enGits GmbH
Marie-Curie-Strae 8
79539 Lrrach
Germany

phone : +49 (0)7621 5500 530
fax : +49 (0)7621 5500 539
email : info@engits.com

# enGrid manual

| | |
|---|---|
| title | enGrid manual |
| date | 12th June 2009 |
| author | O. Gloth |
| document-version | CVS-1.4 |

# Contents


**1 Introduction** **1**

1.1 Current Release (1.0) . . . . . . . . . . 2

1.2 Supported Platforms . . . . . . . . . . 2

1.3 Supported File Formats . . . . . . . . . . 2

**2 Using ENGRID** **3**

2.1 Compilation and Installation . . . . . . . . . . 3

2.1.1 ENGRID on a UNIX system . . . . . . . . . . 3

2.1.2 Installing the Windows Binary . . . . . . . . . . 4

2.2 Tutorials . . . . . . . . . . 6

2.2.1 Tutorial 1: Creating a First Mesh . . . . . . . . . . 6

**3 Background** **17**

3.1 Settings . . . . . . . . . . 17

3.1.1 Feature angle . . . . . . . . . . 17

3.2 Technical Details . . . . . . . . . . 18

3.2.1 Mesh data structures . . . . . . . . . . 18

3.2.2 Initial Boundary Layer Generation . . . . . . . . . . 19

3.2.3 Mesh-Smoothing . . . . . . . . . . 19

3.2.4 Using NETGEN for Tetra-Meshing . . . . . . . . . . 19

3.3 Element Numbering . . . . . . . . . . 19

3.4 Planned Developments . . . . . . . . . . 19

**A GNU Free Documentation License** **21**

References . . . . . . . . . . 28

# 1 Introduction

ENGRID is an open-source mesh generation software with CFD applications in mind. ENGRID uses the NETGEN [4] library for tetrahedral grid generation and an in-house development for prismatic boundary layer grids. Internally, ENGRID uses the VTK [2] data structures as well as the *.vtu file format. To create grids for Currently ENGRID cannot generate surface grids. In order to create a volume grid it is required to import an existing surface mesh. Gmsh [1] is an excellent open-source tool to create surface triangulations for ENGRID . Gmsh is able to import STEP and IGES files and it can also be used for simple geometry modelling.

The 1.0release of ENGRID provides native export to OpenFOAM®[1][3]. For future releases, export capabilities for complete OpenFOAM® cases (including boundary conditions) and support for polyhedral cells are planned as well.

ENGRID is released under the GPL and we hope that it is a useful addition to the open-source CFD community. So far the implemented algorithm proved to be quite robust and it does not require much user interaction. Figure 1.1shows a boundary layer grid that has been created around the geometry of what could be a toy plane.

This manual is very much a work in progress and does not claim to be finished, comprehensive, complete, or anything else. We hope that, even in this early stage, it offers a little help while using ENGRID !

[1] OpenFOAM® is a registered trade mark of OpenCFD®Limited

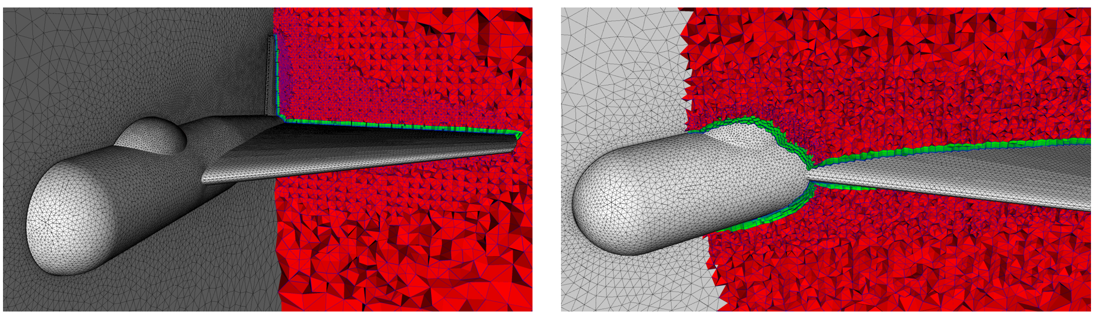


Figure 1.1: Prismatic boundary layer created by ENGRID

## 1.1 Current Release (1.0)

- volume grids from existing surface triangulations (no surface meshing support yet, but planned for future releases)
- prismatic boundary layer support
- GUI based on Qt4
- direct export to OpenFOAM
- experimental support for polyhedral grids in OpenFOAM

## 1.2 Supported Platforms

- ENGRID is developed on a LINUX system (OpenSUSE 10.3), using Qt-4.4.1, VTK 5.2, and an SVN snapshot of NETGEN.
- A Windows executable for Windows-XP (32bit) is also available.

## 1.3 Supported File Formats

- VTK unstructured grids in XML format (ENGRID 's native format)
- VTK poly data in XML format (import)
- legacy VTK files (import)
- OpenFOAM (export)
- Gmsh (import & export)
- STL (import & export)
- NETGEN neutral format (export)

# 2 Using ENGRID

## 2.1 Compilation and Installation

### 2.1.1 ENGRID on a UNIX system

#### Requirements

ENGRID requires Qt-4.X and VTK-5.X. We use Qt-4.4.1 and VTK-5.2 but ENGRID should also compile with earlier versions. Please report any problems to the mailing list. We would, however, also appreciate if you report success with other versions than the ones mentioned before.

Please make sure that VTK is compiled with GUI support for Qt-4.

#### Compilation

ENGRID uses Qt's qmake tool to provide a platform independent compilation mechanism. The source distribution has the following structure:

- enGrid_1.0
  - math
  - netgen_svn
  - resources

First of all, you'll need to set up the following environment variables:

- VTKLIBDIR : Directory containing the VTK libraries
- VTKINCDIR : Directory containing the VTK header files

On Debian or Ubuntu:

```
export VTKLIBDIR=/usr/lib/
export VTKINCDIR=/usr/include/vtk-5.0/
```

On OpenSUSE:

```
export VTKLIBDIR=/usr/lib64
export VTKINCDIR=/usr/include/vtk
```

Then to compile ENGRID you need to first compile the NETGEN library. We have created a Qt project file and a shell script to simplify this. In the main source directory simply type ¨./build-nglib.sh¨. This downloads the latest source code from NETGEN's SVN repository and compiles the necessary library. If this fails, please follow the instructions in the next paragraph. Otherwise compile ENGRID with the following steps:

1. change into the main source directory
2. type qmake
3. type make

#### Compiling NETGEN release

This paragraph is only of interest if the ¨./build-nglib.sh¨ command failed. Download the latest stable release of NETGEN and place it in the "netgen_svn" folder. The following steps should get you a working NETGEN library:

1. create a folder "netgen_svn/netgen-mesher"
2. unpack the netgen-X.Y.Z.tar.gz file
3. move the folder "netgen-X.Y.Z" to "netgen_svn/netgen-mesher/netgen"
4. change directory to "netgen_svn"
5. type qmake
6. type make

After a successful compilation of the NETGEN library you can procede with the compilation of ENGRID as described in the previous paragraph.

#### Installation

There is no installation script yet. You can simply run ENGRID from the source directory by typing "./engrid" or you copy the binary to a place where it will be found by the system (e.g. /usr/local/bin).

### 2.1.2 Installing the Windows Binary

This should, hopefully, be straightforward:

1. Download and save the installer

2. Run the installer
3. Start ENGRID

Of course it is quite possible, if not even likely, that there are issues on certain systems. Please report any problems to the mailing list.

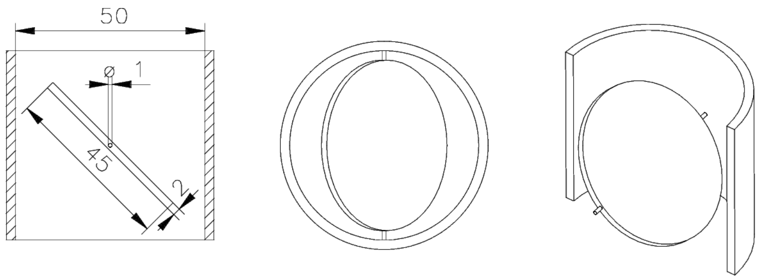



Figure 2.1: Throttle geometry

## 2.2 Tutorials

### 2.2.1 Tutorial 1: Creating a First Mesh

#### Description

This tutorial will demonstrate how to read a surface mesh and create a volume mesh for a CFD simulation. Figure 2.1shows the geometry which will be used for this tutorial; it represents an adjustable throttle. The file containing the surface mesh for this tutorial is called "Throttle.msh" and it can be downloaded from the ENGRID download page.

#### Importing the Surface Mesh

To start, please import the file choosing

*Import » Gmsh » v2.0 (ASCII)*

from the menu bar. A file-dialogue will show and you can browse for the file and open it. Figure 2.2 shows a screen-shot of ENGRID after importing the file. You can use the mouse to rotate, move, and zoom the view. This mouse interaction is the default mouse interaction provided by VTK.

ENGRID colours the faces of the surface grid in order to determine which side of the surface is inside a flow domain and which is outside. The outside is coloured in a pale green, but figure 2.2 shows pale yellow; this means the surface is wrongly oriented and it needs to be corrected. To do this, please choose

*Mesh » change surface orientation*

from the menu-bar. Afterwards the surface will be oriented correctly.

#### Defining Boundary Conditions

Unfortunately all faces belong to the same boundary condition and thus it is not possible to see inside the domain. To change this you can pick a surface on the side of the cylindrical geometry and then change its boundary condition to a different value. To pick a face, please point the mouse over a triangle and press the “P” key on your keyboard. Afterwards you should see something similar to figure 2.3. To change the boundary code, please select

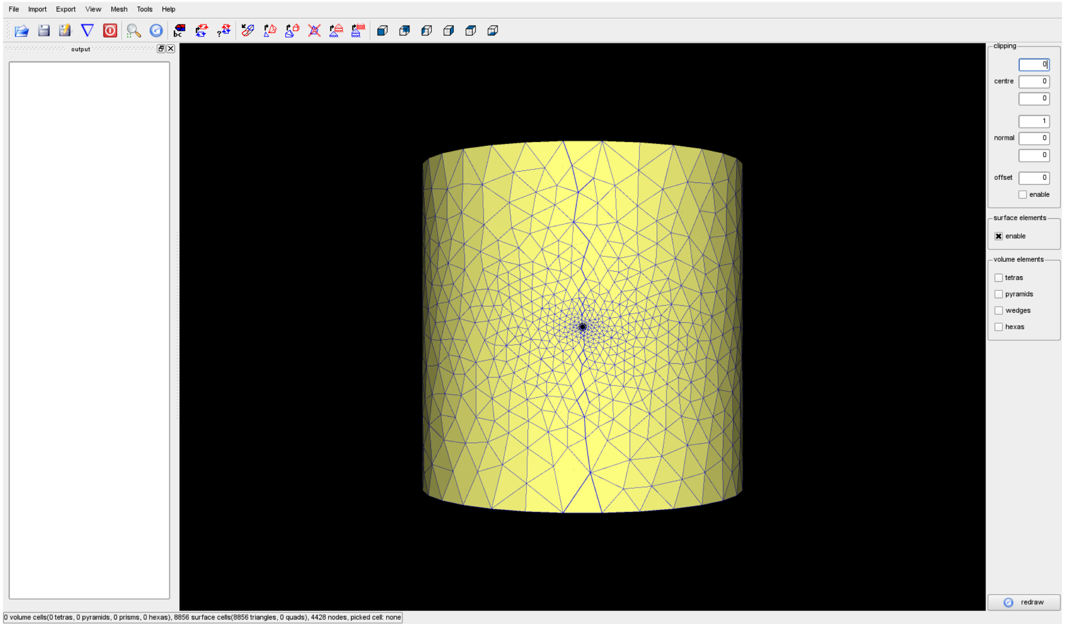



Figure 2.2: After importing the surface mesh

*Mesh » set boundary code*.

A small dialogue will pop up and it offers to select a feature angle and a new boundary code. The new boundary code should be set to "2" and the feature angle can remain at 45 degrees. With this setting you should set the whole side of the cylinder to a new boundary code and the faces should disappear, because they have not been selected for viewing yet. Now, do the same with the top (boundary condition 3) and the bottom (boundary condition 4) of the cylinder. To get rid of the red box, please point the mouse into an empty space and press “P” again. Now would be a good time to save your work. Select

*File » Save Grid As*

to save the file.

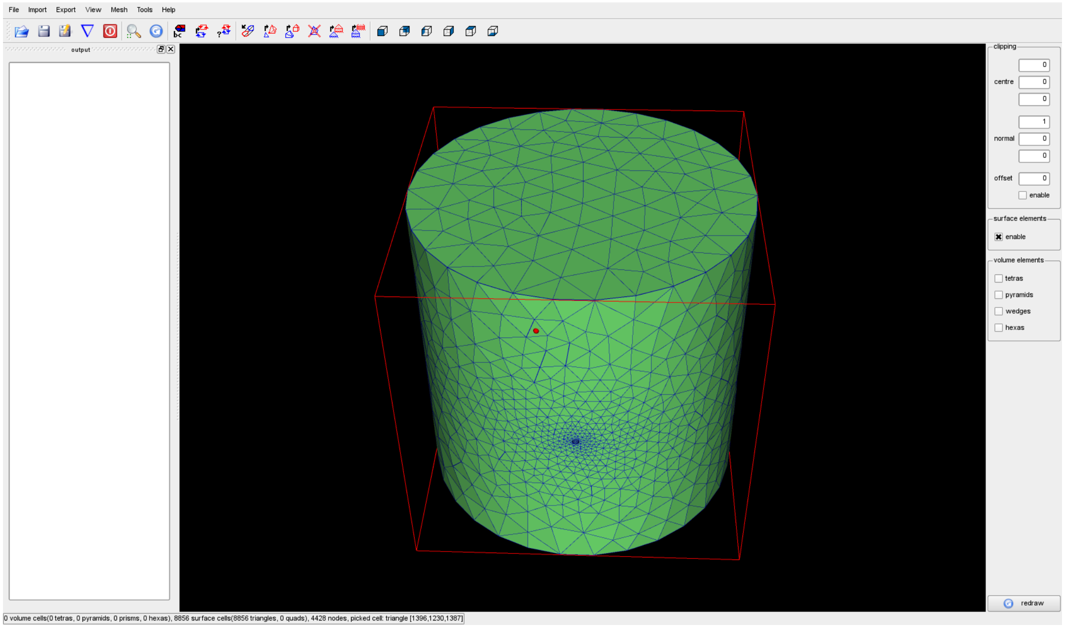


Figure 2.3: After picking a face

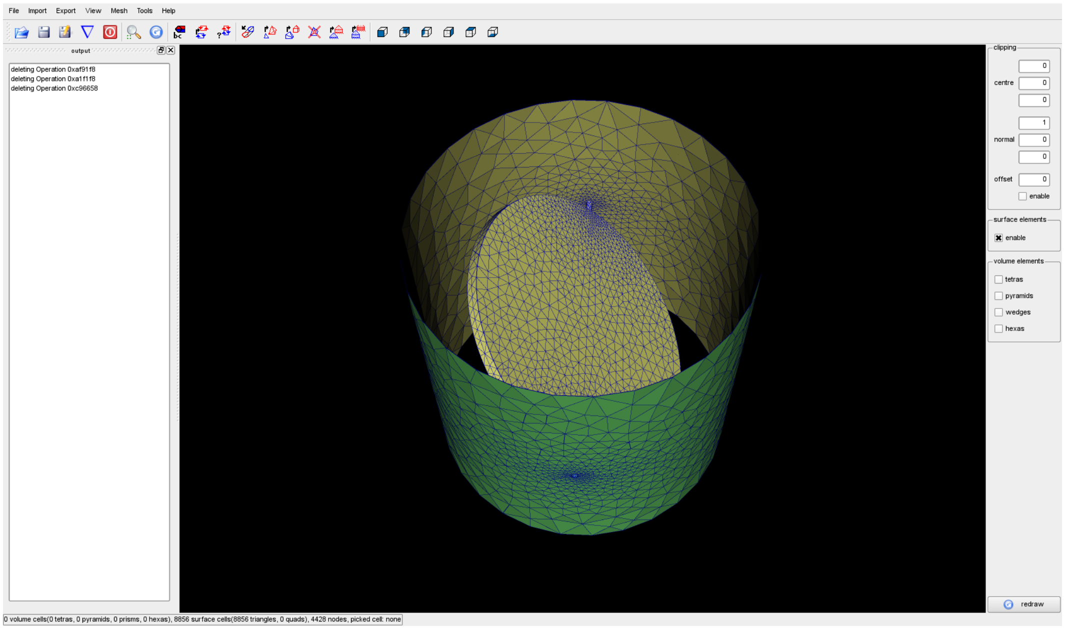


Figure 2.4: Physical walls for prismatic boundary layer

### Create Volume Mesh

Creating a first volume mesh, including the boundary layer, is fairly easy now. First choose

*View » boundary codes*

and select the boundary conditions 1 and 2, because these represent the physical walls of the geometry. You should now have something similar to figure 2.4. To create the grid, simply select

*Mesh » create prismatic boundary layer*,

select the boundary conditions 1 and 2 and click “OK”. You can watch the progress in the output window on the left side of the screen. This output window can be detached, moved somewhere else, or hidden completely. ENGRID indicates that it is busy in the status line at the bottom of the window. After ENGRID has finished you can select “tetras” and “wedges” from the available options on the right side of ENGRID 's main window. In order to see inside you should also enable the clipping options. The origin of the clipping plane can be set to (0,0,0) and the normal vector to (0,0,-1). If you now select to view only boundary condition 1 and choose

*View » redraw*

your screen should look similar to figure 2.5. To get a nice tetrahedral part of the grid it is advisable to execute

*Mesh » create improve volume mesh (NETGEN)*

once or twice. The mesh size distribution is not ideal for the first run of NETGEN. ENGRID uses an existing volume grid to compute a mesh size distribution and uses this as input for the next call of NETGEN. Normally you get a rather coarse tetrahedral grid together with the prismatic layer. The next call will produce a grid that might be somewhat too fine. Starting from the second call of

*Mesh » create improve volume mesh (NETGEN)*

the grid should look rather nice (see figure 2.5).

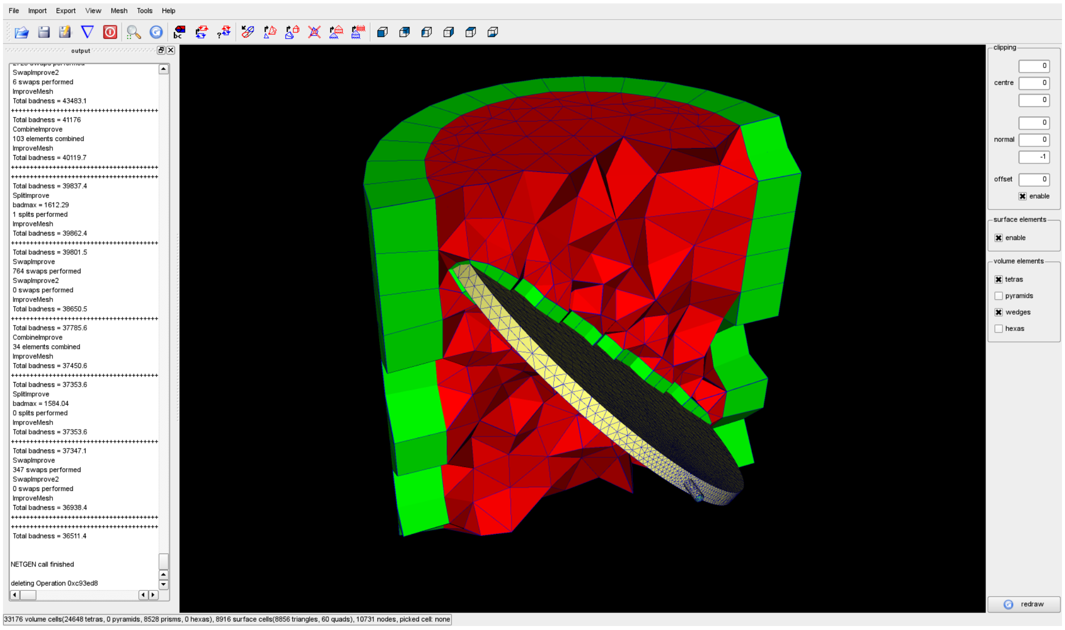



Figure 2.5: First volume grid

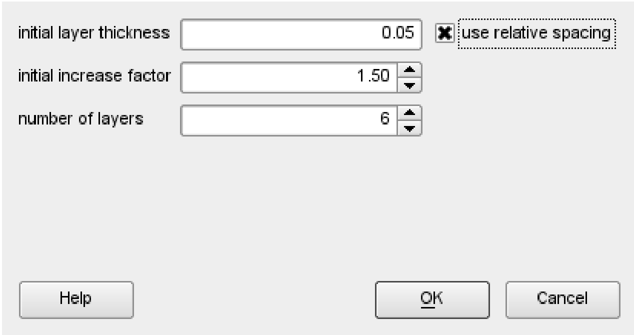



Figure 2.6: Parameters for boundary layer

#### Refining the Boundary-Layer

At the moment the boundary layer consists of a single layer of prisms. Refining the boundary layer is a straightforward process.

Save the grid with the refined boundary layer to a different file name, or don't save it at all (just export). At the moment the refinement cannot be reversed and thus the grid spacing cannot be changed. To do this, load the file with the initial one-layer boundary layer and refine again.

To refine the boundary layer, choose

*Mesh » divide prismatic boundary layer*.

A small pop-up dialogue appears, where you can enter how many layers and how to space them. Relative spacing means, that the initial step size (on the wall) is a fraction of the average local edge length around a node. Absolute spacing uses a fixed distance for all first layer prisms; this will lead to a first layer of prisms which is parallel to the wall. Not all step sizes are possible and ENGRID will issue a warning if it cannot refine your boundary layer. For this tutorial the settings in figure 2.6 should result in a decent boundary layer mesh.

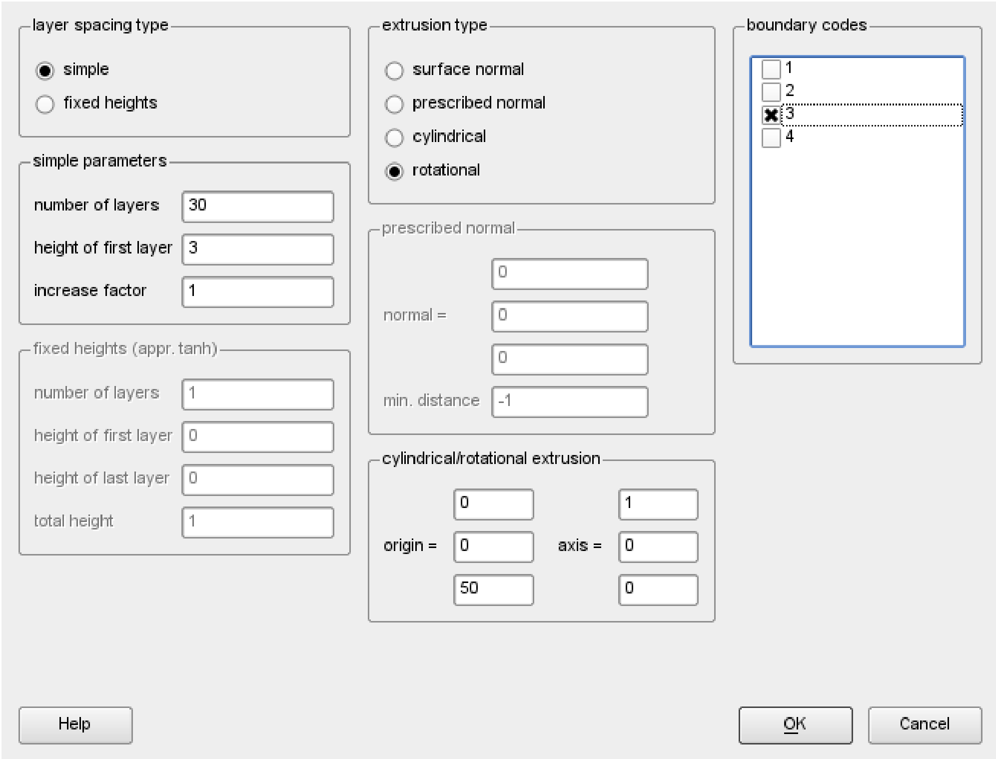



Figure 2.7: Parameters for rotational extrusion

### Applying a few Simple Modifications

ENGRID offers the possibility to modify the grid by extruding certain boundaries. First we will add a pipe bend by applying a rotational extrusion to the upper boundary (code 3). Afterwards we will add straight sections for the in-flow and out-flow boundaries with the help of a normal extrusion. Please select

*Mesh » extrusion*

and enter the parameters exactly as shown in figure 2.7. After clicking OK you should get a grid like the one shown in figure 2.8. The extrusion adds a new boundary code (5) which needs to be enabled with

*View » boundary codes*

in order to view the newly created geometry. The layer height in figure 2.7 corresponds to an angle in degrees for a rotational extrusion. To extend the pipe at the inlet a normal extrusion with the parameters from figure 2.9 shall be used. If you do the same for boundary code 4 the grid should look like in figure 2.10. To simplify the later setup of a simulation it is advisable to reset the newly created boundary codes (5,6,8) to the initially set value of 2 for the pipe.

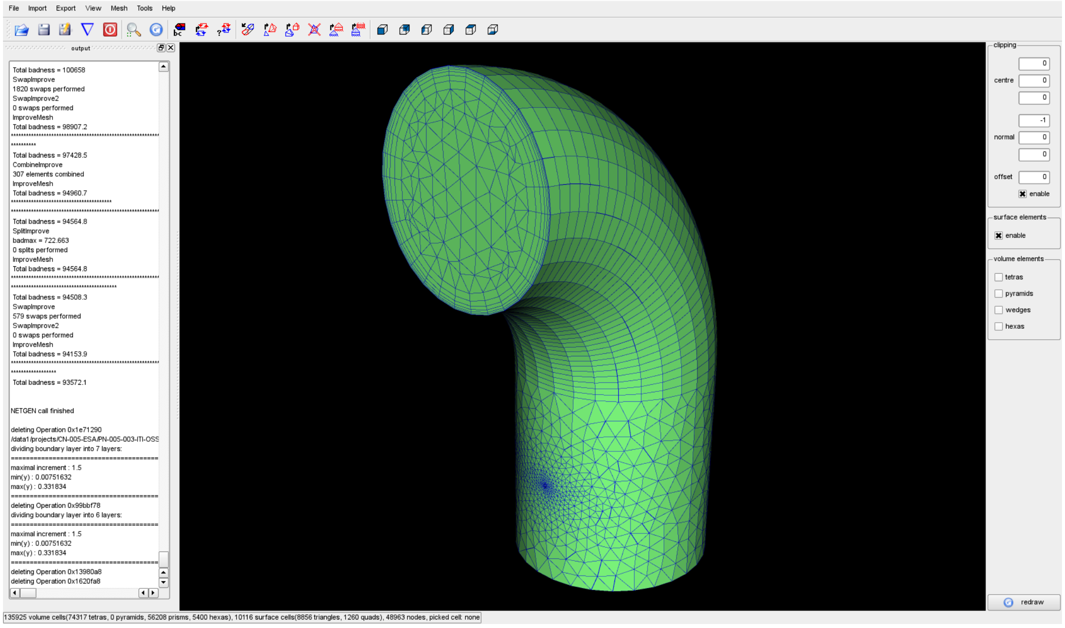


Figure 2.8: Grid after rotational extrusion

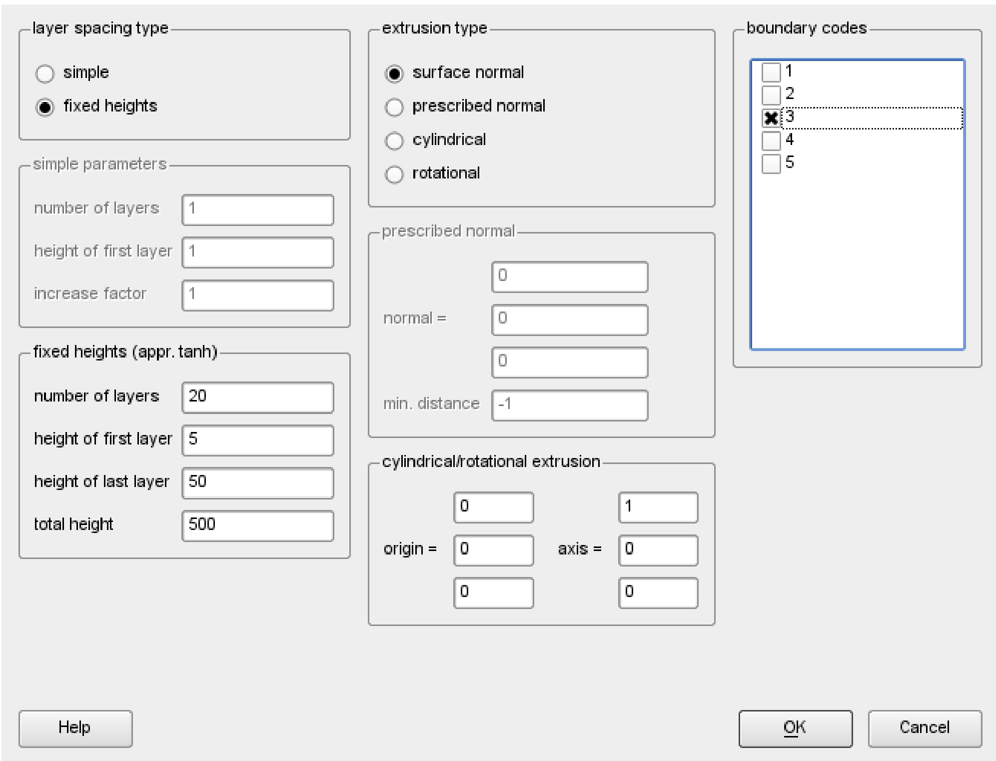



Figure 2.9: Parameters for normal extrusion

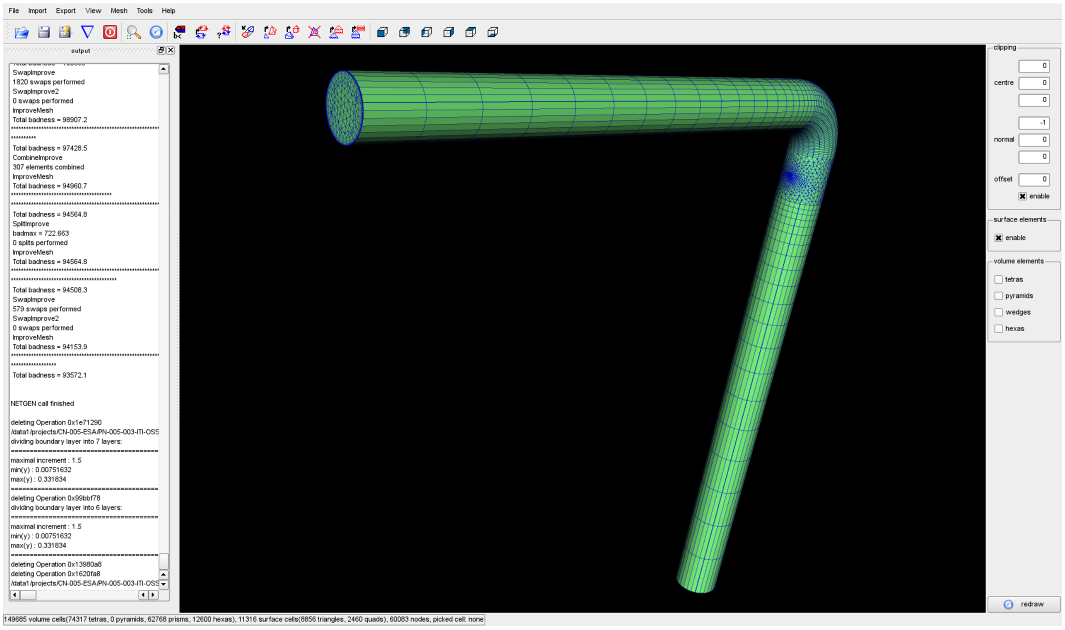



Figure 2.10: Grid after normal extrusion

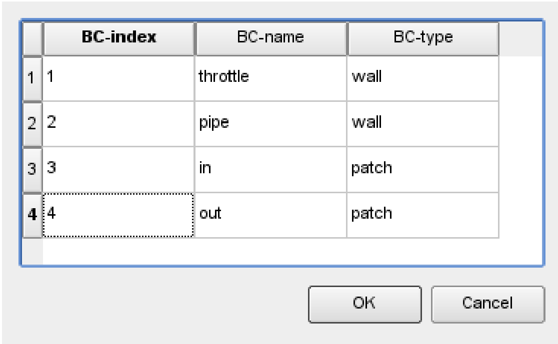



Figure 2.11: Editing the boundary conditions

#### Export the Grid to OpenFOAM®

Please select

*Tools » edit boundary conditions*

and edit the boundary names and types according to figure 2.11. You can export the mesh using:

*Export » OpenFOAM » OpenFOAM*.

This will prompt you for an OpenFOAM® case directory and the mesh will be directly imported to the OpenFOAM® format, using the boundary names and types you have defined earlier.

OpenFOAM's checkMesh utility might report a bad mesh in case of very thin prisms. A good strategy is to export the mesh before the boundary layer is refined, run the checkMesh utility, and then - if everything looks alright - refine the boundary layer.

# 3 Background

## 3.1 Settings

### 3.1.1 Feature angle

The feature angle is used to determine when an edge is a "feature edge", i.e. on the border of a "flat" surface. A feature edge occurs when the angle between the two surface normals of a polygon sharing an edge is greater than the FeatureAngle.

Those feature edges delimit the area which will be set to the given boundary code.

Consider figure 3.1: If you picked cell 1 and chose a feature angle greater than "a", cell 1 and cell 2 will be set to the same boundary code. Otherwise not.

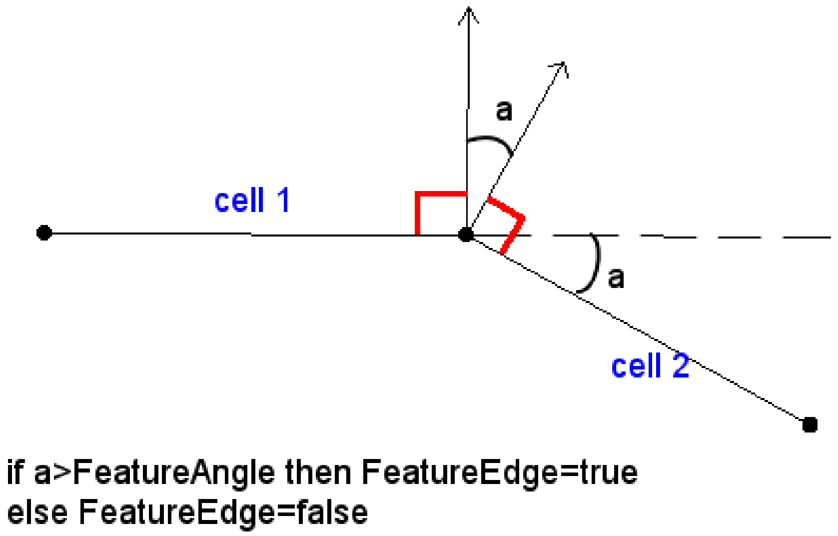



Figure 3.1: The feature angle

## 3.2 Technical Details

### 3.2.1 Mesh data structures

#### Cells

#### Local cells

Depends on:

- cells

#### Nodes

Depends on:

- cells

#### Local nodes

Depends on:

- cells
- nodes

#### N2N (node to node)

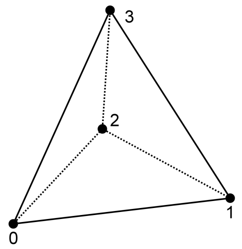
Depends on:

- cells
- nodes
- local nodes

#### N2C (node to cell)

Depends on:

- cells
- nodes
- local nodes




| faces | | edges | |
|---|---|---|---|
| 0 | 2,1,0 | 0 | 0,1 |
| 1 | 1,3,0 | 1 | 0,2 |
| 2 | 3,2,0 | 2 | 0,3 |
| 3 | 2,3,1 | 3 | 1,2 |
| | | 4 | 1,3 |
| | | 5 | 2,3 |

Figure 3.2: Tetrahedron

**C2C (cell to cell)**

Depends on:

- cells

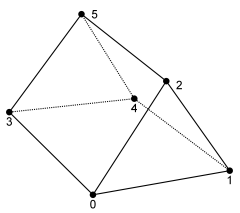
### 3.2.2 Initial Boundary Layer Generation

### 3.2.3 Mesh-Smoothing

### 3.2.4 Using NETGEN for Tetra-Meshing

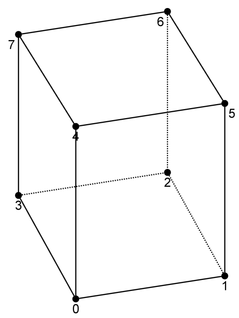
## 3.3 Element Numbering

## 3.4 Planned Developments




| faces | | edges | |
|---|---|---|---|
| 0 | 0,1,2 | 0 | 0,1 |
| 1 | 3,5,4 | 1 | 0,2 |
| 2 | 3,4,1,0 | 2 | 0,3 |
| 3 | 1,4,5,2 | 3 | 1,2 |
| 4 | 0,2,5,3 | 4 | 1,4 |
| | | 5 | 2,5 |
| | | 6 | 3,4 |
| | | 7 | 3,5 |
| | | 8 | 4,5 |

Figure 3.3: Wedge/Prism




| faces | | edges | |
|---|---|---|---|
| 0 | 0,3,2,1 | 0 | 0,1 |
| 1 | 4,5,6,7 | 1 | 0,3 |
| 2 | 0,1,5,4 | 2 | 0,4 |
| 3 | 3,7,6,2 | 3 | 1,2 |
| 4 | 0,4,7,3 | 4 | 1,5 |
| 5 | 1,2,6,5 | 5 | 2,3 |
| | | 6 | 2,6 |
| | | 7 | 3,7 |
| | | 8 | 4,5 |
| | | 9 | 4,7 |
| | | 10 | 5,6 |
| | | 11 | 6,7 |

Figure 3.4: Hexahedron

# A GNU Free Documentation License

## Preamble

The purpose of this License is to make a manual, textbook, or other functional and useful document "free" in the sense of freedom: to assure everyone the effective freedom to copy and redistribute it, with or without modifying it, either commercially or noncommercially. Secondarily, this License preserves for the author and publisher a way to get credit for their work, while not being considered responsible for modifications made by others.

This License is a kind of "copyleft", which means that derivative works of the document must themselves be free in the same sense. It complements the GNU General Public License, which is a copyleft license designed for free software.

We have designed this License in order to use it for manuals for free software, because free software needs free documentation: a free program should come with manuals providing the same freedoms that the software does. But this License is not limited to software manuals; it can be used for any textual work, regardless of subject matter or whether it is published as a printed book. We recommend this License principally for works whose purpose is instruction or reference.

## 1. APPLICABILITY AND DEFINITIONS

This License applies to any manual or other work, in any medium, that contains a notice placed by the copyright holder saying it can be distributed under the terms of this License. Such a notice grants a world-wide, royalty-free license, unlimited in duration, to use that work under the conditions stated herein. The "**Document**", below, refers to any such manual or work. Any member of the public is a licensee, and is addressed as "**you**". You accept the license if you copy, modify or distribute the work in a way requiring permission under copyright law.

A "**Modified Version**" of the Document means any work containing the Document or a portion of it, either copied verbatim, or with modifications and/or translated into another language.

A "**Secondary Section**" is a named appendix or a front-matter section of the Document that deals exclusively with the relationship of the publishers or authors of the Document to the Document's overall subject (or to related matters) and contains nothing that could fall directly within that overall subject. (Thus, if the Document is in part a textbook of mathematics, a Secondary Section may not explain any mathematics.) The relationship could be a matter of historical connection with the subject or with related matters, or of legal, commercial, philosophical, ethical or political position regarding them.

The "**Invariant Sections**" are certain Secondary Sections whose titles are designated, as being those of Invariant Sections, in the notice that says that the Document is released under this License. If a section does not fit the above definition of Secondary then it is not allowed to be designated as

Invariant. The Document may contain zero Invariant Sections. If the Document does not identify any Invariant Sections then there are none.

The "**Cover Texts**" are certain short passages of text that are listed, as Front-Cover Texts or Back-Cover Texts, in the notice that says that the Document is released under this License. A Front-Cover Text may be at most 5 words, and a Back-Cover Text may be at most 25 words.

A "**Transparent**" copy of the Document means a machine-readable copy, represented in a format whose specification is available to the general public, that is suitable for revising the document straightforwardly with generic text editors or (for images composed of pixels) generic paint programs or (for drawings) some widely available drawing editor, and that is suitable for input to text formatters or for automatic translation to a variety of formats suitable for input to text formatters. A copy made in an otherwise Transparent file format whose markup, or absence of markup, has been arranged to thwart or discourage subsequent modification by readers is not Transparent. An image format is not Transparent if used for any substantial amount of text. A copy that is not "Transparent" is called "**Opaque**".

Examples of suitable formats for Transparent copies include plain ASCII without markup, Texinfo input format, LaTeX input format, SGML or XML using a publicly available DTD, and standard-conforming simple HTML, PostScript or PDF designed for human modification. Examples of transparent image formats include PNG, XCF and JPG. Opaque formats include proprietary formats that can be read and edited only by proprietary word processors, SGML or XML for which the DTD and/or processing tools are not generally available, and the machine-generated HTML, PostScript or PDF produced by some word processors for output purposes only.

The "**Title Page**" means, for a printed book, the title page itself, plus such following pages as are needed to hold, legibly, the material this License requires to appear in the title page. For works in formats which do not have any title page as such, "Title Page" means the text near the most prominent appearance of the work's title, preceding the beginning of the body of the text.

A section "**Entitled XYZ**" means a named subunit of the Document whose title either is precisely XYZ or contains XYZ in parentheses following text that translates XYZ in another language. (Here XYZ stands for a specific section name mentioned below, such as "**Acknowledgements**", "**Dedications**", "**Endorsements**", or "**History**".) To "**Preserve the Title**" of such a section when you modify the Document means that it remains a section "Entitled XYZ" according to this definition.

The Document may include Warranty Disclaimers next to the notice which states that this License applies to the Document. These Warranty Disclaimers are considered to be included by reference in this License, but only as regards disclaiming warranties: any other implication that these Warranty Disclaimers may have is void and has no effect on the meaning of this License.

## 2. VERBATIM COPYING

You may copy and distribute the Document in any medium, either commercially or noncommercially, provided that this License, the copyright notices, and the license notice saying this License applies to the Document are reproduced in all copies, and that you add no other conditions whatsoever to those of this License. You may not use technical measures to obstruct or control the reading or further copying of the copies you make or distribute. However, you may accept compensation in exchange for copies. If you distribute a large enough number of copies you must also follow the conditions in section 3.

You may also lend copies, under the same conditions stated above, and you may publicly display copies.

## 3. COPYING IN QUANTITY

If you publish printed copies (or copies in media that commonly have printed covers) of the Document, numbering more than 100, and the Document's license notice requires Cover Texts, you must enclose the copies in covers that carry, clearly and legibly, all these Cover Texts: Front-Cover Texts on the front cover, and Back-Cover Texts on the back cover. Both covers must also clearly and legibly identify you as the publisher of these copies. The front cover must present the full title with all words of the title equally prominent and visible. You may add other material on the covers in addition. Copying with changes limited to the covers, as long as they preserve the title of the Document and satisfy these conditions, can be treated as verbatim copying in other respects.

If the required texts for either cover are too voluminous to fit legibly, you should put the first ones listed (as many as fit reasonably) on the actual cover, and continue the rest onto adjacent pages.

If you publish or distribute Opaque copies of the Document numbering more than 100, you must either include a machine-readable Transparent copy along with each Opaque copy, or state in or with each Opaque copy a computer-network location from which the general network-using public has access to download using public-standard network protocols a complete Transparent copy of the Document, free of added material. If you use the latter option, you must take reasonably prudent steps, when you begin distribution of Opaque copies in quantity, to ensure that this Transparent copy will remain thus accessible at the stated location until at least one year after the last time you distribute an Opaque copy (directly or through your agents or retailers) of that edition to the public.

It is requested, but not required, that you contact the authors of the Document well before redistributing any large number of copies, to give them a chance to provide you with an updated version of the Document.

## 4. MODIFICATIONS

You may copy and distribute a Modified Version of the Document under the conditions of sections 2 and 3 above, provided that you release the Modified Version under precisely this License, with the Modified Version filling the role of the Document, thus licensing distribution and modification of the Modified Version to whoever possesses a copy of it. In addition, you must do these things in the Modified Version:

A. Use in the Title Page (and on the covers, if any) a title distinct from that of the Document, and from those of previous versions (which should, if there were any, be listed in the History section of the Document). You may use the same title as a previous version if the original publisher of that version gives permission.

B. List on the Title Page, as authors, one or more persons or entities responsible for authorship of the modifications in the Modified Version, together with at least five of the principal authors of the Document (all of its principal authors, if it has fewer than five), unless they release you from this requirement.

C. State on the Title page the name of the publisher of the Modified Version, as the publisher.

D. Preserve all the copyright notices of the Document.

E. Add an appropriate copyright notice for your modifications adjacent to the other copyright notices.

F. Include, immediately after the copyright notices, a license notice giving the public permission to use the Modified Version under the terms of this License, in the form shown in the Addendum below.

G. Preserve in that license notice the full lists of Invariant Sections and required Cover Texts given in the Document's license notice.

H. Include an unaltered copy of this License.

I. Preserve the section Entitled "History", Preserve its Title, and add to it an item stating at least the title, year, new authors, and publisher of the Modified Version as given on the Title Page. If there is no section Entitled "History" in the Document, create one stating the title, year, authors, and publisher of the Document as given on its Title Page, then add an item describing the Modified Version as stated in the previous sentence.

J. Preserve the network location, if any, given in the Document for public access to a Transparent copy of the Document, and likewise the network locations given in the Document for previous versions it was based on. These may be placed in the "History" section. You may omit a network location for a work that was published at least four years before the Document itself, or if the original publisher of the version it refers to gives permission.

K. For any section Entitled "Acknowledgements" or "Dedications", Preserve the Title of the section, and preserve in the section all the substance and tone of each of the contributor acknowledgements and/or dedications given therein.

L. Preserve all the Invariant Sections of the Document, unaltered in their text and in their titles. Section numbers or the equivalent are not considered part of the section titles.

M. Delete any section Entitled "Endorsements". Such a section may not be included in the Modified Version.

N. Do not retitle any existing section to be Entitled "Endorsements" or to conflict in title with any Invariant Section.

O. Preserve any Warranty Disclaimers.

If the Modified Version includes new front-matter sections or appendices that qualify as Secondary Sections and contain no material copied from the Document, you may at your option designate some or all of these sections as invariant. To do this, add their titles to the list of Invariant Sections in the Modified Version's license notice. These titles must be distinct from any other section titles.

You may add a section Entitled "Endorsements", provided it contains nothing but endorsements of your Modified Version by various parties–for example, statements of peer review or that the text has been approved by an organization as the authoritative definition of a standard.

You may add a passage of up to five words as a Front-Cover Text, and a passage of up to 25 words as a Back-Cover Text, to the end of the list of Cover Texts in the Modified Version. Only one passage of Front-Cover Text and one of Back-Cover Text may be added by (or through arrangements made by) any one entity. If the Document already includes a cover text for the same cover, previously added by you or by arrangement made by the same entity you are acting on behalf of, you may not add another; but you may replace the old one, on explicit permission from the previous publisher that added the old one.

The author(s) and publisher(s) of the Document do not by this License give permission to use their names for publicity for or to assert or imply endorsement of any Modified Version.

## 5. COMBINING DOCUMENTS

You may combine the Document with other documents released under this License, under the terms defined in section 4 above for modified versions, provided that you include in the combination all of the Invariant Sections of all of the original documents, unmodified, and list them all as Invariant Sections of your combined work in its license notice, and that you preserve all their Warranty Disclaimers.

The combined work need only contain one copy of this License, and multiple identical Invariant Sections may be replaced with a single copy. If there are multiple Invariant Sections with the same name but different contents, make the title of each such section unique by adding at the end of it, in parentheses, the name of the original author or publisher of that section if known, or else a unique number. Make the same adjustment to the section titles in the list of Invariant Sections in the license notice of the combined work.

In the combination, you must combine any sections Entitled “History” in the various original documents, forming one section Entitled “History”; likewise combine any sections Entitled “Acknowledgements”, and any sections Entitled “Dedications”. You must delete all sections Entitled “Endorsements”.

## 6. COLLECTIONS OF DOCUMENTS

You may make a collection consisting of the Document and other documents released under this License, and replace the individual copies of this License in the various documents with a single copy that is included in the collection, provided that you follow the rules of this License for verbatim copying of each of the documents in all other respects.

You may extract a single document from such a collection, and distribute it individually under this License, provided you insert a copy of this License into the extracted document, and follow this License in all other respects regarding verbatim copying of that document.

## 7. AGGREGATION WITH INDEPENDENT WORKS

A compilation of the Document or its derivatives with other separate and independent documents or works, in or on a volume of a storage or distribution medium, is called an “aggregate” if the copyright resulting from the compilation is not used to limit the legal rights of the compilation’s users beyond what the individual works permit. When the Document is included in an aggregate, this License does not apply to the other works in the aggregate which are not themselves derivative works of the Document.

If the Cover Text requirement of section 3 is applicable to these copies of the Document, then if the Document is less than one half of the entire aggregate, the Document’s Cover Texts may be placed on covers that bracket the Document within the aggregate, or the electronic equivalent of covers if the

Document is in electronic form. Otherwise they must appear on printed covers that bracket the whole aggregate.

## 8. TRANSLATION

Translation is considered a kind of modification, so you may distribute translations of the Document under the terms of section 4. Replacing Invariant Sections with translations requires special permission from their copyright holders, but you may include translations of some or all Invariant Sections in addition to the original versions of these Invariant Sections. You may include a translation of this License, and all the license notices in the Document, and any Warranty Disclaimers, provided that you also include the original English version of this License and the original versions of those notices and disclaimers. In case of a disagreement between the translation and the original version of this License or a notice or disclaimer, the original version will prevail.

If a section in the Document is Entitled “Acknowledgements”, “Dedications”, or “History”, the requirement (section 4) to Preserve its Title (section 1) will typically require changing the actual title.

## 9. TERMINATION

You may not copy, modify, sublicense, or distribute the Document except as expressly provided for under this License. Any other attempt to copy, modify, sublicense or distribute the Document is void, and will automatically terminate your rights under this License. However, parties who have received copies, or rights, from you under this License will not have their licenses terminated so long as such parties remain in full compliance.

## 10. FUTURE REVISIONS OF THIS LICENSE

The Free Software Foundation may publish new, revised versions of the GNU Free Documentation License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns. See http://www.gnu.org/copyleft/.

Each version of the License is given a distinguishing version number. If the Document specifies that a particular numbered version of this License “or any later version” applies to it, you have the option of following the terms and conditions either of that specified version or of any later version that has been published (not as a draft) by the Free Software Foundation. If the Document does not specify a version number of this License, you may choose any version ever published (not as a draft) by the Free Software Foundation.

# Bibliography


[1] Christophe Geuzaine and Jean-François Remacle. Gmsh: a three-dimensional finite element mesh generator with built-in pre- and post-processing facilities. Online: http://www.geuz.org/gmsh, 2008.

[2] Kitware Inc. The visualization toolkit. Online: http://www.vtk.org, 2008.

[3] OpenCFD Limited. Openfoam: The open source cfd toolbox. Online: http://www.opencfd.co.uk/openfoam, 2008.

[4] Joachim Schöberl. Netgen/ngsolve. Online: http://www.mathcces.rwth-aachen.de/netgen/doku.php, 2008.