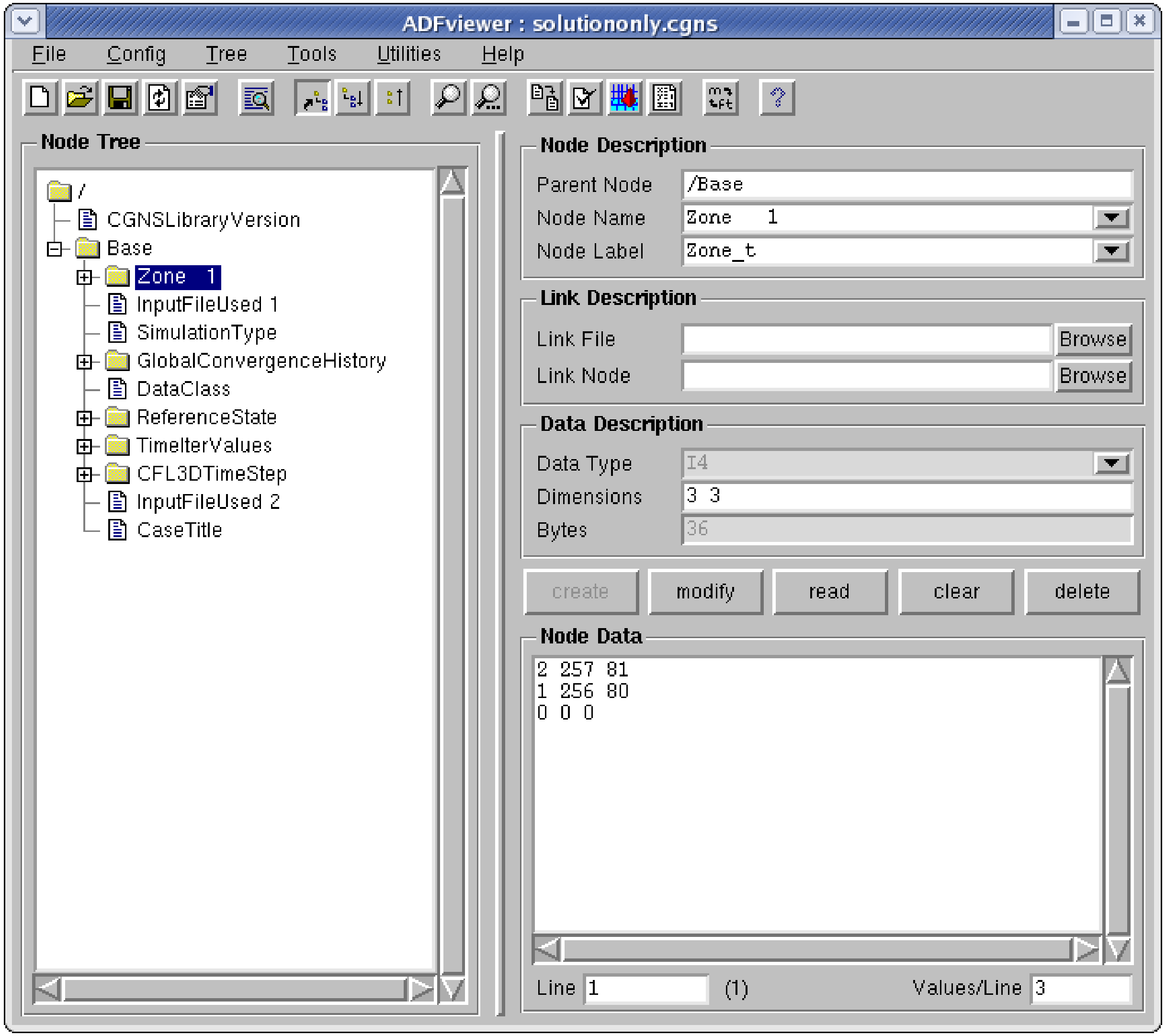
CGNS File Layout



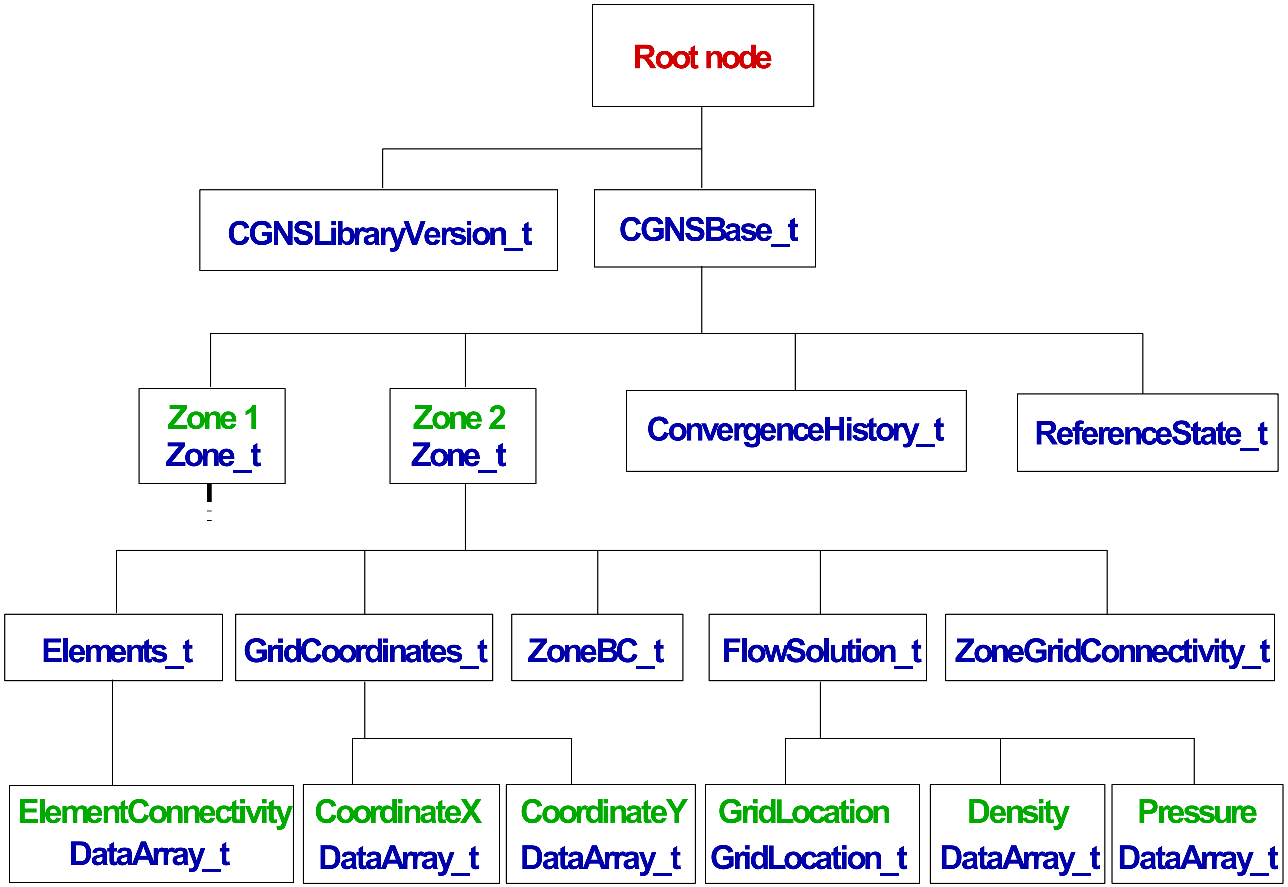
How CGNS works

- Users must download the CGNS software
  - This includes ADF software (basic I/O operations in binary format)
  - Also includes MLL software (for ease of implementation)
  - As of Version 3, HDF5 is automatically included in download. Users wishing to use ADF instead of HDF5 may do so (MLL will work with either ADF or HDF5)
- Users are encouraged to use the MLL to read and write their data (helps ensure CGNS-compatibility)
- Files are portable across computer platforms
- Tools (such as adfviewer) allow user to “see” what is in the CGNS file
- Many commercial pre- and post-processing software support CGNS format

Typical view of CGNS file using adfviewer



Typical CGNS file



Cons and Pros

- Cons
  - Although there are rules, there are also many options and a certain amount of freedom
    - Example: GridLocation = Vertex vs. CellCenter
    - Example: data can be stored dimensional or nondimensional
    - Example: optional use of Rind cells
  - This flexibility places more responsibility on the CGNS reader to figure out how to make use of what is in the file
  - Attempted balance between too rigid and too flexible
- Pros
  - As more people use it, more tools get developed to handle the flexibility
  - Can be as simple as storing only "grid + flow solution", or as complex as storing <u>everything</u> needed to run/describe a case
  - Longevity and infinite extensibility

How CGNS can help you

- Improves longevity (archival quality) of data
  - Self-descriptive (more on this later)
  - Machine-independent
- Easy to share data files between sites
  - Eliminates need to translate between different data formats
  - Rigorous standard means less ambiguity about what the data means
  - For example, CGNS being used in part for AIAA Drag Prediction Workshop (DPW)
- Saves time and money
  - For example, easy to set-up CFD runs because files include grid coordinates, connectivity, and BC information
- Easily extendible to include additional types of data
  - Solver-specific or user-specific data can easily be written & read – file remains CGNS-compliant (others can still read it!)
  - Once defined & agreed upon, new data standards can be added

Status/where CGNS is headed

- Latest version as of June 2009 is 2.5
- Version 3.0 (beta) almost ready for release
- As of June 2009, the CGNSTalk mailing list had 278 participants from 22 different countries and 92 different organizations (sign up at: https://lists.nasa.gov/mailman/listinfo/cgnstalk)
- Many people have expressed interest in CGNS from outside of the traditional aerodynamics community
  - E.g., computational physiology, electromagnetics
- Parallel I/O (through HDF5) available soon as alpha release
- CGNS is already in many widely-used commercial visualization products, e.g., Tecplot, Fieldview, ICEM-CFD, VisIt
- Continuous process: approval and implementation of extensions for handling new capabilities

Getting CGNS

- Go to http://www.cgns.org and follow instructions
  - All documentation available here (in HTML or PDF)
  - You can get the official released version (currently 2.5), or use CVS to keep up with the latest fixes
  - Follow instructions in README file to compile
- Also highly recommended (from same place):
  - cgnstools (tools for viewing/editing)
  - CGNS Users Guide (practical entry-level manual for getting started with CGNS – includes simple source codes)

Basics of using CGNS

- Simple example: opening, closing, writing, & reading Base
- Aspects for data longevity
  - Boundary conditions
  - Convergence history
  - Descriptor nodes
  - Data & equation descriptions
  - Flowfield variables

Opening/closing file & writing Base

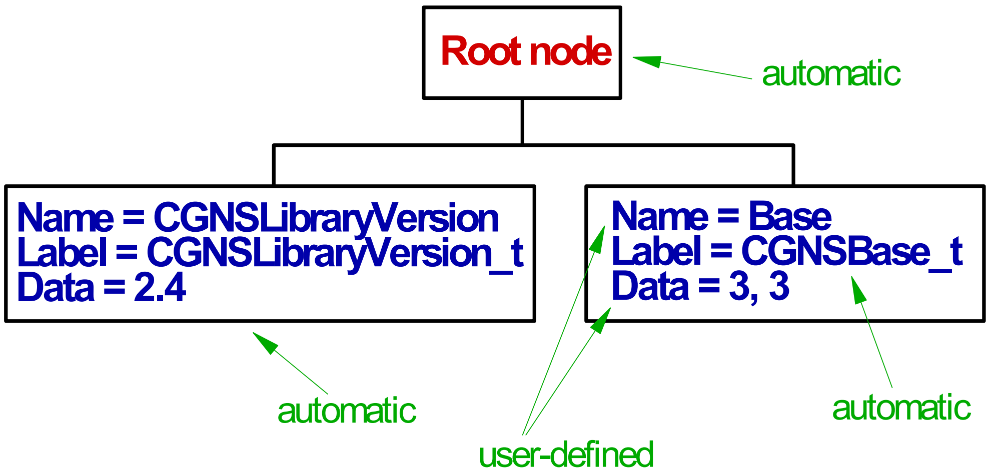
- C

```
cg_open("grid.cgns", CG_MODE_WRITE, &indexf);
strcpy (basename,"Base");
icelldim=3;  /* dimensionality of cell (3 for volume cell) */
iphysdim=3;  /* number of coordinates (3 for 3-D) */
cg_base_write(indexf, basename, icelldim, iphysdim, &indexb);
    ……..
cg_close(indexf);
```

- Fortran

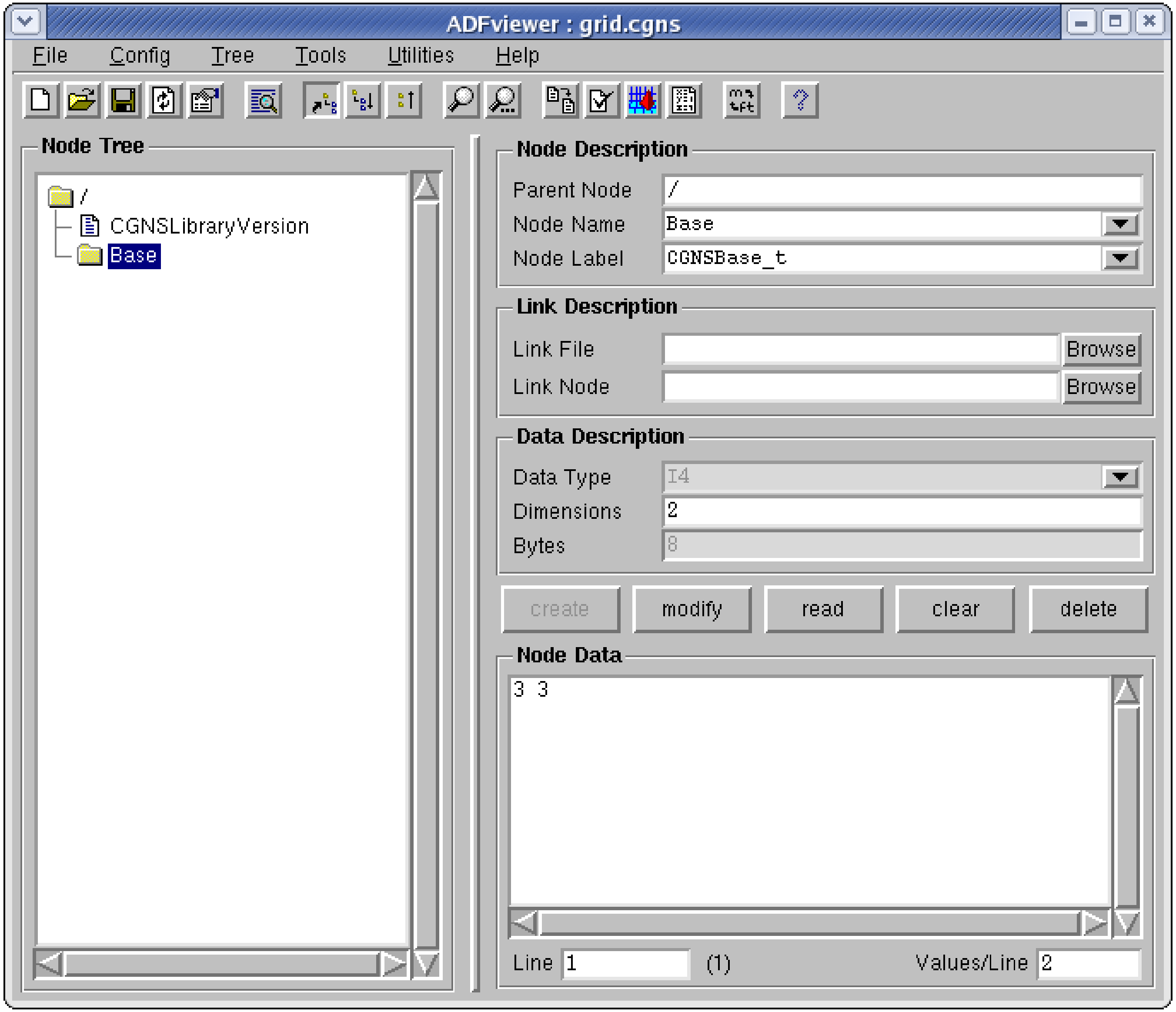
```
call cg_open_f('grid.cgns', CG_MODE_WRITE, indexf, ier)
basename='Base'
icelldim=3
iphysdim=3
call cg_base_write_f(indexf, basename, icelldim, iphysdim, indexb, ier)
    ……..
call cg_close_f(indexf, ierr)
```

What the file looks like…



Notes: icelldim = dimensionality of cell (2 for face, 3 for volume)
iphysdim = no. of coordinates required to define a node position (1 for 1-D, 2 for 2-D, 3 for 3-D)

What the file looks like in adfviewer…



Reading the Base

- C

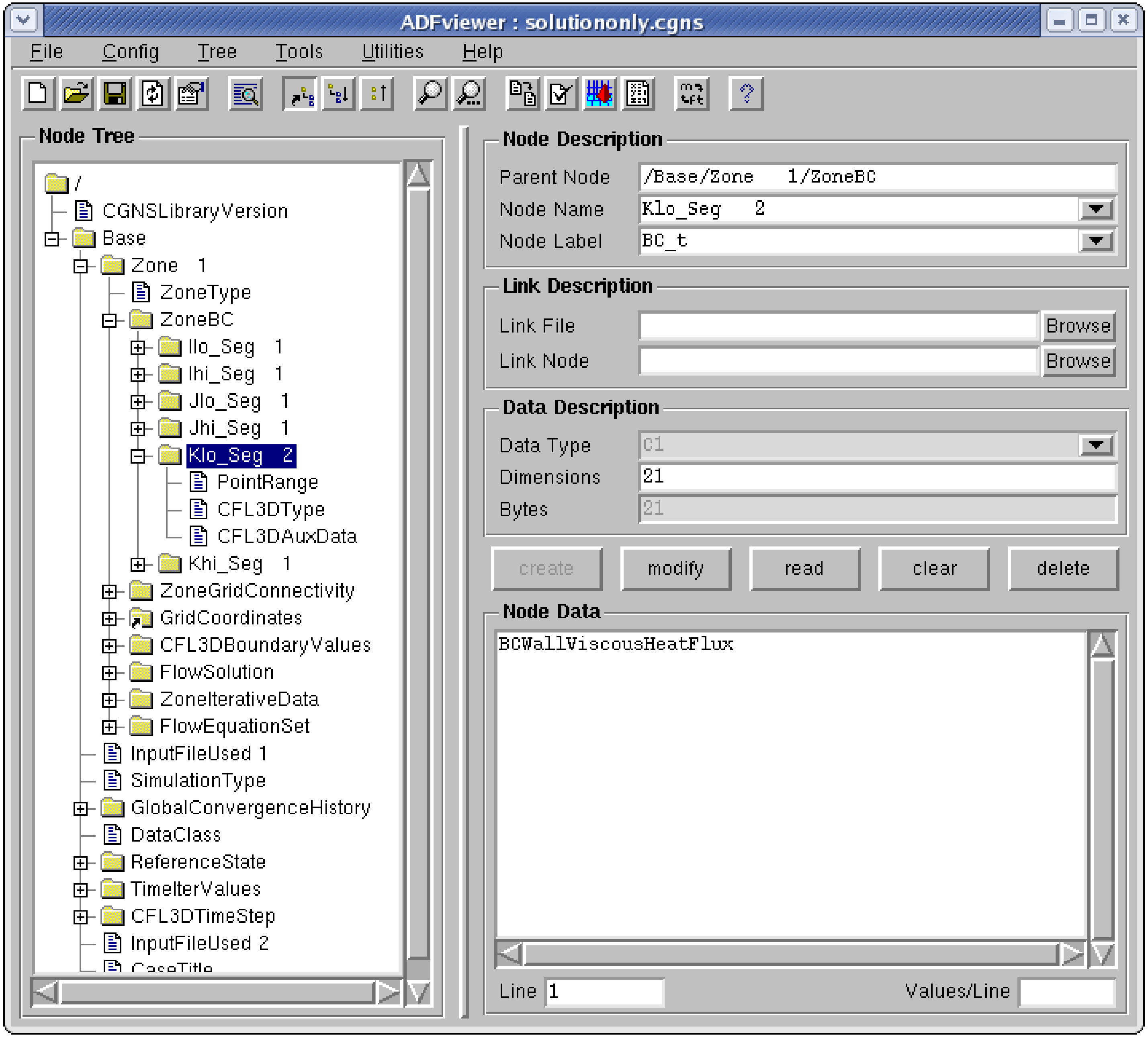
```
cg_open("grid.cgns", CG_MODE_READ, &indexf);
cg_nbases(indexf, &nbases);
for (i=1; i <= nbases; i++)
    {cg_base_read(indexf, i, basename, &icelldim, &iphysdim);}
cg_close(indexf);
```

- Fortran

```
call cg_open_f('grid.cgns', CG_MODE_READ, indexf, ier)
call cg_nbases_f(indexf, nbases, ier)
do i=1,nbases
    call cg_base_read_f(indexf, i, basename, icelldim, iphysdim, ier)
enddo
call cg_close_f(indexf, ier)
```

Aspects for data longevity
boundary conditions

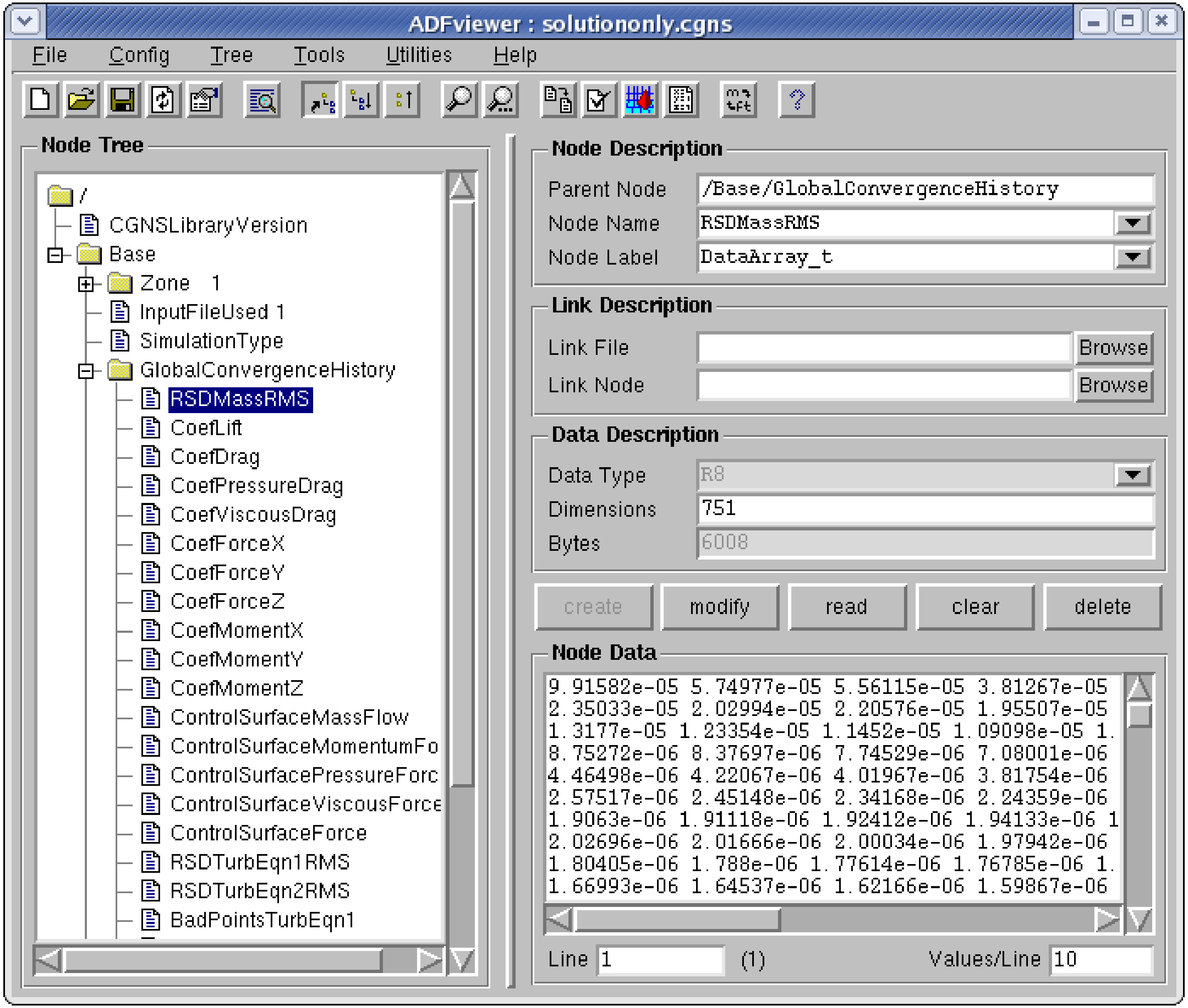
- BCs are included in the CGNS file
- Including BCs makes it easier for someone else to duplicate the same flow conditions
- Eliminates doubt as to how the solution was run, when later looking at the file
- BCs can be simple or have high level of detail
  - Minimum: list of points and their BC type (name)
  - Can also include Dirichlet or Neumann-type data



ADFviewer : solutiononly.cgns
File Config Tree Tools Utilities Help
Node Tree
/
CGNSLibraryVersion
Base
Zone 1
ZoneType
ZoneBC
Ilo_Seg 1
Ihi_Seg 1
Jlo_Seg 1
Jhi_Seg 1
Klo_Seg 2
PointRange
CFL3DType
CFL3DAuxData
Khi_Seg 1
ZoneGridConnectivity
GridCoordinates
CFL3DBoundaryValues
FlowSolution
ZoneIterativeData
FlowEquationSet
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
DataClass
ReferenceState
TimeIterValues
CFL3DTimeStep
InputFileUsed 2
Node Description
Parent Node /Base/Zone 1/ZoneBC
Node Name Klo_Seg 2
Node Label BC_t
Link Description
Link File Browse
Link Node Browse
Data Description
Data Type C1
Dimensions 21
Bytes 21
create modify read clear delete
Node Data
BCWallViscousHeatFlux
Line 1 Values/Line

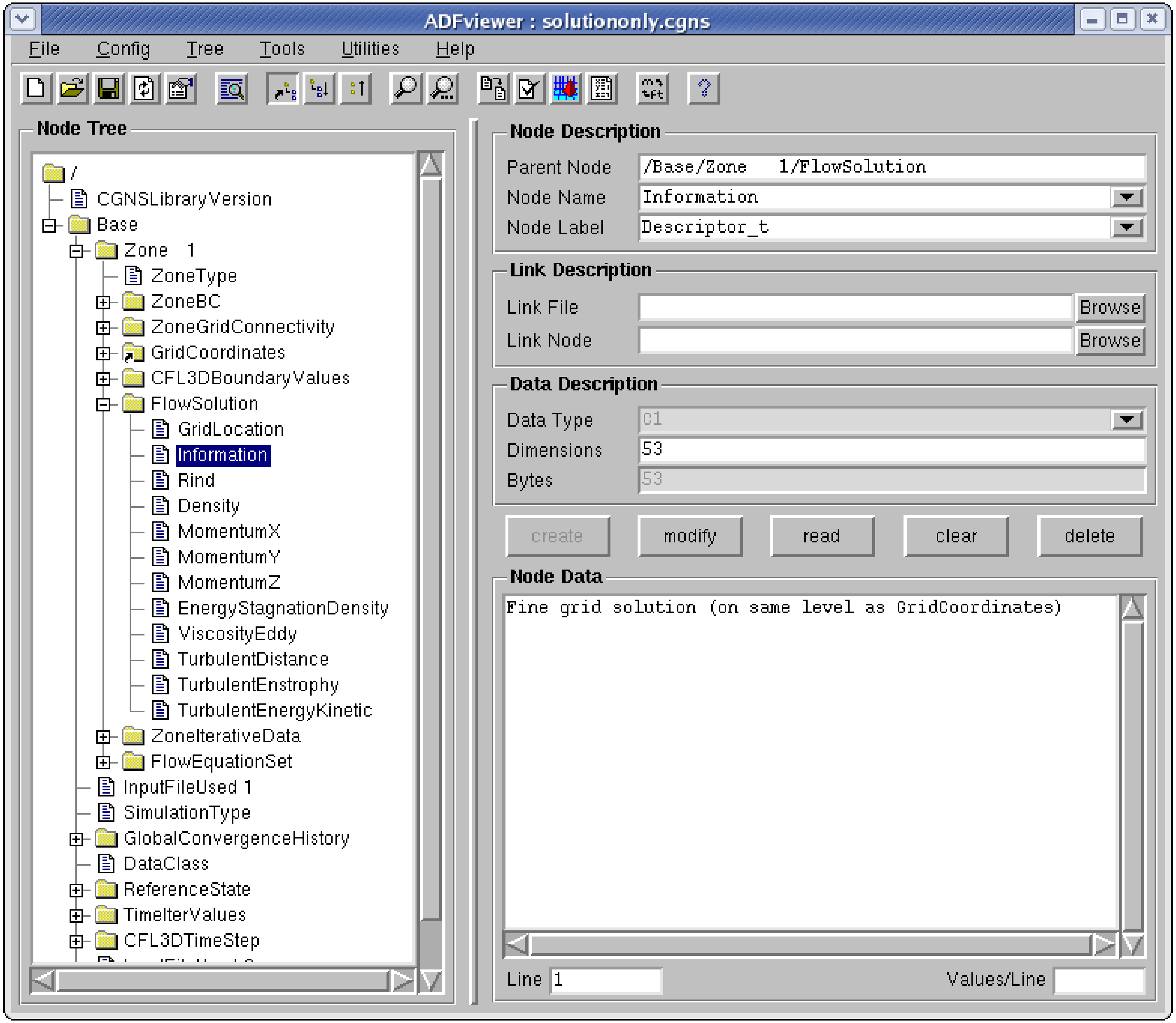
Aspects for data longevity
convergence history

- GlobalConvergenceHistory tracks history of residual(s), forces, moments, etc.
- Part of a complete record of the flow solution, easily readable by others


ADFviewer : solutiononly.cgns
File
Config
Tree
Tools
Utilities
Help
Node Tree
/
CGNSLibraryVersion
Base
Zone 1
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
RSDMassRMS
CoefLift
CoefDrag
CoefPressureDrag
CoefViscousDrag
CoefForceX
CoefForceY
CoefForceZ
CoefMomentX
CoefMomentY
CoefMomentZ
ControlSurfaceMassFlow
ControlSurfaceMomentumFo
ControlSurfacePressureForc
ControlSurfaceViscousForce
ControlSurfaceForce
RSDTurbEqn1RMS
RSDTurbEqn2RMS
BadPointsTurbEqn1
Node Description
Parent Node
/Base/GlobalConvergenceHistory
Node Name
RSDMassRMS
Node Label
DataArray_t
Link Description
Link File
Browse
Link Node
Browse
Data Description
Data Type
R8
Dimensions
751
Bytes
6008
create
modify
read
clear
delete
Node Data
9.91582e-05 5.74977e-05 5.56115e-05 3.81267e-05
2.35033e-05 2.02994e-05 2.20576e-05 1.95507e-05
1.3177e-05 1.23354e-05 1.1452e-05 1.09098e-05 1.
8.75272e-06 8.37697e-06 7.74529e-06 7.08001e-06
4.46498e-06 4.22067e-06 4.01967e-06 3.81754e-06
2.57517e-06 2.45148e-06 2.34168e-06 2.24359e-06
1.9063e-06 1.91118e-06 1.92412e-06 1.94133e-06 1
2.02696e-06 2.01666e-06 2.00034e-06 1.97942e-06
1.80405e-06 1.788e-06 1.77614e-06 1.76785e-06 1.
1.66993e-06 1.64537e-06 1.62166e-06 1.59867e-06
Line 1
(1)
Values/Line 10

Aspects for data longevity
descriptor nodes

- Allow user to add notes, descriptions, important factors associated with the particular run, etc.
- As part of the permanent record, descriptor nodes make the file potentially more useful/meaningful in the future
- Full inclusion of flow solver input deck(s) is particularly useful
- Eliminates doubt as to how the solution was run, when later looking at the file


ADFviewer : solutiononly.cgns
File Config Tree Tools Utilities Help
Node Tree
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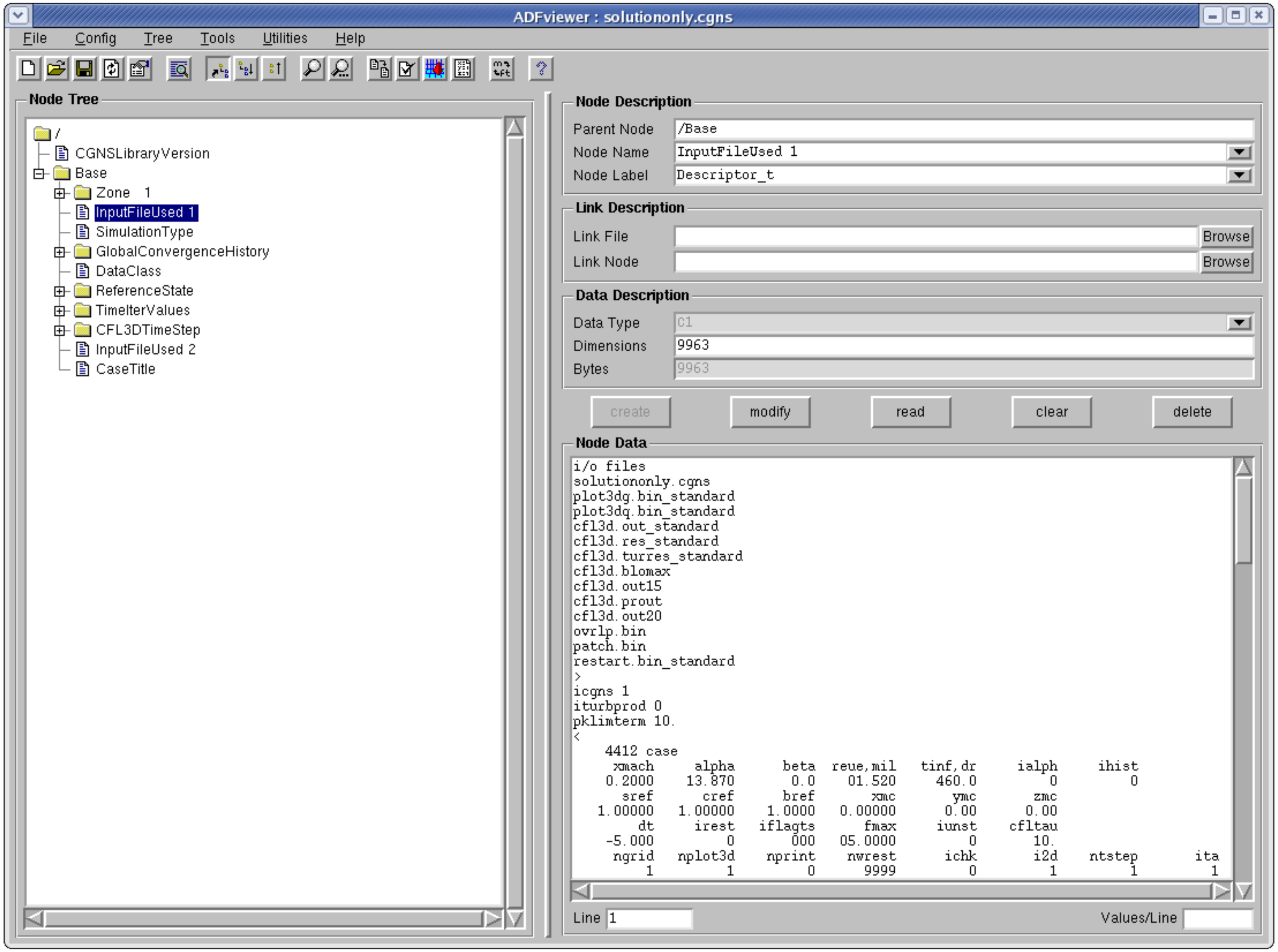
CGNSLibraryVersion
Base
Zone 1
ZoneType
ZoneBC
ZoneGridConnectivity
GridCoordinates
CFL3DBoundaryValues
FlowSolution
GridLocation
Information
Rind
Density
MomentumX
MomentumY
MomentumZ
EnergyStagnationDensity
ViscosityEddy
TurbulentDistance
TurbulentEnstrophy
TurbulentEnergyKinetic
ZoneIterativeData
FlowEquationSet
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
DataClass
ReferenceState
TimeIterValues
CFL3DTimeStep
Node Description
Parent Node /Base/Zone 1/FlowSolution
Node Name Information
Node Label Descriptor_t
Link Description
Link File Browse
Link Node Browse
Data Description
Data Type C1
Dimensions 53
Bytes 53
create modify read clear delete
Node Data
Fine grid solution (on same level as GridCoordinates)
Line 1
Values/Line


ADFviewer : solutiononly.cgns
File
Config
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Tools
Utilities
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Node Tree
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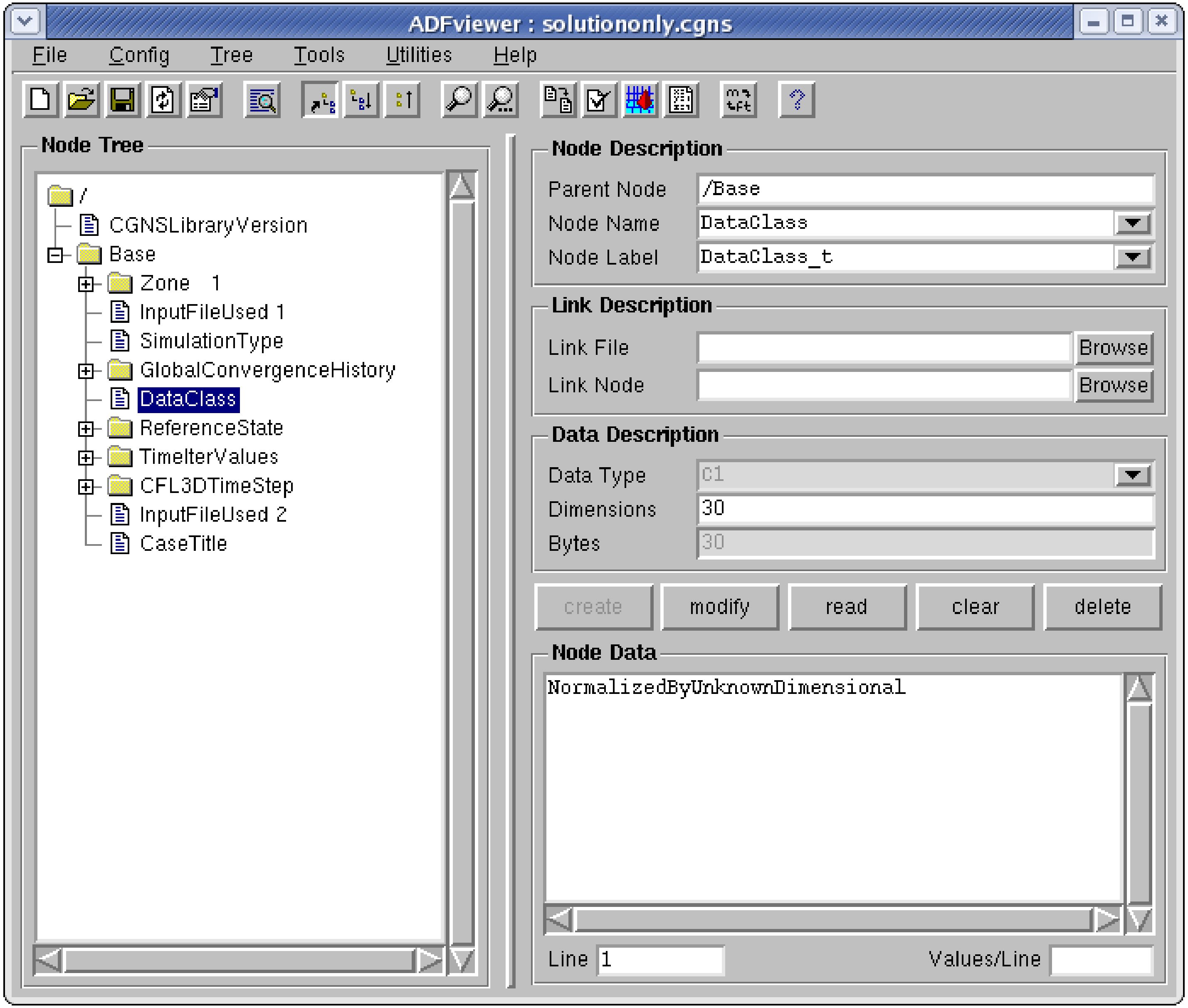
CGNSLibraryVersion
Base
Zone 1
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
DataClass
ReferenceState
TimeIterValues
CFL3DTimeStep
InputFileUsed 2
CaseTitle
Node Description
Parent Node
/Base
Node Name
InputFileUsed 1
Node Label
Descriptor_t
Link Description
Link File
Browse
Link Node
Browse
Data Description
Data Type
C1
Dimensions
9963
Bytes
9963
create
modify
read
clear
delete
Node Data
i/o files
solutiononly.cgns
plot3dg.bin_standard
plot3dq.bin_standard
cfl3d.out_standard
cfl3d.res_standard
cfl3d.turres_standard
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch.bin
restart.bin_standard
>
icgns 1
iturbprod 0
pklimterm 10.
<
4412 case
xmach alpha beta reue,mil tinf,dr ialph ihist
0.2000 13.870 0.0 01.520 460.0 0 0
sref cref bref xmc ymc zmc
1.00000 1.00000 1.0000 0.00000 0.00 0.00
dt irest iflagts fmax iunst cfltau
-5.000 0 000 05.0000 0 10.
ngrid nplot3d nprint nwrest ichk i2d ntstep ita
1 1 0 9999 0 1 1 1
Line
1
Values/Line

Aspects for data longevity
data & equation descriptions

- Documents the dimensionality & units (or normalization) of the data
- Reference state and flow solution method become part of permanent record
- Eliminates doubt as to what the variables represent and how the solution was run, when later looking at the file


ADFviewer : solutiononly.cgns
File Config Tree Tools Utilities Help
Node Tree
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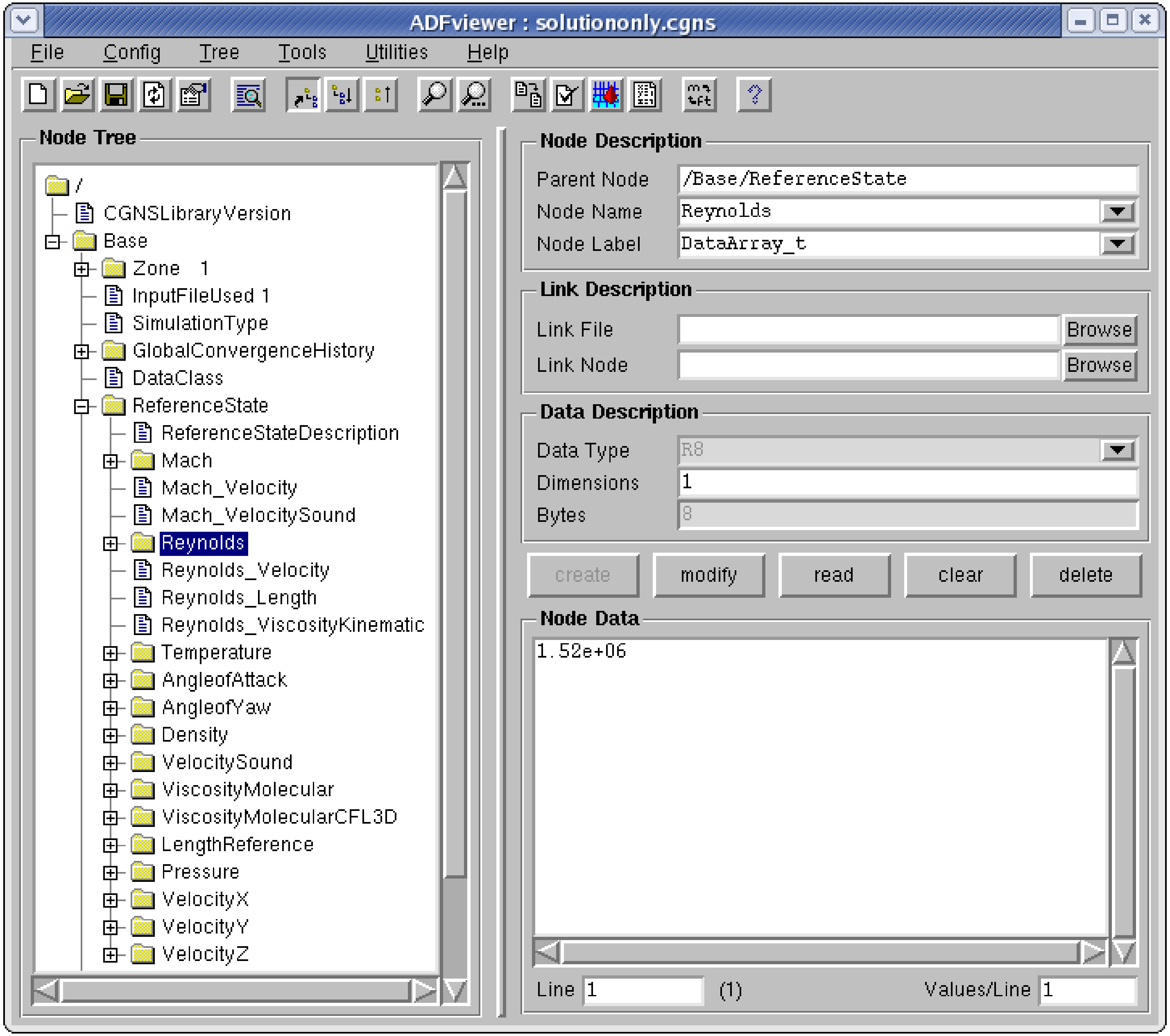
CGNSLibraryVersion
Base
Zone 1
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
DataClass
ReferenceState
TimeIterValues
CFL3DTimeStep
InputFileUsed 2
CaseTitle
Node Description
Parent Node /Base
Node Name DataClass
Node Label DataClass_t
Link Description
Link File Browse
Link Node Browse
Data Description
Data Type C1
Dimensions 30
Bytes 30
create modify read clear delete
Node Data
NormalizedByUnknownDimensional
Line 1 Values/Line


ADFviewer : solutiononly.cgns
File
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Utilities
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Node Tree
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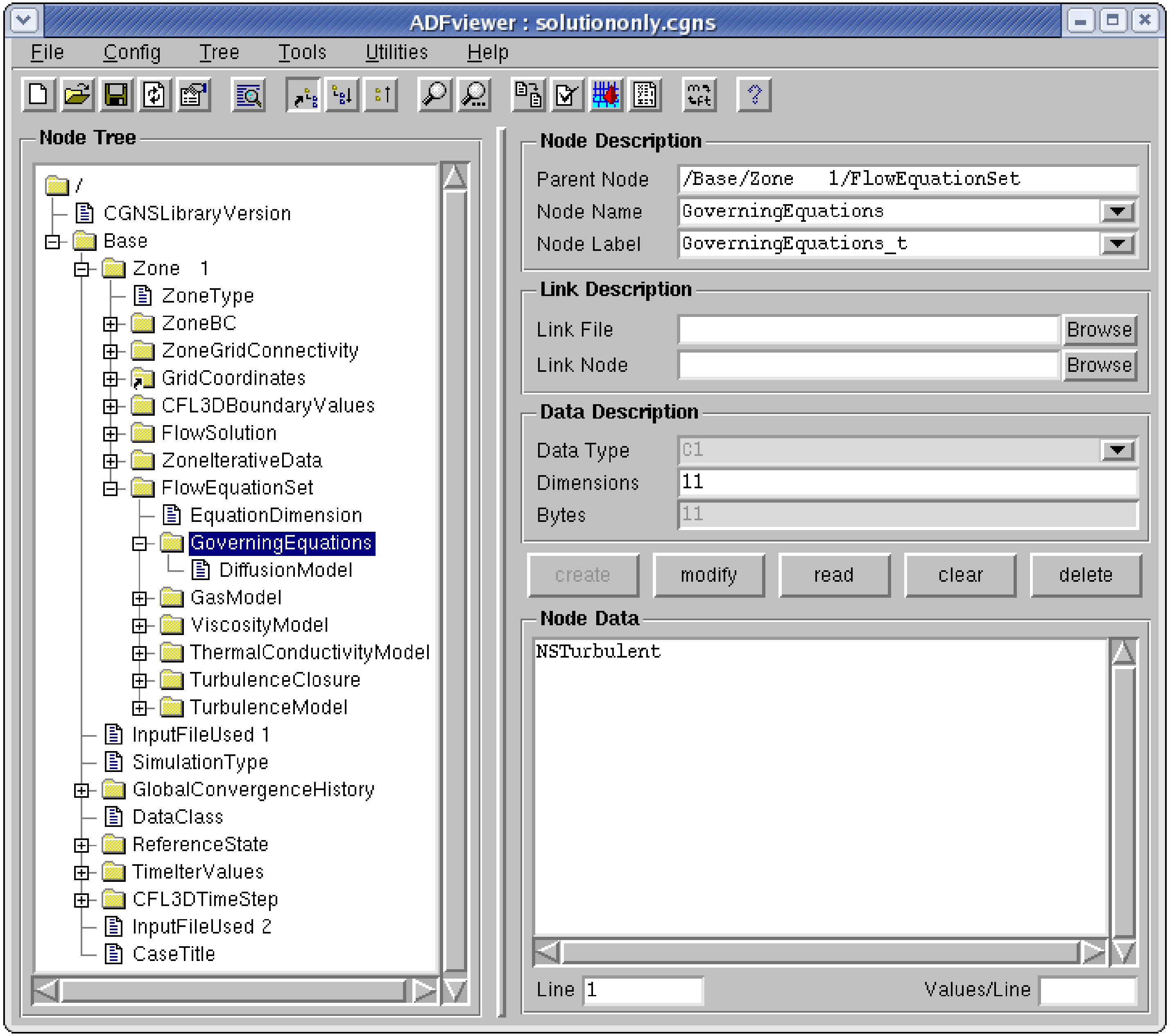
CGNSLibraryVersion
Base
Zone 1
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
DataClass
ReferenceState
ReferenceStateDescription
Mach
Mach_Velocity
Mach_VelocitySound
Reynolds
Reynolds_Velocity
Reynolds_Length
Reynolds_ViscosityKinematic
Temperature
AngleofAttack
AngleofYaw
Density
VelocitySound
ViscosityMolecular
ViscosityMolecularCFL3D
LengthReference
Pressure
VelocityX
VelocityY
VelocityZ
Node Description
Parent Node
/Base/ReferenceState
Node Name
Reynolds
Node Label
DataArray_t
Link Description
Link File
Browse
Link Node
Browse
Data Description
Data Type
R8
Dimensions
1
Bytes
8
create
modify
read
clear
delete
Node Data
1.52e+06
Line
1
(1)
Values/Line
1


ADFviewer : solutiononly.cgns
File Config Tree Tools Utilities Help
Node Tree
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CGNSLibraryVersion
Base
Zone 1
ZoneType
ZoneBC
ZoneGridConnectivity
GridCoordinates
CFL3DBoundaryValues
FlowSolution
ZoneIterativeData
FlowEquationSet
EquationDimension
GoverningEquations
DiffusionModel
GasModel
ViscosityModel
ThermalConductivityModel
TurbulenceClosure
TurbulenceModel
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
DataClass
ReferenceState
TimeIterValues
CFL3DTimeStep
InputFileUsed 2
CaseTitle
Node Description
Parent Node /Base/Zone 1/FlowEquationSet
Node Name GoverningEquations
Node Label GoverningEquations_t
Link Description
Link File Browse
Link Node Browse
Data Description
Data Type C1
Dimensions 11
Bytes 11
create modify read clear delete
Node Data
NSTurbulent
Line 1 Values/Line

Aspects for data longevity
flowfield variables

- As many flowfield variables as desired can be stored; for example:
  - Conserved and/or primitive variables
  - Plus all turbulence quantities, eddy viscosity, distance functions, species mass fractions, or other flowfield quantities of interest
- Eliminates having to go back and restart or reconstruct when you want to obtain non-standard quantities

Some final comments

- A CGNS file can be as full or as sparse as you want to make it
  - The fuller it is, the more complete and archival the file
  - Always easy to read only the parts you want
- Easy to build CGNS into existing processes
  - Start by writing only the “basic” elements of CGNS file (e.g., grid, flow solution, connectivity, and BCs) as a postprocessing file for flow visualization
  - Gradually add to completeness of file
  - Eventually, CGNS file can replace your restart file, if desired
  - Self-contained package: everything you need to run a CFD case can be put in the CGNS file

Conclusions

- CGNS is a well-established, stable format with world-wide acceptance, use, and support
- Provides seamless communication of data between applications, sites, and system architectures
- Supported by many commercial visualization and CFD vendors
- Extensible and flexible – easily adapted to other fields of computational physics through specification in the SIDS
- Backward compatible with previous versions; forward compatible within major release numbers
- Allows new software development to focus on important matters, rather than on time-consuming data I/O, storage, and compatibility issues