
Caelus Python Library (CPL)

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Applied CCM

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Caelus Python Library is a companion package for interacting with [OpenFOAM](#) and its derivative [Caelus CML](#) open-source CFD packages. The library provides utilities for pre and post-processing, as well as automating various aspects of the CFD simulation workflow. Written in Python, it provides a consistent user-interface across the three major operating systems Linux, Windows, and Mac OS X ensuring that the scripts written in one platform can be quickly copied and used on other platforms.

Like CML, CPL is also an open-source library released under the Apache License Version 2.0 license. See [Apache License Version 2.0](#) for more details on use and distribution.

This documentation is split into two parts: a *user* and a *developer* manual. New users should start with the user manual that provides an overview of the features and capabilities currently available in CPL, the installation process and examples of usage. The developer manual documents the application programming interface (API) and is useful for users and developers looking to write their own python scripts to extend functionality or add features to the library. See [Introduction](#) for more details.

Part I

User Manual

The primary motivation for CPL is to provide a platform-agnostic capability to automate the CFD simulation workflow with OpenFOAM and Caelus CML packages. The package is configurable to adapt to different user needs and system configurations and can interact with multiple software versions simultaneously without the need to source *environment* files (e.g., using `caelus-bashrc` or `OpenFOAM/etc/bashrc` on Unix systems).

Some highlights of CPL include:

- The library is built using Python programming language and uses scientific python libraries (e.g., NumPy, Matplotlib). Versions 2.0.0 and older support both python 2.7 and 3.x. Newer versions only support python 3.6 and higher.
- Uses **YAML** format for configuration files and input files. The YAML files can be read, manipulated, and written out to disk using libraries available in several programming languages, not just Python.
- Provides modules and python classes to work with OpenFOAM and Caelus case directories, process and plot logs, etc. The API is documented to allow users to build custom workflows that are currently not part of CPL.
- A YAML-based *task* workflow capable of automating the mesh, pre-process, solve, post-process workflow on both local workstations as well as high-performance computing (HPC) systems with job schedulers.

1.1 Usage

CPL is distributed under the terms Apache License Version 2.0 open-source license. Users can install the package using `conda`, or access the [Git repository](#) hosted on BitBucket. Please follow *Installing Caelus Python Library (CPL)* for more details on how to install CPL and its dependencies within an existing Python installation on your system.

Please contact the developers with questions, issues, or bug reports.

1.2 Contributing

CPL is an open-source project and welcomes the contributions from the user community. Users wishing to contribute should submit pull requests to the public git repository.

Installing Caelus Python Library (CPL)

CPL is a python package for use with [OpenFOAM](#) or [Caelus CML](#) simulation suite. Therefore, it is assumed that users have a properly functioning OpenFOAM or CML installation on their system. In addition to OpenFoAM/Caelus CML and python, it also requires several scientific python libraries:

- [NumPy](#) – Arrays, linear algebra
- [Pandas](#) – Data Analysis library
- [Matplotlib](#) – Plotting package

The quickest way to install CPL is to install through [Anaconda Python Distribution](#). This distribution provides a comprehensive set of python packages necessary to get up and running with CPL. Once installed, please proceed to [Check installation](#) to learn how to use CPL.

For users wishing to install CPL from the git repository, this user guide recommends the use of Anaconda. An alternate approach using Python *virtualenv* is described at the end of this section, but will require some Python expertise on the part of the user.

The default installation instructions use Python v2.7. However, CPL is designed to work with both Python v2.7 and Python v3.x versions.

2.1 Installing CPL with Anaconda Python Distribution

2.1.1 Install Anaconda

1. [Download the Anaconda installer](#) for your operating system.
2. Execute the downloaded file and follow the installation instructions. It is recommended that you install the default packages.
3. Update the anaconda environment according to [installation instructions](#)

Note: Make sure that you answer `yes` when the installer asks to add the installation location to your default `PATH` locations. Or else the following commands will not work. It might be necessary to open a new shell for the environment to be updated.

2.1.2 Install CPL from conda-forge (recommended)

1. Install CPL using the Anaconda package manager.

```
conda install -c conda-forge caelus
```

2.1.3 Install CPL from source

1. Obtain the CPL source from the public Git repository.

```
# Change to directory where you want to develop/store sources
git clone https://bitbucket.org/appliedccm/CPL
cd CPL
```

2. Create a custom conda environment

```
# Ensure working directory is CPL
conda env create -f etc/caelus3.yml
```

Note:

1. Developers interested in developing CPL might want to install the development environment available in `etc/caelus2-dev.yml`. This installs additional packages like `sphinx` for document generation, and `pytest` for running the test suite.
 2. By default, the environment created is named `caelus` when using `etc/caelus3.yml` and `caelus-dev` when using `etc/caelus3-dev.yml`. The user can change the name of the environment by using `-n <env_name>` option in the previous command.
-

3. Activate the custom environment and install CPL within this environment

```
source activate caelus
pip install .
```

For *editable* development versions of CPL use `pip install -e .` instead.

After completing this steps, please proceed to [Check installation](#) to test that your installation is working properly.

2.2 Alternate Installation – Virtualenv

This method is suitable for users who prefer to use the existing python installations in their system (e.g., from `apt-get` for Linux systems). A brief outline of the installation process is described here. Users are referred to the [virtual environments docs](#) for more information.

2.2.1 Install CPL

1. Obtain the CPL source from the public Git repository.

```
# Change to directory where you want to develop/store sources
git clone https://bitbucket.org/appliedccm/CPL
cd CPL
```

2. Create a virtual environment with all dependencies for CPL

```
# Create virtual environment
python3 -m venv --system-site-packages .venv

# Activate virtual environment
source .venv/bin/activate

# Install dependencies
python3 -m pip install -r requirements.txt
```

3. Activate virtual environment and install CPL into it

```
# Ensure that we are in the right environment
source .venv/bin/activate
pip install . # Install CPL within this environment
```

2.3 Check installation

After installing CPL, please open a command line terminal, activate the right python environment, and execute **caelus -h** to check if the installation process was completed successfully. If everything was installed and configured successfully, users should see a detailed help message summarizing the usage of **caelus**. At this stage, you can either learn about building documentation and executing unit tests (provided with CPL) in the next sections or skip to *Configuring Caelus Python Library* to learn how to configure and use CPL.

2.4 Building documentation

A local version of this documentation can be built using sphinx. See *Install CPL from conda-forge (recommended)* for more details on installing the developer environment and sources.

```
# Change working directory to CPL
cd docs/

# Build HTML documentation
make html
# View in browser
open build/html/index.html

# Build PDF documentation
make latexpdf
open build/latex/CPL.pdf
```

2.5 Running tests

The unit tests are written using `py.test`. To run the tests executing `py.test tests` from the top-level CPL directory. Note that this will require the user to have initialized the environment using `etc/caelus3-dev.yml`.

Configuring Caelus Python Library

CPL provides a YAML-based configuration utility that can be used to customize the library depending on the operating system and user's specific needs. A good example is to provide non-standard install locations for the OpenFOAM or Caelus CML executables, as well as using different versions of OpenFOAM/CML with CPL simultaneously.

The use of configuration file is optional, CPL provides defaults that should work on most systems and will attempt to auto-detect CML installations on standard paths. On Linux/OS X systems, CPL will look at `~/Caelus/caelus-VERSION` to determine the installed CML versions and use the `VERSION` tag to determine the latest version to use. On Windows systems, the default search path is `C:\Caelus`.

Upon invocation, CPL will search and load configuration files from the following locations, if available. The files are loaded in sequence shown below and options found in succeeding files will overwrite configuration options found in preceding files.

1. Default configuration supplied with CPL;
2. The system-wide configuration in file pointed by environment variable `CAELUSRC_SYSTEM` if it exists;
3. The per-user configuration file, if available. On Linux/OS X, this is the file `~/.caelus/caelus.yaml`, and `%APPDATA%/caelus/caelus.yaml` on Windows systems;
4. The per-user configuration file pointed by the environment variable `CAELUSRC` if it exists;
5. The file `caelus.yaml` in the current working directory, if it exists.

While CPL provides a way to auto-discover installed OpenFOAM and CML versions, often it will be necessary to provide at least a system-wide or per-user configuration file to allow CPL to use the right CML executables present in your system. A sample CPL configuration is shown below download `caelus.yaml`:

```
# -- mode: yaml --
#
# Sample CPL configuration file
#
# Root CPL configuration node
caelus:
  # Control logging of CPL library
```

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```

logging:
  log_to_file: true
  log_file: ~/Caelus/cpl.log

# Configuration for Caelus CML or OpenFOAM versions
caelus_cml:
  # Pick the development version of CML available; use "latest" to choose the
  # latest version available.
  default: "v2012"

# Versions that can be used with CPL
versions:
- version: "9.04"
  path: ~/Caelus/caelus-9.04

- version: "10.04"
  path: ~/Caelus/caelus-10.04

- version: "dev-gcc"
  path: ~/Caelus/caelus-cml           # Use latest git repository
  mpi_path: /usr/local/openmpi       # Use system OpenMPI
  build_option: "linux64gcc++DPOpt" # Use the GCC version

- version: "v2012"
  path: ~/OpenFOAM/OpenFOAM-v2012    # Use OpenFOAM
  mpi_path: /usr/local/openmpi       # Use system OpenMPI

```

The above configuration would be suitable as a system-wide or per-user configuration stored in the home directory, and the user can override specific options used for particular runs by using, for example, the following `caelus.yaml` within the case directory:

```

# Local CPL settings for this working directory
caelus:
  logging:
    log_file: cpl_dev.log # Change log file to a local file

  caelus_cml:
    default: "dev-gcc" # Use the latest dev version for this run

```

Note that only options that are being overridden need to be specified. Other options are populated from the system-wide or per-user configuration file if they exist.

3.1 Checking current configuration

To aid debugging and troubleshooting, CPL provides a command `caelus cfg` to dump the configuration used by the library based on all available configuration files. A sample usage is shown here:

```

1 $ caelus -v cfg
2 DEBUG: Loaded configuration from files = ['/home/caelus/.caelus/caelus.yaml']
3 INFO: Caelus Python Library (CPL) v0.1.0
4 # -- mode: yaml --
5 #
6 # Caelus Python Library (CPL) v0.1.0
7 #

```

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```

8 # Auto-generated on: 2018-04-21 17:03:35 (UTC)
9 #
10
11 caelus:
12   cpl:
13     python_env_type: conda
14     python_env_name: caelus
15     conda_settings:
16       conda_bin: ~/anaconda/bin
17   system:
18     job_scheduler: local_mpi
19     always_use_scheduler: false
20     scheduler_defaults:
21       join_outputs: true
22       shell: /bin/bash
23       mail_opts: NONE
24   logging:
25     log_to_file: true
26     log_file: null
27   caelus_cml:
28     default: latest
29     versions: []

```

The **final** configuration after parsing all available configuration files is shown in the output. If the user provides `-v` (verbose) flag, then the command also prints out all the configuration files that were detected and read during the initialization process. Users can also use `caelus cfg` to create a configuration file with all the current settings using the `-f` option. Please see `caelus` command documentation for details.

3.2 CPL configuration reference

CPL configuration files are in YAML format and must contain at least one node `caelus`. Two other optional nodes can be present in the file, `caelus_scripts` and `caelus_user` whose purpose is described below.

caelus

The root YAML node containing the core CPL configuration object. This node contains all configuration options used internally by the library.

caelus_scripts

An optional node used to store configuration for CPL CLI apps.

caelus_user

An optional node reserved for user scripts and applications that will be built upon CPL.

Note: In the following sections, the configuration parameters are documented in the format `root_node.sub_node.config_parameter`. Please see the sample configuration file above for the exact nesting structure used for `caelus.logging.log_file`.

3.2.1 Core library configuration

3.2.1.1 Python environment options

caelus.cpl

This section contains options to configure the python environment (either Anaconda/Conda environment or virtualenv settings).

caelus.cpl.python_env_type

Type of python environment. Currently this can be either `conda` or `virtualenv`.

caelus.cpl.python_env_name

The name of the Python environment for use with CPL, e.g., `caelus` or `caelus-dev`.

caelus.cpl.conda_settings

Extra information for Conda installation on your system.

3.2.1.2 System configuration

caelus.system

This section provides CPL with necessary information on the system settings, particularly the queue configuration on HPC systems.

caelus.system.job_scheduler

The type of job-scheduler available on the system and used by CPL when executing CML executables on the system. By default, all parallel jobs will use the job scheduler, user can configure even serial jobs (e.g., mesh generation, domain decomposition and reconstruction) be submitted on queues.

Name	Description
<code>local_mpi</code>	No scheduler, submit locally
<code>slurm</code>	Use SLURM commands to submit jobs

caelus.system.always_use_scheduler

A Boolean flag indicating whether even serial jobs (e.g., mesh generation) should use the queue system. This flag is useful when the user intends to generate large meshes and requires access to the high-memory compute nodes on the HPC system.

caelus.system.scheduler_defaults

This section contains options that are used by default when submitting jobs to an HPC queue system.

Option	Description
<code>queue</code>	Default queue for submitting jobs
<code>account</code>	Account for charging core hours
<code>stdout</code>	Default file pattern for redirecting standard output
<code>stderr</code>	Default file pattern for redirecting standard error
<code>join_outputs</code>	Join <code>stdout</code> and <code>stderr</code> (queue specific)
<code>mail_options</code>	A string indicating mail options for queue
<code>email_address</code>	Address where notifications should be sent
<code>time_limit</code>	Wall clock time limit
<code>machinefile</code>	File used in <code>mpirun -machinefile <FILE></code>

Note: Currently, these options accept strings and are specific to the queue system (e.g., SLURM or PBS Torque). So the user must consult their queue system manuals for appropriate values to these options.

3.2.1.3 CPL logging options

caelus.logging

This section of the configuration file controls the logging options for the CPL library. By default, CPL only outputs messages to the standard output. Users can optionally save all messages from CPL into a log file of their choice. This is useful for tracking and troubleshooting, or providing additional information regarding bugs observed by the user.

Internally, CPL uses the `logging` module. For brevity, messages output to console are usually at log levels INFO or higher. However, all messages DEBUG and above are captured in log files.

caelus.logging.log_to_file

A Boolean value indicating whether CPL should output messages to the log file. The default value is `false`. If set to `true`, then the log messages will also be saved to the file indicated by `log_file` as well as output to the console.

caelus.logging.log_file

Filename where the log messages are saved if `log_to_file` evaluates to `True`.

3.2.2 CML version configuration

caelus.caelus_cml

The primary purpose of CPL is to interact with OpenFOAM and CML executables and utilities. This section informs CPL of the various OpenFOAM/CML installations available on a system and the desired `version` used by CPL when invoking OpenFOAM or CML executables.

caelus.caelus_cml.default

A string parameter indicating default version used when invoking OpenFOAM or CML executables. It must be one of the `version` entries provided in the file. Alternately, the user can specify `latest` to indicate that the latest version must be used. If users rely on auto-discovery of Caelus versions in default install locations, then it is recommended that this value be `latest` so that CPL picks the latest CML version. For example, with the following configuration, CPL will choose version `10.04` when attempting to execute programs like `pisosolver`.

```
caelus:
  caelus_cml:
    default: "latest"

  versions:
    - version: "9.04"
      path: ~/Caelus/caelus-9.04

    - version: "10.04"
      path: ~/Caelus/caelus-10.04

    - version: "v2012"
      path: ~/OpenFOAM/OpenFOAM-v2012
```

caelus.caelus_cml.versions

A list of configuration mapping listing various versions available for use with CPL. It is recommended that

the users only provide *version* and *path* entries, the remaining entries are optional. CPL will auto-detect remaining parameters.

caelus.caelus_cml.versions.version

A unique string identifier that is used to tag this specific instance of OpenFOAM or CML installation. Typically, this is the version number of the OpenFOAM or Caelus CML release, e.g., `10.04`. However, as indicated in the example CPL configuration file, users can use any unique tag to identify a specific version. If this identifier does not follow the conventional version number format, then it is recommended that the user provide a specific version in `caelus.caelus_cml.default` instead of using `latest`.

caelus.caelus_cml.versions.path

The path to the C++ code/executables install. This is equivalent to the directory pointed by the `WM_PROJECT_DIR` or `CAELUS_PROJECT_DIR` environment variable, e.g., `/home/caelus_user/projects/caelus/caelus-10.04`.

caelus.caelus_cml.versions.build_option

A string parameter identifying the OpenFOAM or Caelus build, if multiple builds are present within a CML install, to be used with CPL. This is an **expert** only option used by developers who are testing multiple compilers and build options. It is recommended that the normal users let CPL autodetect the build option.

caelus.caelus_cml.versions.mpi_root

Path to the MPI installation used to compile OpenFOAM or Caelus for parallel execution. By default, CPL expects the MPI library to be present within the project directory.

caelus.caelus_cml.versions.mpi_bin_path

Directory containing MPI binaries used for **mpiexec** when executing in parallel mode. If absent, CPL will assume that the binaries are located within the subdirectory `bin` in the path pointed by `mpi_root`.

caelus.caelus_cml.versions.mpi_lib_path

Directory containing MPI libraries used for **mpiexec** when executing in parallel mode. If absent, CPL will assume that the libraries are located within the subdirectory `lib` in the path pointed by `mpi_root`.

Command-line Applications

CPL provides command-line interface (CLI) to several frequently used workflows without having to write custom python scripts to access features within the library. These CLI apps are described in detail in the following sections.

4.1 Common CLI options

All CPL command-line applications support a few common options. These options are described below:

-h, --help

Print a brief help message that describes the purpose of the application and what options are available when interacting with the application.

--version

Print the CPL version number and exit. Useful for submitting bug-reports, etc.

-v, --verbose

Increase the verbosity of messages printed to the standard output. Use `-vv` and `-vvv` to progressively increase verbosity of output.

--no-log

Disable logging messages from the script to a log file.

--cml-version

Specify CML version to use for this particular invocation of CPL command.

--cli-logs *log_file*

Customize the filename used to capture log messages during execution. This overrides the configuration parameter *log_file* provided in the user configuration files.

4.2 Available command-line applications

4.2.1 caelus – Common CPL actions

New in version 0.0.2.

The *caelus* command provides various sub-commands that can be used to perform common tasks using the CPL library. Currently the following sub-commands (or actions) are available through the **caelus** script.

Action	Purpose
cfg	Print CPL configuration to stdout or file
clone	Clone a case directory
tasks	Automatic execution of workflow from a YAML file
run	Run a CML executable in the appropriate environment
runpy	Run a python script in the appropriate environment
logs	Parse a solver log file and extract data for analysis
clean	Clean a case directory after execution
build	Compile OpenFOAM or CML sources

Note: The script also supports the *common options* documented in the previous section. Care must be taken to include the common options before the subcommand, i.e.,

```
# Correct usage
caelus -vvv cfg -f caelus.yaml

# The following will generate an error
# caelus cfg -vvv # ERROR
```

4.2.1.1 caelus cfg – Print CPL configuration

Print out the configuration dictionary currently in use by CPL. This will be a combination of all the options loaded from the configuration files described in *configuration* section. By default, the command prints the YAML-formatted dictionary to the standard output. The output can be redirected to a file by using the *caelus cfg -f* option. This is useful for debugging.

```
$ caelus cfg -h
usage: caelus cfg [-h] [-f CONFIG_FILE] [-b]

Dump CPL configuration

optional arguments:
  -h, --help            show this help message and exit
  -f CONFIG_FILE, --config-file CONFIG_FILE
                        Write to file instead of standard output
  -b, --no-backup       Overwrite existing config without saving a backup
```

-f output_file, --config-file output_file
Save the current CPL configuration to the *output_file* instead of printing to standard output.

-b, --no-backup
By default, when using the *caelus cfg -f* CPL will create a backup of any existing configuration file before

writing a new file. This option overrides the behavior and will not create backups of existing configurations before overwriting the file.

4.2.1.2 caelus clone – Clone a case directory

`caelus clone` takes two mandatory parameters, the source template case directory, and name of the new case that is created. By default, the new case directory is created in the current working directory and must not already exist. CPL will not attempt to overwrite existing directories during clone.

```
$ caelus clone -h
usage: caelus clone [-h] [-m] [-z] [-s] [-e EXTRA_PATTERNS] [-d BASE_DIR]
                  template_dir case_name

Clone a case directory into a new folder.

positional arguments:
  template_dir          Valid Caelus case directory to clone.
  case_name             Name of the new case directory.

optional arguments:
  -h, --help            show this help message and exit
  -m, --skip-mesh       skip mesh directory while cloning
  -z, --skip-zero       skip 0 directory while cloning
  -s, --skip-scripts    skip scripts while cloning
  -e EXTRA_PATTERNS, --extra-patterns EXTRA_PATTERNS
                        shell wildcard patterns matching additional files to
                        ignore
  -d BASE_DIR, --base-dir BASE_DIR
                        directory where the new case directory is created
```

-m, --skip-mesh

Do not copy the constant/polyMesh directory when cloning. The default behavior is to copy the mesh along with the case directory.

-z, --skip-zero

Do not copy the 0 directory during clone. The default behavior copies time $t=0$ directory.

-s, --skip-scripts

Do not copy any python or YAML scripts during clone.

-e pattern, --extra-patterns pattern

A shell-wildcard pattern used to skip additional files that might exist in the source directory that must be skipped while cloning the case directory. This option can be repeated multiple times to provide more than one pattern.

```
# Skip all bash files and text files in the source directory
caelus clone -e "*.sh" -e "*.txt" old_case_dir new_case_dir
```

-d basedir, --base-dir basedir

By default, the new case directory is created in the current working directory. This option allows the user to modify the behavior and create the new case in a different location. Useful for use within scripts.

4.2.1.3 caelus tasks – run tasks from a file

Read and execute tasks from a YAML-formatted file. Task files could be considered recipes or workflows. By default, it reads `caelus_tasks.yaml` from the current directory. The behavior can be modified to read other file names and locations.

```
$ caelus tasks -h
usage: caelus tasks [-h] [-f FILE]

Run pre-defined tasks within a case directory read from a YAML-formatted file.

optional arguments:
  -h, --help            show this help message and exit
  -f FILE, --file FILE  file containing tasks to execute (caelus_tasks.yaml)
```

-f task_file, --file task_file
Execute the task file named `task_file` instead of `caelus_tasks.yaml` in current working directory

4.2.1.4 caelus run – run an executable in the appropriate environment

Run a single application. The application name is the one mandatory argument. Additional command arguments can be specified. The behavior can be modified to enable parallel execution of the application. By default, the application runs from the current directory. This behavior can be modified to specify the case directory.

Note: When passing `cmd_args`, `--` is required between `run` and `cmd_name` so the `cmd_args` are parsed correctly. E.g. `caelus run -- renumberMesh "-overwrite"`. This ensures that the arguments meant for the CML executable are not parsed as arguments to the `caelus` executable during the run.

```
$ caelus run -h
usage: caelus run [-h] [-p] [-l LOG_FILE] [-d CASE_DIR] [-m MACHINEFILE]
                cmd_name [cmd_args [cmd_args ...]]

Run an executable in the correct environment

positional arguments:
  cmd_name            name of the executable
  cmd_args            additional arguments passed to command

optional arguments:
  -h, --help            show this help message and exit
  -p, --parallel        run in parallel
  -l LOG_FILE, --log-file LOG_FILE
                        filename to redirect command output
  -d CASE_DIR, --case-dir CASE_DIR
                        path to the case directory
  -m MACHINEFILE, --machinefile MACHINEFILE
                        machine file for distributed runs (local_mpi only)
```

-p, --parallel
Run the executable in parallel

-m, --machinefile
File containing nodes used for a distributed MPI run. This option is ignored if `job_scheduler` is not `local_mpi`. This option has no effect if the `parallel option` is not used.

-l log_file, --log-file log_file
By default, a log file named `<application>.log` is created. This option allows the user to modify the behavior and create a differently named log file.

-d casedir, --case-dir casedir
By default, executables run from the current working directory. This option allows the user to modify the

behavior and specify the path to the case directory.

4.2.1.5 caelus runpy – Run a custom python script

Runs a user-provided python script in the case directory. CPL ensures that the correct version of OpenFOAM or CML and python environment are setup prior to the invocation of the python script. Like **caelus run**, it is recommended that the arguments meant for the user script be separated from `:program`: *caelus runpy* arguments with `--`.

```
$ caelus runpy -h
usage: caelus runpy [-h] [-l LOG_FILE] [-d CASE_DIR]
                  script [script_args [script_args ...]]

Run a custom python script with OpenFOAM or CML and CPL environment

positional arguments:
  script                path to the python script
  script_args          additional arguments passed to command

optional arguments:
  -h, --help            show this help message and exit
  -l LOG_FILE, --log-file LOG_FILE
                        filename to redirect command output
  -d CASE_DIR, --case-dir CASE_DIR
                        path to the case directory
```

-l log_file, --log-file log_file

By default, a log file named `<application>.log` is created. This option allows the user to modify the behavior and create a differently named log file.

-d casedir, --case-dir casedir

By default, executables run from the current working directory. This option allows the user to modify the behavior and specify the path to the case directory.

4.2.1.6 caelus logs – process a solver log file from a run

Process a single solver log. The log file name is the one mandatory argument. Additional command arguments can be specified. By default, the log file is found in the current directory and the output is written to `logs` directory. The behavior can be modified to specify the case directory and output directory.

```
$ caelus logs -h
usage: caelus logs [-h] [-l LOGS_DIR] [-d CASE_DIR] [-p] [-f PLOT_FILE] [-w]
                  [-i INCLUDE_FIELDS | -e EXCLUDE_FIELDS]
                  log_file

Process logfiles for an OpenFOAM or Caelus run

positional arguments:
  log_file              log file (e.g., simpleSolver.log)

optional arguments:
  -h, --help            show this help message and exit
  -l LOGS_DIR, --logs-dir LOGS_DIR
                        directory where logs are output (default: logs)
  -d CASE_DIR, --case-dir CASE_DIR
                        path to the case directory
```

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```

-p, --plot-residuals  generate residual time-history plots
-f PLOT_FILE, --plot-file PLOT_FILE
                        file where plot is saved
-w, --watch           Monitor residuals during a run
-i INCLUDE_FIELDS, --include-fields INCLUDE_FIELDS
                        plot residuals for given fields
-e EXCLUDE_FIELDS, --exclude-fields EXCLUDE_FIELDS

```

-l logs_dir, --logs-dir logs_dir

By default, the log files are output to logs. This option allows the user to modify the behavior and create a differently named log file output directory.

-d, case_dir, --case-dir case_dir

By default, the log file is found in the current working directory. This option allows the user to specify the path to the case directory where the log file exists.

-p, --plot-residuals

This option allows the user to plot and save the residuals to an image file.

-f plot_file, --plot-file plot_file

By default, plots are saved to residuals.png in the current working directory. This option allows the user to modify the behavior and specify a differently named plot file.

-w, --watch

This option allows the user to dynamically monitor residuals for a log file from an ongoing run. To exit before the completion of the run, hit Ctrl+C.

-i include_fields, --include-fields include_fields

By default, all field equation residuals are plotted. This option can be used to only include specific fields in residual plot. Multiple fields can be provided to this option. For example,

```

# Plot pressure and momentum residuals from simpleSolver case log
caelus logs -p -i "p Ux Uy Uz" simpleSolver.log

```

-e exclude_fields, --exclude-patterns exclude fields

By default, all field equation residuals are plotted. This option can be used to exclude specific fields in residual plot. Multiple fields be provided to this option. For example,

```

# Exclude TKE and omega residuals from simpleSolver case log
caelus logs -p -e "k epsilon" simpleSolver.log

```

4.2.1.7 caelus clean – clean a case directory

Cleans files generated by a run. By default, this function will always preserve system, constant, and 0 directories as well as any YAML or python files. The behavior can be modified to presevere additional files and directories.

```

$ caelus clean -h
usage: caelus clean [-h] [-d CASE_DIR] [-m] [-z] [-t] [-P] [-p PRESERVE]

Clean a case directory

optional arguments:
  -h, --help            show this help message and exit
  -d CASE_DIR, --case-dir CASE_DIR
                        path to the case directory

```

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```

-m, --clean-mesh      remove polyMesh directory (default: no)
-z, --clean-zero      remove 0 directory (default: no)
-t, --clean-time-dirs
                      remove time directories (default: no)
-P, --clean-processors
                      clean processor directories (default: no)
-p PRESERVE, --preserve PRESERVE
                      shell wildcard patterns of extra files to preserve

```

-d, `case_dir`, `--case-dir case_dir`

By default, the case directory is the current working directory. This option allows the user to specify the path to the case directory.

-m, `--clean-mesh`

By default, the `polyMesh` directory is not removed. This option allows the user to modify the behavior and remove the `polyMesh` directory.

-z, `--clean-zero`

By default, the `0` files are not cleaned. This option allows the user to modify the behavior and remove the `0` directory.

-t, `--clean-time-dirs`

Remove time directories from the case directory. Note, this only removes the reconstructed time directories and not the decomposed directories that exist within `processor*` directories.

-P, `--clean-processors`

Remove decomposed `processor*` directories from the case directory.

-p `preserve_pattern`, `--preserve preserve_pattern`

A shell-wildcard patterns of files or directories that will not be cleaned.

4.2.1.8 caelus build – Compile OpenFOAM or CML sources

`caelus build` is a wrapper that can be used to build executables for OpenFOAM or CML project and user directories. The command can be executed from any directory when building project or user directories. For CML, It determines the actual paths to the project and user directories based on the *user configuration* files, and the SCons configuration within those projects. For OpenFOAM, it assumes an `Allwmake` script exists in the target source directory. For either package, the user can override the default project and user directories by specifying the `:option: -cml-version <cpl -cml-version>` flag when invoking this command.

Warning: When using CPL with Python 3.x versions, you will need a recent version of CML to invoke `caelus build`. This is because the SCons versions shipped with CML versions v8.04 and older can only run on Python 2.x.

```

$ caelus build -h
usage: caelus build [-h] [-l LOG_FILE] [-c] [-j JOBS]
                  [-a | -p | -u | -d SOURCE_DIR]
                  [scons_args [scons_args ...]]

Compile OpenFOAM or Caelus CML

positional arguments:
  scons_args            additional arguments passed to SCons

```

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```
optional arguments:
  -h, --help            show this help message and exit
  -l LOG_FILE, --log-file LOG_FILE
                        filename to redirect build output
  -c, --clean           clean CML build
  -j JOBS, --jobs JOBS  number of parallel jobs
  -a, --all             Build both project and user directories (default: no)
  -p, --project         Build Caelus CML project (default: no)
  -u, --user           Build user project (default: no)
  -d SOURCE_DIR, --source-dir SOURCE_DIR
                        Build sources in path (default: CWD)
```

The positional arguments are passed directly to SCons providing user with full control over how the SCons build must be handled. It is recommended that the user separate the *optional arguments* to `caelus build` command from the arguments that must be passed to SCons using double dashes (`--`).

-d, --source-dir

Build sources in the current working directory. This is the default option. If the user is in the top-level directory containing the `SConstruct` file, then it builds the entire project. If the user is in a sub-directory containing a `SConscript` file, then it just builds the libraries and executables defined in that directory and sub-directories. An example would be to recompile just the turbulence model libraries during development phase.

-p, --project

Build the sources in project directory only.

-u, --user

Build the sources in user directory only.

-a, --all

Build both the project and the user directories. The command will abort compilation if the compilation of the project files fail and will not attempt to build the sources in user directory.

-j, --jobs

The number of concurrent compilation jobs that must be launched with SCons. The default value is determined by the number of CPU cores available on the user's system.

-c, --clean

Instead of recompiling the sources, execute the `clean` command through SCons.

4.2.2 caelus_sim – Parametric Run CLI

The `caelus_sim` is a shell executable that provides a command-line interface to setup and execute a parametric analysis. Currently, the following sub-commands are available through `caelus_sim` executable. Please see *Parametric runs using CPL* tutorial for a detailed description of usage.

Action	Purpose
setup	Setup a new parametric run
prep	Execute pre-processing actions
solve	Run the solver
post	Execute post-processing actions
status	Print out status of the analysis

Note: The script also supports *common options* documented previously. Care must be taken to include the common options before the subcommand, i.e.,

```
# Correct usage
caelus_sim -v setup

# Incorrect usage, will generate an error
caelus_sim setup -v
```

4.2.2.1 caelus_sim setup – Setup a parametric run

By default, this command will parse the `caelus_sim.yaml` input file and setup a new analysis under a new directory name provided either at the command line or in the input file. The individual cases corresponding to the run matrix appear as subdirectories to the top-level analysis directory.

```
$ caelus_sim setup -h
usage: caelus_sim setup [-h] [-n SIM_NAME] [-d BASE_DIR] [-s] [-p]
                        [-f SIM_CONFIG]

setup a parametric run

optional arguments:
  -h, --help            show this help message and exit
  -n SIM_NAME, --sim-name SIM_NAME
                        name of this simulation group
  -d BASE_DIR, --base-dir BASE_DIR
                        base directory where the simulation structure is
                        created
  -s, --submit          submit solve jobs on successful setup
  -p, --prep            run pre-processing steps after successful setup
  -f SIM_CONFIG, --sim-config SIM_CONFIG
                        YAML-formatted simulation configuration
                        (caelus_sim.yaml)
```

-f, --sim-config

The input file containing the details of the analysis to be performed. Default value is `caelus_sim.yaml`

-n, --sim-name

Name of this parametric run. This option overrides the `sim_name` entry in the input file.

-d, --base-dir

Directory where the parametric analysis is setup. This directory must exist. Default value is the current working directory.

-s, --submit

Submit the solve jobs after setup is complete.

-p, --prep

Run pre-processing tasks upon successful setup.

4.2.2.2 caelus_sim status – Print status of the parametric runs

This command prints out the status of the runs so far. The meanings of the different status types are described in the table below

Status	Description
Setup	Case setup successfully
Prepped	Pre-processing completed
Submitted	Solver initialized
Running	Solver is running
Solved	Solve has completed
DONE	Post-processing completed
FAILED	Some action failed

4.2.3 caelus_tutorials – Run tutorials

This is a convenience command to automatically run tutorials provided within the Caelus CML distribution.

```
$ caelus_tutorials -h
usage: caelus_tutorials [-h] [--version] [-v] [--no-log | --cli-logs CLI_LOGS]
                        [-d BASE_DIR] [-c CLONE_DIR] [-f TASK_FILE]
                        [-i INCLUDE_PATTERNS | -e EXCLUDE_PATTERNS]

Run Caelus Tutorials

optional arguments:
  -h, --help                show this help message and exit
  --version                 show program's version number and exit
  -v, --verbose             increase verbosity of logging. Default: No
  --no-log                 disable logging of script to file.
  --cli-logs CLI_LOGS     name of the log file (caelus_tutorials.log)
  -d BASE_DIR, --base-dir BASE_DIR
                          directory where tutorials are run
  -c CLONE_DIR, --clone-dir CLONE_DIR
                          copy tutorials from this directory
  --clean                  clean tutorials from this directory
  -f TASK_FILE, --task-file TASK_FILE
                          task file containing tutorial actions
                          (run_tutorial.yaml)
  -i INCLUDE_PATTERNS, --include-patterns INCLUDE_PATTERNS
                          run tutorial case if it matches the shell wildcard
                          pattern
  -e EXCLUDE_PATTERNS, --exclude-patterns EXCLUDE_PATTERNS
                          exclude tutorials that match the shell wildcard
                          pattern

Caelus Python Library (CPL) v0.0.2
```

-f task_file, --task-file task_file

The name of the task file used to execute the steps necessary to complete a tutorial. The default value is `run_tutorial.yaml`

-i pattern, --include-patterns pattern

A shell wildcard pattern to match tutorial names that must be executed. This option can be used multiple times to match different patterns. For example,

```
# Run all simpleSolver cases and pisoSolver's cavity case
caelus_tutorials -i "*simpleSolver*" -i "*cavity*"
```

This option is mutually exclusive to `caelus_tutorials -e`

-e pattern, **--exclude-patterns** pattern

A shell wildcard pattern to match tutorial names that are skipped during the tutorial run. This option can be used multiple times to match different patterns. For example,

```
# Skip motorBikeSS and motorBikeLES cases
caelus_tutorials -e "*motorBike*"
```

This option is mutually exclusive to `caelus_tutorials -i`

CPL provides a *tasks* interface to automate various aspects of the CFD simulation workflow that can be executed by calling **caelus tasks** (see *tasks documentation*).

5.1 Quick tutorial

The *tasks* interface requires a list of tasks provided in a YAML-formatted file as shown below (download):

```
tasks:
- clean_case:
  remove_zero: no
  remove_mesh: yes

- run_command:
  cmd_name: blockMesh

- run_command:
  cmd_name: pisoSolver

- process_logs:
  log_file: pisoSolver.log
  plot_residuals: true
  residuals_plot_file: residuals.pdf
  residuals_fields: [Ux, Uy]
```

The file lists a set of actions to be executed sequentially by **caelus tasks**. The tasks can accept various options that can be used to further customize the workflow. A sample interaction is shown below

```
$ caelus -v tasks -f caelus_tasks.yaml
INFO: Caelus Python Library (CPL) v0.1.0
INFO: Caelus CML version: 7.04
INFO: Loaded tasks from: cavity/caelus_tasks.yaml
INFO: Begin executing tasks in cavity
```

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```
INFO: Cleaning case directory: cavity
INFO: Executing command: blockMesh
INFO: Executing command: pisoSolver
INFO: Processing log file: pisoSolver.log
INFO: Saved figure: cavity/residuals.pdf
INFO: Residual time history saved to residuals.pdf
INFO: Successfully executed 4 tasks in cavity
INFO: All tasks executed successfully.
```

For a comprehensive list of task file examples, please consult the `run_tutorial.yaml` files in the `tutorials` directory of Caelus CML distribution. In particular, the `motorBike` case provides an example of a tasks workflow involving two different case directories.

Note: When using CPL with `OpenFOAM`, please replace `pisoSolver` with `pisoFoam` etc. Other than the name of the solvers, the rest of the commands do not change when switching between CML and `OpenFOAM`.

5.2 Tasks reference

This section documents the various *tasks* available currently within CPL and the options that can be used to customize execution of those tasks.

- The task file must be in YAML format, and must contain one entry `tasks` that is a list of tasks to be executed.
- The tasks are executed sequentially in the order provided until an error is encountered or all tasks are executed successfully.
- The tasks must be invoked from within a valid Caelus case directory (see `task_set` for an exception). All filenames in the task file are interpreted relative to the execution directory where the command is invoked.

5.2.1 run_command – Run OpenFOAM or CML executables

This *task type* is used to execute an OpenFOAM or Caelus CML executable (e.g., `blockMesh` or `pimpleSolver`). CPL will ensure that the appropriate version of OpenFOAM or CML is selected and the runtime environment is setup properly prior to executing the task. The task must provide one mandatory parameter `run_command.cmd_name` that is the name of the OpenFOAM or CML executable. Several other options are available and are documented below. Example:

```
- run_command:
  cmd_name: potentialSolver
  cmd_args: "-initialiseUBCs -noFunctionObjects"
  parallel: true
```

`run_command.cmd_name`

The name of the CML executable. This option is mandatory.

`run_command.cmd_args`

Extra arguments that must be passed to the OpenFOAM or CML executable. It is recommended that arguments be enclosed in a double-quoted string. Default value is an empty string.

`run_command.log_file`

The filename where the output of the command is redirected. By default, it is the OpenFOAM or CML exe-

cutable name with the `.log` extension appended to it. The user can change this to any valid filename of their choice using this option.

run_command.parallel

A Boolean flag indicating whether the executable is to be run in parallel mode. The default value is `False`. If `parallel` is `True`, then the default options for job scheduler are used from CPL configuration file, but can be overridden with additional options to `run_command`.

run_command.num_ranks

The number of MPI ranks for a parallel run.

run_command.mpi_extra_args

Extra arguments to be passed to `mpiexec` command (e.g., `hostfile` options). As with `cmd_args`, enclose the options within quotes.

```
- run_command:
  cmd_name: pimpleSolver
  parallel: true
  mpi_extra_args: "--hostfile my_hostfile"
```

5.2.2 run_python – Run user python scripts

This task will run a python script within the case directory. Like `run_command` task, CPL will ensure that the appropriate OpenFOAM or CML version as well as python environment is setup correctly prior to invoking the script. The task must provide one mandatory parameter `run_python.script` that contains the path to the python script to be executed. User can pass additional options to this task as documented below.

```
- run_python:
  script: "../mytestscript.py"
  script_args: "-v -f option1 arg1 arg2"
  log_file: "mycustom.log"
```

run_python.script

Path to the custom python script.

run_python.script_args

Arguments that must be passed to the python script during invocation. As with `run_command` quote the arguments appropriately to ensure that it is passed correctly to the script.

run_python.log_file

The filename where the outputs and error messages from the script is redirected.

5.2.3 copy_files – Copy files

This task copies files in a platform-agnostic manner.

copy_files.src

A unix-style file pattern that is used to match the pattern of files to be copied. The path to the files must be relative to the execution directory, but can exist in other directories as long as the relative paths are provided correctly. If the pattern matches multiple files, then `copy_files.dest` must be a directory.

copy_files.dest

The destination where the files are to be copied.

5.2.4 copy_tree – Recursively copy directories

This task takes an existing directory (`src`) and copies it to the destination. Internally, this task uses `copytree` function to copy the directory, please refer to Python docs for more details.

Warning: If the destination directory already exists, the directory is deleted before copying the contents of the source directory. Currently, this task does not provide a way to copy only non-existent files to the destination. Use with caution.

`copy_tree.src`

The source directory that must be recursively copied.

`copy_tree.dest`

The pathname for the new directory to be created.

`copy_tree.ignore_patterns`

A list of Unix-style file patterns used to ignore files present in source directory when copying it to destination. A good example of this is to prevent copying the contents of `polyMesh` when copying the contents of `constant` from one case directory to another.

`copy_tree.preserve_symlinks`

A Boolean flag indicating whether symbolic links are preserved when copying. Linux and Mac OSX only.

5.2.5 clean_case – Clean a case directory

Use this task to clean up a case directory after a run. By default, this task will preserve all YAML and python files found in the case directory as well as the `0/` directory. For example,

```
- clean_case:
  remove_zero: yes
  remove_mesh: no
  preserve: [ "0.org" ]
```

`clean_case.remove_zero`

Boolean flag indicating whether the `0/` directory should be removed. The default value is `no`.

`clean_case.remove_mesh`

Boolean flag indicating whether the `constant/polyMesh` directory should be removed. The default value is `no`.

`clean_case.remove_time_dirs`

Boolean flag indicating whether time directories from a previous run should be removed. The default value is `no`.

`clean_case.remove_processors`

Boolean flag indicating whether processor directories from a previous run should be removed. The default value is `no`.

`clean_case.purge_generated`

A Boolean flag when enabled will set `remove_time_dirs` and `remove_processors` to `yes`.

`clean_case.purge_all`

A shortcut to set `remove_zero`, `remove_mesh`, `remove_time_dirs` and `remove_processors` to `yes`.

`clean_case.preserve`

A list of Unix-style file patterns that match files that should be preserved within the case directory.

5.2.6 process_logs – Process solver outputs

This task takes one mandatory argument `log_file` that contains the outputs from a CFD run. The time-histories of the residuals are extracted and output to files that can be loaded by `gnuplot`, or loaded in python using `loadtxt` command or using Pandas library. Users can also plot the residuals by using the `plot_residuals` option. For example,

```
- process_logs:
  log_file: pimpleSolver.log
  log_directory: pimpleSolver_logs

- process_logs:
  log_file: simpleSolver.log
  plot_residuals: yes
  residuals_plot_file: residuals.pdf
  residuals_fields: [Ux, Uy, p]
```

`process_logs.log_file`

The filename containing the solver residual outputs. This parameter is mandatory.

`process_logs.logs_directory`

The directory where the processed residual time-history outputs are stored. Default: `logs` within the execution directory.

`process_logs.plot_residuals`

Boolean flag indicating whether a plot of the convergence time-history is generated. Default value is `False`.

`process_logs.residuals_plot_file`

The file where the plot is saved. Default value is `residuals.png`. The user can use an appropriate extension (e.g., `.png`, `.pdf`, `.jpg`) to change the image format of the plot generated.

`process_logs.residual_fields`

A list of fields that are plotted. If not provided, all fields available are plotted.

`process_logs.plot_continuity_errors`

A Boolean flag indicating whether time-history of continuity errors are plotted along with residuals.

5.2.7 task_set – Group tasks

A `task_set` groups a sub-set of tasks that can be executed in a different case directory. Download an example.

`task_set.case_dir`

The path to a valid case directory where the sub-tasks are to be executed. This parameter is mandatory.

`task_set.name`

A unique name to identify this task group.

`task_set.tasks`

The list of sub-tasks. This list can contain any of the tasks that have been documented above.

6.1 Parametric runs using CPL

CPL provides two classes `CMLSimulation` and `CMLSimCollection` that can be used to create workflows that can automate the CFD analysis process. It also provides an implementation of `CMLSimCollection` called `CMLParametricRun` that can be used to automate running a parametric study over several variables and managing the analysis as a group. These classes serve as simple examples for the user to derive sub-classes from CPL to develop their own custom workflows.

The parametric run capability is also accessible from the command-line via `caelus_sim`. This tutorial provides a step-by-step walkthrough of exercising CPL's parametric run capabilities through the command-line. This tutorial will demonstrate an example of generating airfoil polars for a range of angles of attack at different Reynolds numbers. In addition to varying, the angle of attack and Reynolds number, it will also show how to specify other flow parameters through CPL.

6.1.1 Preliminaries

To use CPL's parametric run interface, the user needs to provide a simulation configuration file (in YAML format), and a case template directory (similar to the one used with `caelus clone` command).

To follow along with this tutorial, we recommend that the user download the parametric run setup file and a case template. For the purposes of this tutorial we will assume that the user is executing the commands from within `$HOME/run` directory. Once downloaded please unzip the zip file.

```
# Files downloaded for the tutorial walkthrough
bash:/tmp/run$ ls
airfoil_demo.zip caelus_sim.yaml

# Unzip the file
bash:/tmp/run$ unzip airfoil_demo.zip
Archive:  airfoil_demo.zip
   creating: airfoil_template/
```

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```

creating: airfoil_template/0.orig/
inflating: airfoil_template/0.orig/k
inflating: airfoil_template/0.orig/nut
inflating: airfoil_template/0.orig/omega
inflating: airfoil_template/0.orig/p
inflating: airfoil_template/0.orig/U
inflating: airfoil_template/cmlControls
  creating: airfoil_template/constant/
  creating: airfoil_template/constant/polyMesh/
inflating: airfoil_template/constant/polyMesh/boundary
inflating: airfoil_template/constant/polyMesh/faces.gz
inflating: airfoil_template/constant/polyMesh/neighbour.gz
inflating: airfoil_template/constant/polyMesh/owner.gz
inflating: airfoil_template/constant/polyMesh/points.gz
inflating: airfoil_template/constant/RASProperties
inflating: airfoil_template/constant/transportProperties
inflating: airfoil_template/constant/turbulenceProperties
  creating: airfoil_template/system/
inflating: airfoil_template/system/controlDict
inflating: airfoil_template/system/decomposeParDict
inflating: airfoil_template/system/fvSchemes
inflating: airfoil_template/system/fvSolution

```

6.1.1.1 Preparing a case template directory

In order to simplify the process of setting up parametric run, CPL assumes that all user-configurable entries are provided in `cmlControls` within the case directory. Other files within the case directory use the `#include` option to include this file and use variable replacement macro syntax `$variable` to interface with the parametric run utility. In this airfoil demonstration example, a `cmlControls` that will be used is shown below:

```

1 FoamFile
2 {
3   version      2.0;
4   format       ascii;
5   class        dictionary;
6   object       "cmlControls";
7 }
8
9 // * * * * *
10
11 density       1.225;
12
13 Uinf          15.0;
14
15 chord        1.0;
16
17 Re           1000000.0;
18
19 aoa          0.0;
20
21 turbKe       3.75e-07;
22
23 velVector    (15.0 0.0 0.0);
24
25 nuValue      1.0e7;

```

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```

26
27 turbulenceModel kOmegaSST;
28
29 // ***** //

```

An example of using this file to set the turbulence model in `constant/RASProperties` is shown below:

```

FoamFile
{
  version      2.0;
  format       ascii;
  class        dictionary;
  location     "constant";
  object       RASProperties;
}
// ***** //

#include "../cmlControls"

RASModel      $turbulenceModel;

turbulence    on;

printCoeffs   on;

kMin          1.e-20;

// ***** //

```

Notice how the `cmlControls` file is included in line 11, and the property `RASModel` is set with `$turbulenceModel` (see line 27 in `cmlControls` snippet above). The user is referred to `constant/transportProperties`, `0.orig/U`, `0.orig/k`, and `functions` section of `system/controlDict` for further examples of how the inputs from `cmlControls` is used to customize the case.

Tip: Currently, `cmlControls` and CPL's dictionary manipulation capabilities are restricted to text files only. If you want to customize binary files within `0/` directory, then we recommend using `cmlControls` to modify `system/changeDictionaryDict` and execute CML's **changeDictionary** executable in the pre-processing phase to modify binary files.

Note: With newer versions of OpenFOAM, the RANS inputs must be part of the `constant/turbulenceProperties` file.

6.1.1.2 Inputs for setting up parametric run

The first step to creating a parametric analysis directory structure is to execute the `caelus_sim setup` command. By default, this command will attempt to load the analysis configuration from the `caelus_sim.yaml`. The user can, however, change this by providing an alternate file with the `-f` flag. The contents of the `caelus_sim.yaml` used for this demo is shown below.

```

1 # -- mode: yaml --
2

```

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```

3 # caelus_sim requires a simulation section in YAML file
4 simulation:
5
6 # Name of the parametric run top-level directory. Can also set using -n flag
7 # at command line which takes precedence
8 sim_name: airfoil_demo
9
10 # The template directory for creating case directories. Requires 'path'
11 # argument. Other optional variables can be provided to control clone behavior
12 template:
13   path: "./airfoil_template"
14   # copy_polymesh: no
15   # copy_zero: no
16   # copy_scripts: no
17   # extra_patterns: ["*.py"]
18
19 # This section details the parametric run options
20 simulation_setup:
21   # User defined format for case directory names
22   case_format: "Re_{Re:.1e}/aoa_{aoa:+06.2f}"
23
24   # The matrix of runs
25   run_matrix:
26     - Re: [1.0e6, 2.0e6]
27       aoa:
28         start: 0.0
29         stop: 2.0
30         step: 2.0
31
32     # Only run one Re for the negative AOA
33     - Re: [1.0e6]
34       aoa: [-4.0, -2.0]
35
36   # Other parameters that are passed to cmlControls file
37   constant_parameters:
38     density: 1.225
39     Uinf: 15.0
40     chord: 1.0
41     turbKe: 3.75e-07
42     turbulenceModel: kOmegaSST
43
44   # User-defined transformations on the variables
45   apply_transforms:
46     transform_type: code
47     # Only pass these variables to cmlControls
48     extract_vars: [velVector, Re, nuValue, liftVector, dragVector]
49     # Python code that is executed before generating case parameters
50     code: |
51       Re = float(Re)
52       aoaRad = np.radians(aoa)
53       Ux = Uinf * np.cos(aoaRad)
54       Uy = Uinf * np.sin(aoaRad)
55       velVector = np.array([Ux, Uy, 0.0])
56       nuValue = Uinf / Re
57       liftVector = np.array([-np.sin(aoaRad), np.cos(aoaRad), 0.0])
58       dragVector = np.array([np.cos(aoaRad), np.sin(aoaRad), 0.0])
59

```

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```

60 # Configuration for running each case within this analysis group
61 run_configuration:
62     # Number of MPI ranks for parallel runs
63     num_ranks: 2
64     # Extra MPI arguments passed during parallel runs
65     # mpi_extra_args: -machinefile mymachines
66
67     # Should the case be reconstructed on successful run
68     reconstruct: no
69
70     # Modify the default template input files
71     change_inputs:
72         controlDict:
73             endTime: 1
74             writeFormat: binary
75
76     # Pre-processing actions to be performed before solve. The syntax is similar
77     # to the Tasks YAML interface. Note, the case manager will automatically
78     # perform decomposition and similar tasks. Users only need to provide
79     # non-standard pre-processing actions (e.g., copy actions, changeDictionary,
80     # or mesh generation) during the prep phase.
81     prep:
82         - copy_tree:
83             src: "0.orig"
84             dest: "0"
85
86     # Perform the solve
87     solve: simpleSolver
88
89     # solve:
90     #     - solver: potentialSolver
91     #       solver_args: "-initializeUBCs -noFunctionObjects"
92
93     #     - solver: pimpleSolver
94
95     # Similar to prep, perform post-processing actions
96     # post:
97     #     - run_command:
98     #         cmd_name: "python ./my_post_process.py"

```

The input file must contain one section `simulation` that provides all the information necessary for setting up and executing the parametric run. The `simulation` dictionary contains the following major sections:

`sim_name`

The name of the parametric analysis group. The program creates a unique run directory with this name. This parameter can also be overridden from the command line.

`template`

Details of the case template that will be used to create the individual case directories. It must contain one mandatory entry: `path`, that is the path to the template case directory. In this demo we will use the `airfoil_template` that we unzipped from the `airfoil_demo.zip`. Additional parameters are passed to control the cloning of the template directory and are similar to `caelus clone` command.

`simulation_setup`

This section contains the details of the parametric run. `case_template` is a template suitable to be processed by `python str.format()` method.

`run_matrix` contains the list of parametric combinations that will be run. In this example, we will run two angles of attack for each of the two Reynolds numbers specified. Each entry in the list generates all possible combinations of runs possible, and these are sub-groups of parametric runs. User can provide multiple entries in the list to generate additional custom combinations.

`constant_parameters`, if present, are variables that that will be populated in addition to the variable parameters (in `run_matrix`) when setting up the case.

Finally, `apply_transforms` is an optional section, that uses valid python code snippets to perform user-defined transformations to the variables in `run_matrix` and `constant_parameters` to generate dependent variables or perform additional processing. After transformation, by default, all variables introduced by the python code is extracted and passed along with `constant_parameters` and variables in `run_matrix` to `cmlControls`. However, if the user has imported modules or defined functions, this could lead to error. So it is recommended that the user manually specify the variables to extracted through the `extract_vars` option in `apply_transforms` section.

run_configuration

This section contains the details on how each case is executed after setup. It has a general section that has information regarding parallel run setup etc.

`change_inputs` lists changes to be performed to input files cloned from the template directory. This step is performed after setting up case directory, but before execution of any pre-processing or solve tasks.

`prep` contains tasks (see *Caelus Tasks*) that must be executed before decomposing and executing the case. Note that the user need not specify the `decomposePar` task, as this is handled automatically by the parametric run interface.

`solve` indicates the name of the solver that is used to run these cases. It can also accept a list entry with multiple solvers (e.g., running `potentialSolver` before `simpleSolver`, etc.)

`post` is similar to `prep` but are tasks that are executed after a successful solver completion.

6.1.2 Setting up a parametric run

Now that we have the requisite inputs for setting up a parametric run, we will use `caelus_sim setup` command to setup a case (see *caelus_sim – Parametric Run CLI* for more details).

```
bash:/tmp/run$ caelus_sim setup
INFO: Caelus Python Library (CPL) v0.1.1
#
# Output deleted
#
INFO: Successfully setup simulation: airfoil_demo (6)
```

On successful execution, you should see a new directory `airfoil_demo` that contains six Caelus case directories for the various combinations of Reynolds number and angles of attack. User can query the status of the analysis by executing the `status` sub-command.

```
bash:/tmp/run/airfoil_demo$ ls
Re_1.0e+06      Re_2.0e+06      caelus_sim.yaml
bash:/tmp/run/airfoil_demo$ caelus_sim status
INFO: Caelus Python Library (CPL) v0.1.1

Run status for: airfoil_demo
Directory: /private/tmp/run/airfoil_demo
=====
#.  NAME                                     STATUS
```

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```

=====
1. Re_1.0e+06/aoa_+00.00    Setup
2. Re_1.0e+06/aoa_+02.00    Setup
3. Re_2.0e+06/aoa_+00.00    Setup
4. Re_2.0e+06/aoa_+02.00    Setup
5. Re_1.0e+06/aoa_-04.00    Setup
6. Re_1.0e+06/aoa_-02.00    Setup
=====
TOTAL = 6; SUCCESS = 0; FAILED = 0
=====

```

For a description of the various status tags, please consult *caelus_sim status* documentation.

Note:

1. If you are running from a directory outside of `airfoil_demo` then provide the case path using the `-d` option to `caelus_sim status -d`. You don't need to provide this if you were, say, within `airfoil_demo/Re_1.0e+06` directory or any of the subdirectories.
2. Setup sub-command allows the user to immediately perform `prep` tasks or submit the `solve` jobs immediately upon setup using the `-p` or `-s` flags during the invocation of `setup`.

6.1.3 Prep, solve, and post

Now that the cases as setup, the user can examine the auto-generated case directories to ensure everything is setup properly and can *run* the simulation by just invoking the `solve` sub-command. CPL will detect if pre-processing and case decomposition haven't been performed and will perform these tasks. User also has the option to explicitly invoke the `prep` task separately from command line. Without any arguments, these sub-commands will choose all the cases within a parametric run for execution. User can, however, pass shell-style wildcard arguments to select a subset of cases where the command is executed. In this tutorial, we will demonstrate this behavior by executing `prep` only on the cases where $Re = 2 \times 10^6$.

```

#
# Submit prep only for Re=2e6
#
bash:/tmp/run/airfoil_demo$ caelus_sim prep 'Re_2.0*/*'
INFO: Caelus Python Library (CPL) v0.1.144-g41f57bc-dirty
INFO: Executing pre-processing tasks for case: Re_2.0e+06/aoa_+00.00
INFO: Writing Caelus input file: system/decomposeParDict
INFO: Decomposing case: Re_2.0e+06/aoa_+00.00
INFO: Executing pre-processing tasks for case: Re_2.0e+06/aoa_+02.00
INFO: Writing Caelus input file: system/decomposeParDict
INFO: Decomposing case: Re_2.0e+06/aoa_+02.00

#
# Check status of simulation
#
bash:/tmp/run/airfoil_demo$ caelus_sim status
INFO: Caelus Python Library (CPL) v0.1.1-44-g41f57bc-dirty

Run status for: airfoil_demo
Directory: /private/tmp/run/airfoil_demo
=====

```

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```

# . NAME                                STATUS
=====
1. Re_1.0e+06/aoa_+00.00              Setup
2. Re_1.0e+06/aoa_+02.00              Setup
3. Re_2.0e+06/aoa_+00.00              Prepped
4. Re_2.0e+06/aoa_+02.00              Prepped
5. Re_1.0e+06/aoa_-04.00              Setup
6. Re_1.0e+06/aoa_-02.00              Setup
=====
TOTAL = 6; SUCCESS = 0; FAILED = 0
=====

```

Note the use of single quotes around the wildcard arguments to prevent expansion by the shell when parsing the command line.

In the next step, we will directly invoke `solve` on the positive angle of attack cases for $Re = 1 \times 10^6$ to demonstrate the automatic invocation of `prep` if not already performed.

```

#
# Submit solve only for positive aoa and Re=1e6
#
bash:/tmp/run/airfoil_demo$ caelus_sim solve 'Re_1.0*/aoa_+*'
INFO: Caelus Python Library (CPL) v0.1.1
INFO: Executing pre-processing tasks for case: Re_1.0e+06/aoa_+00.00
INFO: Submitting solver (simpleSolver) for case: Re_1.0e+06/aoa_+00.00
INFO: Executing pre-processing tasks for case: Re_1.0e+06/aoa_+02.00
INFO: Submitting solver (simpleSolver) for case: Re_1.0e+06/aoa_+02.00

#
# Check status of simulation
#
bash:/tmp/run/airfoil_demo$ caelus_sim status
INFO: Caelus Python Library (CPL) v0.1.1

Run status for: airfoil_demo
Directory: /private/tmp/run/airfoil_demo
=====
# . NAME                                STATUS
=====
1. Re_1.0e+06/aoa_+00.00              Solved
2. Re_1.0e+06/aoa_+02.00              FAILED
3. Re_2.0e+06/aoa_+00.00              Prepped
4. Re_2.0e+06/aoa_+02.00              Prepped
5. Re_1.0e+06/aoa_-04.00              Setup
6. Re_1.0e+06/aoa_-02.00              Setup
=====
TOTAL = 6; SUCCESS = 0; FAILED = 1
=====

```

Note: For the purposes of demonstration, the `endTime` in `controlDict` is set to one timestep. Also a deliberate error was introduced in `solve` step to demonstrate the `FAILED` status flag.

User can execute the `post` step and it will only execute post-processing actions on cases that have completed the `solve`.


```

#
# Execute post-processing actions
#
bash:/tmp/run/airfoil_demo$ caelus_sim post
INFO: Caelus Python Library (CPL) v0.1.1
INFO: Executing post-processing tasks for case: Re_1.0e+06/aoa_+00.00
WARNING: Re_1.0e+06/aoa_+02.00: No previous solve detected, skipping post
WARNING: Re_2.0e+06/aoa_+00.00: No previous solve detected, skipping post
WARNING: Re_2.0e+06/aoa_+02.00: No previous solve detected, skipping post
WARNING: Re_1.0e+06/aoa_-04.00: No previous solve detected, skipping post
WARNING: Re_1.0e+06/aoa_-02.00: No previous solve detected, skipping post

#
# Check status of simulation
#
bash:/tmp/run/airfoil_demo$ caelus_sim status
INFO: Caelus Python Library (CPL) v0.1.1

Run status for: airfoil_demo
Directory: /private/tmp/run/airfoil_demo
=====
#. NAME                                STATUS
=====
1. Re_1.0e+06/aoa_+00.00             DONE
2. Re_1.0e+06/aoa_+02.00             FAILED
3. Re_2.0e+06/aoa_+00.00             Prepped
4. Re_2.0e+06/aoa_+02.00             Prepped
5. Re_1.0e+06/aoa_-04.00             Setup
6. Re_1.0e+06/aoa_-02.00             Setup
=====
TOTAL = 6; SUCCESS = 1; FAILED = 1
=====

```

6.2 Manipulating input files with CPL

CPL provides a pythonic interface to read, create, modify, and write out input files necessary for running simulations using OpenFOAM or CML executables within a case directory. Users can interact with input files as python objects and use python data structures and functions to manipulate them. The modified objects can then be written out to files and CPL will pretty-print the files in the appropriate locations in the case directory. Most OpenFOAM/CML objects have a one-to-one correspondence with python data structures within CPL. For example, OpenFOAM dictionaries are accessed as Python dictionaries, specifically an instance of *CaelusDict* which provides both attribute and dictionary-style access to entries. FOAM `List<Scalar>` data types are accessible as NumPy arrays, whereas generic lists containing mixed datatype entries (e.g., the *blocks* entry in `blockMeshDict`) are represented as lists.

This tutorial provides a walkthrough of using `caelus.io` module to read, manipulate, and write out input files in a case directory. The code snippets shown in this tutorial will use the `ACCM_airFoil2D` tutorial in the `$PROJECT_DIR/tutorials/incompressible/simpleSolver/ras/ACCM_airFoil2D` directory. To execute the example code snippets shown in this tutorial, it is recommended that execute them from this case directory and have the following modules loaded in your script or interactive shell

```

import numpy as np
import caelus.io as cio

```

The most general interface to an input file is through the *DictFile* class. It provides three ways of creating an input file object that can be manipulated using CPL in python scripts. Using the constructor creates a default file

object that can be populated by the user. In most situations, however, the user would load a template file using `read_if_present()` or `load()` functions. The former as the name indicates will load the file if present in the case directory, whereas the latter will generate an error if the file doesn't exist. The first example will use `system/controlDict` file to show how the user can load, examine, and manipulate the contents of a simple input file.

```
# Load the controlDict file from the case directory
cdict = cio.DictFile.load("system/controlDict")

# Show the keywords present in the controlDict file
print(cdict.keys())

# Change the variable 'startFrom' to 'latestTime'
cdict['startFrom'] = 'latestTime'

# Change 'writeFormat' to 'binary'
cdict['writeFormat'] = 'binary'

# Show the current state of the controlDict contents
print(cdict)

# Save the updated controlDict file to the case directory
cdict.write()
```

The next example uses the `DictFile` to modify the `O/U`. For the purposes of this demonstration, we will change the inflow conditions from $\alpha = 0^\circ$ angle of attack to a flow at $\alpha = 6^\circ$ angle of attack.

```
# Load the U field file
ufile = cio.DictFile.load("O/U")

# Access the internalField variable
internal = ufile['internalField']
```

If you print out `ufile['internalField']` you will notice that it is an instance of `Field` that contains two attributes: `fType` representing the field type (uniform or nonuniform), and `value` that contains the value of the field. In this the present example, we will access the uniform velocity field value and update it with the `u` and `v` velocities corresponding to $\alpha = 6^\circ$.

```
# Access the wind speed
wspd = internal.value[0]

# Compute u and v components
aoa_rad = np.radians(6.0)
uvel = wspd * np.cos(aoa_rad)
vvel = wspd * np.sin(aoa_rad)

# Update the velocity field
internal.value[0] = uvel
internal.value[1] = vvel

# Update the inlet value also (note attribute-style access)
inlet = ufile['boundaryField'].inlet
inlet.value = internal.value

# Check the current state of the O/U file
print(ufile)

# Write the updated O/U file
ufile.write()
```

6.2.1 Specialized CPL classes for CML input files

While *DictFile* provides a generic interface to all input files, CPL also defines specialized classes that provide additional functionality for those specific input files. The available classes that provide customized functionality are listed below

<i>ControlDict</i>	system/controlDict interface
<i>FvSchemes</i>	system/fvSchemes interface
<i>FvSolution</i>	system/fvSolution interface
<i>DecomposeParDict</i>	system/decomposeParDict interface
<i>TransportProperties</i>	constant/transportProperties interface
<i>TurbulenceProperties</i>	constant/turbulenceProperties interface
<i>RASProperties</i>	constant/RASProperties interface
<i>LESProperties</i>	constant/LESProperties interface
<i>BlockMeshDict</i>	constant/polyMesh/blockMeshDict interface

The specialized classes provide the ability to create default entries as well as provide a limited amount of syntax checking to ensure that the keywords contain acceptable values. It also allows attribute style access (in addition to dictionary style access) for the keywords present in the input file. The *read_if_present()* method is really useful with the specialized classes, as the user does not have to provide the file name, as shown below

```
# Load files from system directory
cdict = cio.ControlDict.read_if_present()
fvsol = cio.FvSolution.read_if_present()
fvsch = cio.FvSchemes.read_if_present()
```

For example, when using the *DictFile* interface with system/controlDict file, the user could assign any arbitrary value to *startFrom*. However, when using the *ControlDict*, CPL will raise an error if the user provides invalid value

```
# Attempt to pass invalid value will raise a ValueError as shown below
cdict.startFrom = "bananas"
# ValueError: ControlDict: Invalid option for 'startFrom'. Valid options are:
# ('firstTime', 'startTime', 'latestTime')

# The keywords in file can be accessed either as attributes or keys
print ( cdict.stopAt, cdict['stopAt'])
```

6.2.2 Accessing keywords with special characters

While most keywords can be accessed as attributes, certain OpenFOAM/CML keywords contain invalid characters and therefore must be accessed as dictionary keys only. The *fvSolution* and *fvSchemes* provide good examples of such keywords.

```
# Accessing the divSchemes for specific equation must use dictionary style
# access
divU = fvsch.divSchemes["div(phi,U)"]

# Accessing the "(k|omega|nuTilda)" solver in fvSolution
turbSolver = fvsol.solvers["(k|omega|nuTilda)"]
```

Note the nested quotation marks for the "(k|omega|nuTilda)" keyword. OpenFOAM/CML requires the double quotes because keyword starts with a non-alphabetical character. Wrapping the entire thing in single quotes protects the double quotes within Python.

6.2.3 Input files for turbulence models

```

# Load the TurbulenceProperties file
tprops = cio.TurbulenceProperties.read_if_present()

# Examine the type of turbulence model being used
print(tprops.simulationType)

# Get an instance of the model input file (returns None if laminar)
rans = tprops.get_turb_file()

# Show the model and coeffs
print(rans.model)
print(rans.coeffs)

# Options common to both RASProperties and LESProperties
rans.turbulence # Flag indicating if turbulence is active
rans.printCoeffs # Flag indicating whether coeffs are printed

# Switch to k-omega SST model
rans.model = "kOmegaSST"
# Note that coeffs has switched to 'kOmegaSSTCoeffs' present in input file
print(rans.coeffs)

# Turn curvature correction on (this updates kOmegaSSTCoeffs now)
rans.coeffs.curvatureCorrection = "on"

# Note, we can still access SpalartAllmarasCoeffs manually
# However, need to use dictionary style access
sacoeffs = rans['SpalartAllmarasCoeffs']

# Can still change S-A coeffs if necessary
sacoeffs.curvatureCorrection = 'off'

# Save updated RASProperties file
rans.write()

```

In the next example, we will change the turbulence model from RANS to LES and let CPL generate a default LESProperties file for us.

```

# Load the TurbulenceProperties file
tprops = cio.TurbulenceProperties.read_if_present()

# Switch to LES model
tprops.simulationType = "LESModel"

# Get the default LESProperties file generated by CPL
les = tprops.get_turb_file()

# Show default values created by CPL
print(les)

# Set up the appropriate coefficients for Smagorinsky
coeffs = les.coeffs
coeffs.ce = 1.05
coeffs.ck = 0.07

```

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```
# Write out the updated files
les.write()
tprops.write()
```

6.3 Custom scripts using CPL

CPL can be used to create custom CFD workflows that may fall outside the capabilities of the command-line applications. The classes used to build the command-line applications can likewise be used to create custom Python scripts, as shown with following example.

This tutorial mimics the workflow of the task file used for the VOF multiphase solver *damBreak* tutorial provided with Caelus. To follow along it is recommended that the user download the custom CPL script. It is assumed the user is executing the script from within the `$CAELUS_PROJECT_DIR/tutorials/multiphase/vof/vofSolver/ras/damBreak` directory. To use CPL's Python interface directly, the user needs to ensure is CPL installed, preferably in a conda or virtualenv environment (see: *Installing Caelus Python Library (CPL)*). As a Python script, other non-CPL functionality can be used in coordination with CPL (e.g. *matplotlib*).

```
import os
import sys
import shutil

import matplotlib.pyplot as plt
```

Several CPL classes and methods are required. Refer to the CPL Python API docs (*caelus*) for a complete listing of modules and associated functionality.

```
from caelus.config.cmlenv import cml_get_version
from caelus.io import DictFile, DecomposeParDict
from caelus.run.cmd import CaelusCmd
from caelus.run.core import get_mpi_size
from caelus.post.logs import LogProcessor, SolverLog
from caelus.post.plots import CaelusPlot
```

An environment specifies the particular OpenFOAM or CML version and installation location. This examples loads the default (no argument to *cml_get_version* returns the default).

```
print("Searching for default caelus version...")
cenv_default = cml_get_version()

cenv = cenv_default
print("Using Caelus version: " + cenv.version)
print("Caelus path: " + cenv.project_dir)
```

Commands are run using *CaelusCmd*. The environment to the job manager object. The command is executed by calling the object and a boolean is returned to enable status checking. Here, the meshing application, *blockMesh*, is run.

```
status = 0
print("Executing blockMesh... ")
caelus_cmd = CaelusCmd("blockMesh", cml_env=cenv)
status = caelus_cmd()
if status != 0:
    print("ERROR generating blockMesh. Exiting!")
    sys.exit(1)
```

Use built-in Python modules for filesystem related tasks.

```
shutil.copy2("0/alpha1.org", "0/alpha1")
```

The solution is initialized using `setFields` with the `CaelusCmd` as shown previously.

```
status = 0
print("Executing setFields... ")
caelus_cmd = CaelusCmd("setFields", cml_env=cenv)
caelus_cmd.cml_exe_args = "-latestTime"
status = caelus_cmd()
if status != 0:
    print("ERROR running setFields. Exiting!")
    sys.exit(1)
```

An automated way to detect and set up a parallel run is to check for a `system/decomposeParDict` file, use the `CaelusDict` class to retrieve the `numberOfSubdomains` parameter, and set the number of MPI ranks to run applications with.

```
decomp_dict = DecomposeParDict.read_if_present()

parallel = True if decomp_dict['numberOfSubDomains'] > 1 else False

status = 0
solver_cmd = CaelusCmd("vofSolver", cml_env=cenv)

if parallel:
    print("Executing decomposePar... ")
    decomp_cmd = CaelusCmd("decomposePar", cml_env=cenv)
    decomp_cmd.cml_exe_args = ("-force")
    status = decomp_cmd()
    if status != 0:
        print("ERROR running decomposePar. Exiting!")
        sys.exit(1)
    solver_cmd.num_mpi_ranks = decomp_dict['numberOfSubDomains']
    solver_cmd.parallel = True
    print("Executing vofSolver in parallel on %d cores..."%solver_cmd.num_mpi_ranks)
else:
    print("Executing vofSolver...")

status = solver_cmd()
if status != 0:
    print("ERROR running vofSolver. Exiting!")
    sys.exit(1)
```

Finally, the `SolverLog` class is invoked to parse the log file and generate a plot of the residuals.

```
print("Processing logs... ")
clog = SolverLog(logfile="vofSolver.log")
cplot = CaelusPlot(clog.casedir)
cplot.plot_continuity_errors = True
cplot.plot_residuals_hist(plotfile="residuals.png")
```

Part II

Developer Manual

7.1 caelus.config – Caelus Configuration Infrastructure

`caelus.config` performs the following tasks:

- Configure the behavior of the Caelus python library using YAML based configuration files.
- Provide an interface to Caelus CML installations and also aid in automated discovery of installed Caelus versions.

<code>get_config</code>	Get the configuration object
<code>reload_config</code>	Reset the configuration object
<code>reset_default_config</code>	Reset to default configuration
<code>cml_get_version</code>	Get the CML environment for the version requested
<code>cml_get_latest_version</code>	Get the CML environment for the latest version available.
<code>CMLEnv</code>	CML Environment Interface.

7.1.1 Caelus Python Configuration

The `config` module provides functions and classes for loading user configuration via YAML files and a central location to configure the behavior of the Caelus python library. The user configuration is stored in a dictionary format within the `CaelusCfg` and can be modified during runtime by user scripts. Access to the configuration object is by calling the `get_config()` method defined within this module which returns a fully populated instance of the configuration dictionary. This module also sets up logging (to both console as well as log files) during the initialization phase.

```
class caelus.config.config.CaelusCfg
    Bases: caelus.utils.struct.Struct
    Caelus Configuration Object
```

A (key, value) dictionary containing all the configuration data parsed from the user configuration files. It is recommended that users obtain an instance of this class via the `get_config()` function instead of directly instantiating this class.

yaml_decoder

alias of `caelus.utils.struct.gen_yaml_decoder.<locals>.StructYAMLLoader`

yaml_encoder

alias of `caelus.utils.struct.gen_yaml_encoder.<locals>.StructYAMLDumper`

write_config (*fh*=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>)

Write configuration to file or standard output.

Parameters *fh* (*handle*) – An open file handle

`caelus.config.config.configure_logging` (*log_cfg*=None)

Configure python logging.

If *log_cfg* is None, then the basic configuration of python logging module is used.

See [Python Logging Documentation](#) for more information.

Parameters *log_cfg* – Instance of *CaelusCfg*

`caelus.config.config.get_appdata_dir` ()

Return the path to the Windows APPDATA directory

`caelus.config.config.get_caelus_root` ()

Get Caelus root directory

In Unix-y systems this returns `{HOME}/Caelus` and on Windows it returns `C:\Caelus`.

Returns Path to Caelus root directory

Return type path

`caelus.config.config.get_config` (*base_cfg*=None, *init_logging*=False)

Get the configuration object

On the first call, initializes the configuration object by parsing all available configuration files. Successive invocations return the same object that can be mutated by the user. The config dictionary can be reset by invoking `reload_config()`.

Parameters

- **base_cfg** (*CaelusCfg*) – A base configuration object that is updated
- **init_logging** (*bool*) – If True, initializes logging

Returns The configuration dictionary

Return type *CaelusCfg*

`caelus.config.config.get_cpl_root` ()

Return the root path for CPL

`caelus.config.config.get_default_config` ()

Return a fresh instance of the default configuration

This function does not read the `caelus.yaml` files on the system, and returns the configurations shipped with CPL.

Returns The default configuration

Return type *CaelusCfg*

`caelus.config.config.rcfiles_loaded()`

Return a list of the configuration files that were loaded

`caelus.config.config.reload_config(base_cfg=None)`

Reset the configuration object

Forces reloading of all the available configuration files and resets the modifications made by user scripts.

See also: `reset_default_config()`

Parameters `base_cfg` – A CMLEnv object to use instead of default

Returns The configuration dictionary

Return type *CaelusCfg*

`caelus.config.config.reset_default_config()`

Reset to default configuration

Resets to library default configuration. Unlike `reload_config()`, this function does not load the configuration files.

Returns The configuration dictionary

Return type *CaelusCfg*

`caelus.config.config.search_cfg_files()`

Search locations and return all possible configuration files.

The following locations are searched:

- The path pointed by `CAELUSRC_SYSTEM`
- The user's home directory `~/caelus/caelus.yaml` on Unix-like systems, and `%APPDATA%/caelus/caelus.yaml` on Windows systems.
- The path pointed by `CAELUSRC`, if defined.
- The file `caelus.yaml` in the current working directory

Returns List of configuration files available

7.1.2 Caelus CML Environment Manager

`cmlenv` serves as a replacement for Caelus/OpenFOAM `bashrc` files, providing ways to discover installed versions as well as interact with the installed Caelus CML versions. By default, `cmlenv` attempts to locate installed Caelus versions in standard locations: `~/Caelus/caelus-VERSION` on Unix-like systems, and in `C:Caelus` in Windows systems. Users can override the default behavior and point to non-standard locations by customizing their Caelus Python configuration file.

class `caelus.config.cmlenv.CMLEnv(cfg)`

Bases: `object`

CML Environment Interface.

This class provides an interface to an installed Caelus CML version.

Parameters `cfg` (*CaelusCfg*) – The CML configuration object

etc_file (*fname*)

Return the first configuration file from etc directories

classmethod `from_modules(cfg)`

Instantiate an environment from modules

bin_dir
Return the bin directory for executable

build_dir
Return the build platform directory

environ
Return an environment for running Caelus CML binaries

etc_dirs
Return list of etc directories

lib_dir
Return the bin directory for executable

module_list
Return list of modules

mpi_bindir
Return the MPI executables path for this installation

mpi_dir
Return the MPI directory for this installation

mpi_libdir
Return the MPI library path for this installation

project_dir
Return the project directory path
Typically ~/Caelus/caelus-VERSION

root
Return the root path for the Caelus install
Typically on Linux/OSX this is the ~/Caelus directory.

user_bindir
Return path to user bin directory

user_dir
Return the user directory

user_libdir
Return path to user lib directory

version
Return the Caelus version

class caelus.config.cmlenv.**FOAMEnv**(*cfg*)

Bases: `object`

OpenFOAM environment interface

Parameters *cfg* (*CaelusCfg*) – The CML configuration object

etc_file (*fname*)

Return the first configuration file from etc directories

classmethod **from_modules** (*cfg*)

Instantiate an environment from modules

bin_dir

Return the bin directory for executables

build_dir
Return the build platform directory

build_option
Return the build option

environ
Return the environment

etc_dirs
Return list of etc directories

foam_api_info
Get API information

foam_bashrc
Return the path to the bashrc file

foam_version
Return the OpenFOAM version
Unlike `version` this reports the version from `WM_PROJECT_VERSION`

lib_dir
Return the lib directory for executables

module_list
Return modules to be activated

mpi_bindir
Return the path to MPI binaries

mpi_dir
Return the path to MPI dir

mpi_libdir
Return the path to MPI libraries

project_dir
Return the project directory path
Typically `~/Caelus/caelus-VERSION`

root
Return the root path for the OpenFOAM install
Typically on Linux/OSX this is the `~/OpenFOAM` directory.

site_dir
Return site directory

site_libdir
Return the site lib directory

user_bindir
Return the user binary directory

user_dir
Return the user directory

user_libdir
Return the user lib directory

version

Return the project version

This is the project version as defined in the Caelus configuration file. For the exact version reported in OpenFOAM WMake use `foam_version()`

`caelus.config.cmlenv.cml_get_latest_version()`

Get the CML environment for the latest version available.

Returns The environment object

Return type *CMLEnv*

`caelus.config.cmlenv.cml_get_version(version=None)`

Get the CML environment for the version requested

If version is None, then it returns the version set as default in the configuration file.

Parameters `version` (*str*) – Version string

Returns The environment object

Return type *CMLEnv*

`caelus.config.cmlenv.discover_versions(root=None)`

Discover Caelus versions if no configuration is provided.

If no root directory is provided, then the function attempts to search in path provided by `get_caelus_root()`.

Parameters `root` (*path*) – Absolute path to root directory to be searched

`caelus.config.cmlenv.get_cmlenv_instance(cml)`

Return a Caelus or OpenFOAM instance

Parameters `cml` (*dict*) – A configuration dictionary

`caelus.config.cmlenv.is_foam_var(key)`

Test if the variable is an OpenFOAM variable

7.2 caelus.utils – Basic utilities

Collection of low-level utilities that are accessed by other packages within CPL, and other code snippets that do not fit elsewhere within CPL. The modules present within utils package must only depend on external libraries or other modules within util, they must not import modules from other packages within CPL.

<i>Struct</i>	Dictionary that supports both key and attribute access.
<i>osutils</i>	Miscellaneous utilities

7.2.1 Struct Module

Implements *Struct*.

class `caelus.utils.struct.Struct`

Bases: `collections.OrderedDict`, `collections.abc.MutableMapping`

Dictionary that supports both key and attribute access.

Struct is inspired by Matlab `struct` data structure that is intended to support both key and attribute access. It

has the following features:

1. Preserves ordering of members as initialized
2. Provides attribute and dictionary-style lookups
3. Read/write YAML formatted data

yaml_decoder

alias of `gen_yaml_decoder.<locals>.StructYAMLLoader`

yaml_encoder

alias of `gen_yaml_encoder.<locals>.StructYAMLDumper`

classmethod from_yaml (*stream*)

Initialize mapping from a YAML string.

Parameters **stream** – A string or valid file handle

Returns YAML data as a python object

Return type *Struct*

classmethod load_yaml (*filename*)

Load a YAML file

Parameters **filename** (*str*) – Absolute path to YAML file

Returns YAML data as python object

Return type *Struct*

merge (**args*)

Recursively update dictionary

Merge entries from maps provided such that new entries are added and existing entries are updated.

to_yaml (*stream=None, default_flow_style=False, **kwargs*)

Convert mapping to YAML format.

Parameters

- **stream** (*file*) – A file handle where YAML is output
- **default_flow_style** (*bool*) –
 - False - pretty printing
 - True - No pretty printing

class caelus.utils.struct.StructMeta

Bases: `abc.ABCMeta`

YAML interface registration

Simplify the registration of custom yaml loader/dumper classes for Struct class hierarchy.

`caelus.utils.struct.gen_yaml_decoder` (*cls*)

Generate a custom YAML decoder with non-default mapping class

Parameters **cls** – Class used for mapping

`caelus.utils.struct.gen_yaml_encoder` (*cls*)

Generate a custom YAML encoder with non-default mapping class

Parameters **cls** – Class used for mapping

`caelus.utils.struct.merge(a, b, *args)`

Recursively merge mappings and return consolidated dict.

Accepts a variable number of dictionary mappings and returns a new dictionary that contains the merged entries from all dictionaries. Note that the update occurs left to right, i.e., entries from later dictionaries overwrite entries from preceding ones.

Returns The consolidated map

Return type `dict`

7.2.2 Miscellaneous utilities

This module implements functions that are utilized throughout CPL. They mostly provide a higher-level interface to various `os.path` functions to make it easier to perform some tasks.

<code>set_work_dir</code>	A with-block to execute code in a given directory.
<code>ensure_directory</code>	Check if directory exists, if not, create it.
<code>abspath</code>	Return the absolute path of the directory.
<code>ostype</code>	String indicating the operating system type
<code>timestamp</code>	Return a formatted timestamp for embedding in files

`caelus.utils.osutils.abspath(pname)`

Return the absolute path of the directory.

This function expands the user home directory as well as any shell variables found in the path provided and returns an absolute path.

Parameters `pname` (*path*) – Pathname to be expanded

Returns Absolute path after all substitutions

Return type `path`

`caelus.utils.osutils.backup_file(fname, time_format=None, time_zone=<UTC>)`

Given a filename return a timestamp based backup filename

Parameters

- **time_format** – A time formatter suitable for `strftime`
- **time_zone** – Time zone used to generate timestamp (Default: UTC)

Returns A timestamped filename suitable for creating backups

Return type `str`

`caelus.utils.osutils.clean_directory(dirname, preserve_patterns=None)`

Utility function to remove files and directories from a given directory.

User can specify a list of filename patterns to preserve with the `preserve_patterns` argument. These patterns can contain shell wildcards to glob multiple files.

Parameters

- **dirname** (*path*) – Absolute path to the directory whose entries are purged.
- **preserve_patterns** (*list*) – A list of shell wildcard patterns

`caelus.utils.osutils.copy_tree(srcdir, destdir, symlinks=False, ignore_func=None)`

Enhanced version of `shutil.copytree`

- removes the output directory if it already exists.

Parameters

- **srcdir** (*path*) – path to source directory to be copied.
- **destdir** (*path*) – path (or new name) of destination directory.
- **symlinks** (*bool*) – as in `shutil.copytree`
- **ignore_func** (*func*) – as in `shutil.copytree`

`caelus.utils.osutils.ensure_directory(dname)`

Check if directory exists, if not, create it.

Parameters **dname** (*path*) – Directory name to check for

Returns Absolute path to the directory

Return type Path

`caelus.utils.osutils.ostype()`

String indicating the operating system type

Returns One of ["linux", "darwin", "windows"]

Return type str

`caelus.utils.osutils.path_exists(pname)`

Check path of the directory exists.

This function expands the user home directory as well as any shell variables found in the path provided and checks if that path exists.

Parameters **pname** (*path*) – Pathname to be checked

Returns True if path exists

Return type bool

`caelus.utils.osutils.remove_files_dirs(paths, basedir=None)`

Remove files and/or directories

Parameters

- **paths** (*list*) – A list of file paths to delete (no patterns allowed)
- **basedir** (*path*) – Base directory to search

`caelus.utils.osutils.set_work_dir(dname, create=False)`

A with-block to execute code in a given directory.

Parameters

- **dname** (*path*) – Path to the working directory.
- **create** (*bool*) – If true, directory is created prior to execution

Returns Absolute path to the execution directory

Return type path

Example

```
>>> with osutils.set_work_dir("results_dir", create=True) as wdir:
...     with open(os.path.join(wdir, "results.dat"), 'w') as fh:
...         fh.write("Data")
```

`caelus.utils.osutils.split_path(fname)`
Split a path into directory, basename, extension

Returns (directory, basename, extension)

Return type tuple

`caelus.utils.osutils.timestamp(time_format=None, time_zone=<UTC>)`
Return a formatted timestamp for embedding in files

Parameters

- **time_format** – A time formatter suitable for strftime
- **time_zone** – Time zone used to generate timestamp (Default: UTC)

Returns A formatted time string

Return type str

`caelus.utils.osutils.user_home_dir()`
Return the absolute path of the user's home directory

`caelus.utils.osutils.username()`
Return the username of the current user

7.3 caelus.run – CML Execution Utilities

7.3.1 Caelus Tasks Manager

class `caelus.run.tasks.Tasks`

Bases: `object`

Caelus Tasks.

Tasks provides a simple automated workflow interface that provides various pre-defined actions via a YAML file interface.

The tasks are defined as methods with a `cmd_` prefix and are automatically converted to task names. Users can create additional tasks by subclassing and adding additional methods with `cmd_` prefix. These methods accept one argument `options`, a dictionary containing parameters provided by the user for that particular task.

cmd_change_inputs (*options*)

Change input files in case directory

cmd_clean_case (*options*)

Clean a case directory

cmd_copy_files (*options*)

Copy given file(s) to the destination.

cmd_copy_tree (*options*)

Recursively copy a given directory to the destination.

cmd_exec_tasks (*options*)

Execute another task file

cmd_process_logs (*options*)

Process logs for a case

cmd_run_command (*options*)

Execute a Caelus CML binary.

This method is an interface to `CaelusCmd`

cmd_run_python (*options*)

Execute a python script

cmd_task_set (*options*)

A subset of tasks for grouping

classmethod load (*task_file='caelus_tasks.yaml', task_node='tasks'*)

Load tasks from a YAML file.

If `exedir` is `None` then the execution directory is set to the directory where the tasks file is found.

Parameters `task_file` (*filename*) – Path to the YAML file

case_dir = None

Directory where the tasks are to be executed

env = None

Caelus environment used when executing tasks

task_file = None

File that was used to load tasks

tasks = None

List of tasks that must be performed

class `caelus.run.tasks.TasksMeta` (*name, bases, cdict*)

Bases: `type`

Process available tasks within each `Tasks` class.

`TasksMeta` is a metaclass that automates the process of creating a lookup table for tasks that have been implemented within the `Tasks` and any of its subclasses. Upon initialization of the class, it populates a class attribute `task_map` that contains a mapping between the task name (used in the tasks YAML file) and the corresponding method executed by the `Tasks` class executed.

7.3.2 CML Simulation

This module defines `CMLSimulation` that provides a pythonic interface to detail with a CML case directory. In addition to implementing methods to perform actions, it also tracks the state of the analysis at any given time.

The module also provides an abstract interface `CMLSimCollection` that provides basic infrastructure to manage and manipulate a collection of simulations as a group.

class `caelus.run.case.CMLSimCollection` (*name, env=None, basedir=None*)

Bases: `caelus.utils.tojson.JSONSerializer`

Interface representing a collection of cases

Implementations must implement `setup()` that provides a concrete implementation of how the case is setup (either from a template or otherwise).

Provides `prep()`, `solve()`, `post()`, and `status()` to interact with the collection as a whole. Prep, solve, and post can accept a list of shell-style wildcard patterns that will restrict the actions to matching cases only.

Parameters

- **name** (*str*) – Unique name for this parametric run
- **env** (*CMLEnv*) – CML execution environment
- **basedir** (*path*) – Path where analysis directory is created

filter_cases (*patterns*)

Filter the cases based on a list of patterns

The patterns are shell-style wildcard strings to match case directory names.

Parameters patterns (*list*) – A list of one or more patterns

classmethod load (*env=None, casedir=None, json_file=None*)

Reload a persisted analysis group

Parameters

- **env** (*CMLEnv*) – Environment for the analysis
- **casedir** (*path*) – Path to the case directory
- **json_file** (*filename*) – Persistence information

post (*cnames=None, force=False*)

Run post-processing tasks on the cases

Parameters

- **cnames** (*list*) – Shell-style wildcard patterns
- **force** (*bool*) – Force rerun

prep (*cnames=None, force=False*)

Run prep actions on the cases

Parameters

- **cnames** (*list*) – Shell-style wildcard patterns
- **force** (*bool*) – Force rerun

save_state (***kwargs*)

Dump persistence file in JSON format

setup ()

Logic to set up the analysis

classmethod simulation_class ()

Concrete instance of a Simulation

Default is *CMLSimulation*

solve (*cnames=None, force=False*)

Run solve actions on the cases

Parameters

- **cnames** (*list*) – Shell-style wildcard patterns
- **force** (*bool*) – Force rerun

status ()
Return the status of the runs

Yields *tuple* – (name, status) for each case

classmethod udf_instance (*custom_script=None, udf_params=None*)
Return a UDF instance

basedir = None
Location where parametric run setup is located

case_names = None
Names of cases

casedir = None
Location of the parametric run

cases = None
List of CMLSimulation instances

env = None
CML execution environment

name = None
Unique name for this parametric collection of cases

udf = None
UDF function

udf_params
Return the parameters for UDF script

udf_script
Return the UDF script

class caelus.run.case.CMLSimMeta (*name, bases, cdict*)
Bases: `type`

Decorator to add dictfile accessors to CMLSimulation

add_dictfile_attrs (*attrmap*)
Create getters for dictionary file objects

process_attr (*key, value*)
Create the attribute

class caelus.run.case.CMLSimulation (*case_name, cml_env=None, basedir=None, parent=None*)
Bases: `caelus.utils.tojson.JSONSerializer`

Pythonic interface to CML/OpenFOAM simulation

This class defines the notion of an analysis. It provides methods to interact with an analysis directory from within python, and provides basic infrastructure to track the status of the simulation.

After successful `setup ()`, the simulation moves through a series of stages, that can be queried via `status ()` method:

Status	Description
Setup	Case setup successfully
Prepped	Pre-processing completed
Submitted	Solver initialized
Running	Solver is running
Solved	Solve has completed
DONE	Post-processing completed
FAILED	Some action failed

Parameters

- **case_name** (*str*) – Unique identifier for the case
- **env** (*CMLEnv*) – CML environment used to setup/run the case
- **basedir** (*path*) – Location where the case is located/created
- **parent** (*CMLSimCollection*) – Instance of the group manager

case_log (*force_reload=False*)

Return a SolverLog instance for this case

clean (*preserve_extra=None, preserve_polymesh=True, preserve_zero=True, preserve_times=False, preserve_processors=False*)

Clean an existing case directory.

Parameters

- **preserve_extra** (*list*) – List of shell wildcard patterns to preserve
- **preserve_polymesh** (*bool*) – If False, purges polyMesh directory
- **preserve_zero** (*bool*) – If False, removes the 0 directory
- **preserve_times** (*bool*) – If False, removes the time directories
- **preserve_processors** (*bool*) – If False, removes processor directories

clone (*template_dir, copy_polymesh=True, copy_zero=True, copy_scripts=True, extra_patterns=None, clean_if_present=False*)

Create the case directory from a given template

Parameters

- **template_dir** (*path*) – Case directory to be cloned
- **copy_polymesh** (*bool*) – Copy contents of constant/polyMesh to new case
- **copy_zero** (*bool*) – Copy time=0 directory to new case
- **copy_scripts** (*bool*) – Copy python and YAML files
- **extra_patterns** (*list*) – List of shell wildcard patterns for copying
- **clean_if_present** (*bool*) – Overwrite existing case

Raises *IOError* – If *casedir* exists and *clean_if_present* is False

decompose_case (*dep_job_id=None, force=False*)

Decompose case if necessary

Parameters

- **dep_job_id** (*int*) – Job ID to wait for

- **force** (*bool*) – Force rerun of decomposition tasks

get_input_dict (*dictname*)

Return a CPL instance of the input file

For standard input files, prefer to use the accessors directly instead of this method. For example, `case.controlDict`, `case.turbulenceProperties`, etc.

Parameters **dictname** (*str*) – File name relative to case directory

classmethod **load** (*env=None, casedir=None, parent=None, json_file=None*)

Loads a previously setup case from persistence file

post_case (*post_tasks=None, force=False*)

Execute post-processing tasks for this case

prep_case (*prep_tasks=None, force=False*)

Execute pre-processing tasks for this case

If not tasks are provided, then uses the section `prep` from `run_configuration` that was passed during the setup phase.

Parameters

- **prep_tasks** (*list*) – List of tasks for Tasks
- **force** (*bool*) – Force prep again if already run

reconstruct_case ()

Reconstruct a parallel case

run_tasks (*task_file=None*)

Run tasks within case directory using the tasks file

save_state (***kwargs*)

Dump persistence file in JSON format

solve (*force=False*)

Execute solve for this case

Parameters **force** (*bool*) – Force resubmit even if previously submitted

status ()

Determine status of the run

Returns Status of the run as a string

Return type *str*

update (*input_mods=None*)

Update the input files within a case directory

Parameters **input_mods** (*CaelusDict*) – Dictionary with changes

LESProperties

Return LESProperties instance for this case

RASProperties

Return RASProperties instance for this case

basedir = None

Root directory containing the case

blockMeshDict

Return blockMeshDict instance for this case

casedir = None
Absolute path to the case directory

changeDictionaryDict
Return changeDictionaryDict instance for this case

cmlControls
Return cmlControls instance for this case

controlDict
Return controlDict instance for this case

decomposeParDict
Return decomposeParDict instance for this case

env = None
CML environment used to run this case

fvSchemes
Return fvSchemes instance for this case

fvSolution
Return fvSolution instance for this case

job_ids = None
Job IDs for SLURM/PBS jobs (internal use only)

logfile
The log file for the solver

name = None
Unique name for this case

parent = None
Instance of CMLSimCollection if part of a larger set

run_config = None
Dictionary containing run configuration (internal use only)

run_flags = None
Dictionary tracking status (internal use only)

solver
Return the solver used for this case

task_file = 'caelus_tasks.yaml'
Name of the task file for this case

transportProperties
Return transportProperties instance for this case

turbulenceProperties
Return turbulenceProperties instance for this case

udf = None
User-defined customization class

7.3.3 CML Parametric Run Manager

class caelus.run.parametric.CMLParametricRun (*name, sim_dict, env=None, basedir=None*)
Bases: *caelus.run.case.CMLSimCollection*

A class to handle parametric runs

Parameters

- **name** (*str*) – Unique name for this parametric run
- **sim_dict** (*CaelusDict*) – Dictionary with simulation settings
- **env** (*CMLEnv*) – CML execution environment
- **basedir** (*path*) – Path where the parametric run directories are created

setup ()

Setup the parametric case directories

setup_case (*cname, tpl_dir, cparams, runconf, clone_opts*)

Helper function to setup the cases

sim_dict = None

Dictionary containing the run settings

udf_params

Return the parameters for UDF script

udf_script

Return the UDF script

caelus.run.parametric.iter_case_params (*sim_options, case_name_func*)

Normalize the keys and yield all possible run setups

caelus.run.parametric.normalize_variable_param (*varspec*)

Helper function to normalize the different run matrix options

7.3.4 Caelus Job Manager Interface

class caelus.run.cmd.CaelusCmd (*cml_exe, casedir=None, cml_env=None, output_file=None*)

Bases: *object*

CML execution interface.

CaelusCmd is a high-level interface to execute CML binaries within an appropriate environment across different operating systems.

Parameters

- **cml_exe** (*str*) – The binary to be executed (e.g., blockMesh)
- **casedir** (*path*) – Absolute path to case directory
- **cml_env** (*CMLEnv*) – Environment used to run the executable
- **output_file** (*file*) – Filename to redirect all output

prepare_exe_cmd ()

Prepare the shell command and return as a string

Returns The CML command invocation with all its options

prepare_shell_cmd ()

Prepare the complete command line string as executed

casedir = None

Case directory

cfg = None

CPL configuration object

cml_env = None
 CML version used for this run

cml_exe = None
 CML program to be executed

cml_exe_args = None
 Arguments passed to the CML executable

mpi_extra_args
 Extra arguments passed to MPI

num_mpi_ranks
 Number of MPI ranks for a parallel run

output_file = None
 Log file where all output and error are captured

parallel = None
 Is this a parallel run

runner = None
 Handle to the subprocess instance running the command

7.3.5 CML Execution Utilities

`caelus.run.core.clean_casedir` (*casedir*, *preserve_extra=None*, *preserve_zero=True*,
preserve_times=False, *preserve_processors=False*,
purge_mesh=False)

Clean a Caelus case directory.

Cleans files generated by a run. By default, this function will always preserve `system`, `constant`, and `0` directories as well as any YAML or python files. Additional files and directories can be preserved by using the `preserve_extra` option that accepts a list of shell wildcard patterns of files/directories that must be preserved.

Parameters

- **casedir** (*path*) – Absolute path to a case directory.
- **preserve_extra** (*list*) – List of shell wildcard patterns to preserve
- **purge_mesh** (*bool*) – If true, also removes mesh from constant/polyMesh
- **preserve_zero** (*bool*) – If False, removes the 0 directory
- **preserve_times** (*bool*) – If False, removes the time directories
- **preserve_processors** (*bool*) – If False, removes processor directories

Raises `IOError` – `clean_casedir` will refuse to remove files from a directory that is not a valid Caelus case directory.

`caelus.run.core.clean_polymesh` (*casedir*, *region=None*, *preserve_patterns=None*)

Clean the polyMesh from the given case directory.

Parameters

- **casedir** (*path*) – Path to the case directory
- **region** (*str*) – Mesh region to delete
- **preserve_patterns** (*list*) – Shell wildcard patterns of files to preserve

`caelus.run.core.clone_case(casedir, template_dir, copy_polymesh=True, copy_zero=True, copy_scripts=True, extra_patterns=None)`

Clone a Caelus case directory.

Parameters

- **casedir** (*path*) – Absolute path to new case directory.
- **template_dir** (*path*) – Case directory to be cloned
- **copy_polymesh** (*bool*) – Copy contents of constant/polyMesh to new case
- **copy_zero** (*bool*) – Copy time=0 directory to new case
- **copy_scripts** (*bool*) – Copy python and YAML files
- **extra_patterns** (*list*) – List of shell wildcard patterns for copying

Returns Absolute path to the newly cloned directory

Return type `path`

Raises `IOError` – If either the `casedir` exists or if the `template_dir` does not exist or is not a valid Caelus case directory.

`caelus.run.core.find_caelus_recipe_dirs(basedir, action_file='caelus_tasks.yaml')`

Return case directories that contain action files.

A case directory with action file is determined if the directory succeeds checks in `is_caelus_dir()` and also contains the action file specified by the user.

Parameters

- **basedir** (*path*) – Top-level directory to traverse
- **action_file** (*filename*) – Default is `caelus_tasks.yaml`

Yields Path to the case directory with action files

`caelus.run.core.find_case_dirs(basedir)`

Recursively search for case directories existing in a path.

Parameters **basedir** (*path*) – Top-level directory to traverse

Yields Absolute path to the case directory

`caelus.run.core.find_recipe_dirs(basedir, action_file='caelus_tasks.yaml')`

Return directories that contain the action files

This behaves differently than `find_caelus_recipe_dirs()` in that it doesn't require a valid case directory. It assumes that the case directories are sub-directories and this task file acts on multiple directories.

Parameters

- **basedir** (*path*) – Top-level directory to traverse
- **action_file** (*filename*) – Default is `caelus_tasks.yaml`

Yields Path to the case directory with action files

`caelus.run.core.get_mpi_size(casedir)`

Determine the number of MPI ranks to run

`caelus.run.core.is_caelus_casedir(root=None)`

Check if the path provided looks like a case directory.

A directory is determined to be an OpenFOAM/Caelus case directory if the `system`, `constant`, and `system/controlDict` exist. No check is performed to determine whether the case directory will actually run or if a mesh is present.

Parameters `root` (*path*) – Top directory to start traversing (default: CWD)

7.3.6 Job Scheduler Interface

This module provides a unified interface to submitting serial, local-MPI parallel, and parallel jobs on high-performance computing (HPC) queues.

class `caelus.run.hpc_queue.HPCQueue` (*name, cml_env=None, **kwargs*)

Bases: `object`

Abstract base class for job submission interface

name

Job name

Type `str`

queue

Queue/partition where job is submitted

Type `str`

account

Account the job is charged to

Type `str`

num_nodes

Number of nodes requested

Type `int`

num_ranks

Number of MPI ranks

Type `int`

stdout

Filename where standard out is redirected

Type `path`

stderr

Filename where standard error is redirected

Type `path`

join_outputs

Merge stdout/stderr to same file

Type `bool`

mail_opts

Mail options (see specific queue implementation)

Type `str`

email_address

Email address for notifications

Type `str`

qos
Quality of service
Type `str`

time_limit
Wall clock time limit
Type `str`

shell
shell to use for scripts
Type `str`

mpi_extra_args
additional arguments for MPI
Type `str`

Parameters

- **name** (`str`) – Name of the job
- **cml_env** (`CMLEnv`) – Environment used for execution

static delete (`job_id`)
Delete a job from the queue

get_queue_settings ()
Return a string with all the necessary queue options

static is_job_scheduler ()
Is this a job scheduler

static is_parallel ()
Flag indicating whether the queue type can support parallel runs

prepare_mpi_cmd ()
Prepare the MPI invocation

process_cml_run_env ()
Populate the run variables for script

process_foam_run_env ()
Populate the run variables for OpenFOAM execution

process_run_env ()
Process runtime environment for scripts

classmethod submit (`script_file`, `job_dependencies=None`, `extra_args=None`, `dep_type=None`)
Submit the job to the queue

update (`settings`)
Update queue settings from the given dictionary

write_script (`script_name=None`)
Write a submission script using the arguments provided
Parameters **script_name** (`path`) – Name of the script file

queue_name = `'_ERROR_'`
Identifier used for queue

script_body

The contents of the script submitted to scheduler

class caelus.run.hpc_queue.**PBSQueue** (*name*, *cml_env=None*, ***kwargs*)

Bases: *caelus.run.hpc_queue.HPCQueue*

PBS Queue Interface

Parameters

- **name** (*str*) – Name of the job
- **cml_env** (*CMLEnv*) – Environment used for execution

static delete (*job_id*)

Delete the PBS batch job using job ID

get_queue_settings ()

Return all PBS options suitable for embedding in script

classmethod submit (*script_file*, *job_dependencies=None*, *extra_args=None*, *dep_type='afterok'*)

Submit a PBS job using qsub command

job_dependencies is a list of PBS job IDs. The submitted job will run depending the status of the dependencies.

extra_args is a dictionary of arguments passed to qsub command.

The job ID returned by this method can be used as an argument to delete method or as an entry in *job_dependencies* for a subsequent job submission.

Parameters

- **script_file** (*path*) – Script provided to sbatch command
- **job_dependencies** (*list*) – List of jobs to wait for
- **extra_args** (*dict*) – Extra SLURM arguments

Returns Job ID as a string

Return type *str*

class caelus.run.hpc_queue.**ParallelJob** (*name*, *cml_env=None*, ***kwargs*)

Bases: *caelus.run.hpc_queue.SerialJob*

Interface to a parallel job

Parameters

- **name** (*str*) – Name of the job
- **cml_env** (*CMLEnv*) – Environment used for execution

static is_parallel ()

Flag indicating whether the queue type can support parallel runs

prepare_mpi_cmd ()

Prepare the MPI invocation

class caelus.run.hpc_queue.**SerialJob** (*name*, *cml_env=None*, ***kwargs*)

Bases: *caelus.run.hpc_queue.HPCQueue*

Interface to a serial job

Parameters

- **name** (*str*) – Name of the job

- **cml_env** (`CMLEnv`) – Environment used for execution

static delete (*job_id*)

Delete a job from the queue

get_queue_settings ()

Return queue settings

static is_job_scheduler ()

Flag indicating whether this is a job scheduler

static is_parallel ()

Flag indicating whether the queue type can support parallel runs

prepare_mpi_cmd ()

Prepare the MPI invocation

classmethod submit (*script_file*, *job_dependencies=None*, *extra_args=None*)

Submit the job to the queue

class `caelus.run.hpc_queue.SlurmQueue` (*name*, *cml_env=None*, ***kwargs*)

Bases: `caelus.run.hpc_queue.HPCQueue`

Interface to SLURM queue manager

Parameters

- **name** (*str*) – Name of the job
- **cml_env** (`CMLEnv`) – Environment used for execution

static delete (*job_id*)

Delete the SLURM batch job using job ID

get_queue_settings ()

Return all SBATCH options suitable for embedding in script

prepare_srun_cmd ()

Prepare the call to SLURM srun command

classmethod submit (*script_file*, *job_dependencies=None*, *extra_args=None*, *dep_type='afterok'*)

Submit to SLURM using sbatch command

job_dependencies is a list of SLURM job IDs. The submitted job will not run until after all the jobs provided in this list have been completed successfully.

extra_args is a dictionary of extra arguments to be passed to `sbatch` command. Note that this can override options provided in the script file as well as introduce additional options during submission.

dep_type can be one of: `after`, `afterok`, `afternotok`, `afterany`

The job ID returned by this method can be used as an argument to `delete` method or as an entry in *job_dependencies* for a subsequent job submission.

Parameters

- **script_file** (*path*) – Script provided to sbatch command
- **job_dependencies** (*list*) – List of jobs to wait for
- **extra_args** (*dict*) – Extra SLURM arguments
- **dep_type** (*str*) – Dependency type

Returns Job ID as a string

Return type `str`

```
caelus.run.hpc_queue.caelus_execute (cmd, env=None, stdout=<_io.TextIOWrapper
                                     name='<stdout>' mode='w' encoding='UTF-
                                     8'>, stderr=<_io.TextIOWrapper name='<stderr>'
                                     mode='w' encoding='UTF-8'>)
```

Execute a CML command with the right environment setup

A wrapper around subprocess.Popen to set up the correct environment before invoing the CML executable.

The command can either be a string or a list of arguments as appropriate for Caelus executables.

Examples

```
caelus_execute("blockMesh -help")
```

Parameters

- **cmd** (*str* or *list*) – The command to be executed
- **env** (*CMLEnv*) – An instance representing the CML installation (default: latest)
- **stdout** – A file handle where standard output is redirected
- **stderr** – A file handle where standard error is redirected

Returns The task instance

Return type `subprocess.Popen`

```
caelus.run.hpc_queue.get_job_scheduler (queue_type=None)
```

Return an instance of the job scheduler

```
caelus.run.hpc_queue.python_execute (pyscript, script_args="", env=None, log_file=None,
                                     log_to_file=True)
```

Execute a python script with the right environment

This function will setup the correct CPL and CML environment and execute the python script within this environment. The user should only provide the name of the script and not `python script` as this it is this functions job to detect the correct python executable and execute within that environment.

If `log_file` isn't provided it automatically creates a "py_*.log" file to redirect output messages from the script where `*` is replaced with the basename of the python script.

Parameters

- **pyscript** (*path*) – Filename of the python script
- **script_args** (*str*) – Extra arguments to be passed to the python script
- **env** (*CMLEnv*) – CML environment used for execution
- **log_file** (*filename*) – Filename to redirect output to
- **log_to_file** (*bool*) – Should outputs be redirected to log file

Returns The status of the execution

Return type `status (int)`

7.4 caelus.post – Post-processing utilities

Provides log analysis and plotting utilities

<i>PostProcessing</i>	Main entry point for accessing OpenFOAM postProcessing data.
<i>SolverLog</i>	Caelus solver log file interface.
<i>CaelusPlot</i>	Caelus Data Plotting Interface

7.4.1 Post-processing interface

This module contains the implementation of *PostProcessing* the main entry point for accessing OpenFOAM's postProcessing outputs.

Example

```
>>> post = PostProcessing() # In case directory
>>> print("Available objects: ", post.keys())
Available objects: ['samples', 'samplePlanes', 'forceCoeffs1']
>>> fcoeffs = post['forceCoeffs1']
>>> #print details
... print(fcoeffs.magUInf, fcoeffs.liftDir, fcoeffs.dragDir)
...
20 [0 0 1] [1 0 0]
>>> # Get dataframe corresponding to `coefficient.dat`
... df = fcoeffs()
... print(df[['Cl', 'Cd']].head())
...
      Cl      Cd
0  0.031805  0.003195
1  0.078845  0.001883
2  0.106916  0.001444
3  0.106786  0.001842
4  0.079757  0.002850
>>> df.columns # show available columns
Index(['Time', 'Cd', 'Cs', 'Cl', 'CmRoll', 'CmPitch', 'CmYaw', 'Cd(f)',
      'Cd(r)', 'Cs(f)', 'Cs(r)', 'Cl(f)', 'Cl(r)'],
      dtype='object')
>>>
```

class caelus.post.funcobj.functions.**PostProcessing** (*casedir=None, func_dict=None*)
Bases: object

Main entry point for accessing OpenFOAM postProcessing data.

If the function object dictionary is not provided as an argument, the class will attempt to infer the functions activated in controlDict file.

Parameters

- **casedir** (*path*) – Path to the case directory (default: cwd)
- **func_dict** (*CaelusDict*) – Function objects dictionary

filter (*func_type*)

Retrieve function objects of a particular type.

The filter method is used to select function objects of a certain type. This is useful when the custom user-defined names might not correspond to the exact type of object.

Currently supported: sets, surfaces, forces, forceCoeffs.

Example

```
>>> fig = plt.figure()
>>> for fcoeff in post.filter('forceCoeffs'):
...     df = fcoeff('0')
...     plt.plot(df['Time'], df['Cl'])
```

Parameters `func_type` (*str*) – Type of function object

Yields *FunctionObject* – Function object instances

keys ()

Return the names of the function objects

casedir = None

Absolute path to the case directory

data = None

Input dictionary for this function object

root

Return path to the postProcessing directory.

7.4.2 Core function object utilities

Implements the base classes upon which the concrete function object interfaces are built on. *FunctionObject* implements common methods used by all the subclasses.

class `caelus.post.funcobj.funcobj.DictMeta` (*name, bases, cdict, **kwargs*)

Bases: `abc.ABCMeta`

Create property methods and add validation for properties.

This metaclass implements the boilerplate code necessary to add getter/setters for various entries found in a Caelus input file. It expects a class variable `_dict_properties` that contains tuples for the various entries in the input file. The tuple can be of two forms:

- (name, default_value)
- (name, default_value, valid_values)

process_properties (*proplist*)

Create getters/setters for properties

process_property (*plist*)

Process a property

class `caelus.post.funcobj.funcobj.FuncObjMeta` (*name, bases, cdict, **kwargs*)

Bases: `caelus.post.funcobj.funcobj.DictMeta`

Specialization for Function objects

class `caelus.post.funcobj.funcobj.FunctionObject` (*name, obj_dict, *, casedir=None*)

Bases: `object`

Base class representing an OpenFOAM function object

Initialize object from input dictionary.

Parameters

- **name** (*str*) – User-defined name for this object (in functions)

- **obj_dict** (*CaelusDict*) – Input dictionary for this functionObject
- **casedir** (*path*) – Path to the case directory (default: cwd)

classmethod create (*, *name*, *casedir=None*, ***kwargs*)

Create a function object from scratch

classmethod funcobj_type ()

Return the string representing this functionObject type.

enabled

executeControl

executeInterval

latest_time

Return the latest time available

libs

log

region

root

Root path to the function object in postProcessing

timeEnd

timeStart

times

Return the list of time directories available

writeControl

writeInterval

7.4.3 Sets and surfaces sampling

This module implements the python interface to OpenFOAM's *sets* and *surfaces* sampling objects.

<i>SampledSets</i>	A <i>sets</i> functionObjects entry.
<i>SampledSurfaces</i>	A <i>surfaces</i> functionObjects entry.
<i>SampledSet</i>	A concrete set instance.
<i>SampledSurface</i>	A concrete surface instance.

The different classes are illustrated using this example functionObject entry in *motorBike* tutorial example:

```
cuttingPlane
{
    type            surfaces;
    libs            (sampling);
    writeControl    writeTime;

    surfaceFormat   vtk;
    fields          ( p U );

    interpolationScheme cellPoint;
}
```

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```

surfaces
{
  yNormal
  {
    type          cuttingPlane;
    planeType     pointAndNormal;
    pointAndNormalDict
    {
      point      (0 0 0);
      normal     (0 1 0);
    }
    interpolate   true;
  }
}

```

When the above object is accessed via *PostProcessing* class, the *cuttingPlane* object is represented by *SampledSurfaces*, and the *yNormal* object is represented by *SampledSurface* instance. Similar relationship exists between *SampledSets* and *SampledSet*.

class caelus.post.funcobj.sampling.**SampledData** (*name, fobj_dict, parent*)

Bases: *object*

Base class for a single sampling object.

Initialize data from input dictionary.

Parameters

- **name** (*str*) – User-defined name for this sampling instance
- **fobj_dict** (*CaelusDict*) – Input parameter dictionary
- **parent** (*Sampling*) – Parent collection instance

data = None

Input dictionary containing data for this instance

fields

Return the names of fields requested by user

name = None

User-defined name for this sampling instance

parent = None

The parent sets/surfaces group instance

class caelus.post.funcobj.sampling.**SampledSet** (*name, fobj_dict, parent*)

Bases: *caelus.post.funcobj.sampling.SampledData*

A concrete set instance.

Currently only raw, vtk, and csv formats are supported for *setFormat* if the user intends to load the dataset through this class.

Example

```

>>> post = PostProcessing()      # Access post-processing instance
>>> sets = post['sampledSets1'] # Get the sets group

```

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```

>>> probes = sets['probel']      # Access line probe data
>>> df = probes()                # Get dataframe for latest time
>>> df1 = probes('10')          # Get dataframe for different time

```

Initialize data from input dictionary.

Parameters

- **name** (*str*) – User-defined name for this sampling instance
- **fobj_dict** (*CaelusDict*) – Input parameter dictionary
- **parent** (*Sampling*) – Parent collection instance

axis

coord_cols

Return names of the coordinates column.

If `axis == "xyz"` then returns a list of 3 columns, else returns the column name defined by `axis`.

num_coord_cols

Return the number of expected columns for coordinates.

If the `axis` is `xyz` then returns 3, else returns 1 for all other axis options.

points

type

class `caelus.post.funcobj.sampling.SampledSets` (*name, obj_dict, *, casedir=None*)

Bases: `caelus.post.funcobj.sampling.Sampling`

A `sets` functionObjects entry.

This class provides an interface to a group of sampled set instances. The instances are of type `SampledSet`.

setFormat

class `caelus.post.funcobj.sampling.SampledSurface` (*name, fobj_dict, parent*)

Bases: `caelus.post.funcobj.sampling.SampledData`

A concrete surface instance.

Currently only `vtk` output format is supported for reading data. A `pyvista.Mesh` instance is returned and can be interacted using `vtk.vtkPolyData` methods.

Example

```

>>> post = PostProcessing()      # Access post-processing instance
>>> surfaces = post['cuttingPlane'] # Get the surfaces group
>>> plane = surfaces['yNormal']    # Access plane data
>>> patch = plane()              # Get dataframe for latest time
>>> patch1 = plane('10')        # Get dataframe for different time

```

Initialize data from input dictionary.

Parameters

- **name** (*str*) – User-defined name for this sampling instance
- **fobj_dict** (*CaelusDict*) – Input parameter dictionary

- **parent** (*Sampling*) – Parent collection instance

type

class caelus.post.funcobj.sampling.**SampledSurfaces** (*name, obj_dict, *, casedir=None*)

Bases: *caelus.post.funcobj.sampling.Sampling*

A surfaces functionObjects entry.

This class provides an interface to a group of sampled surface (planes or patches) instances. The instances are of type *SampledSurface*.

surfaceFormat

class caelus.post.funcobj.sampling.**Sampling** (*name, obj_dict, *, casedir=None*)

Bases: *caelus.post.funcobj.funcobj.FunctionObject*

Base class for sets and surfaces sampling groups.

keys ()

Return the names of the sampling entries

fields**interpolationScheme****samples = None**

Mapping of sampling instances to their names.

7.4.4 Force and Force coefficients interface

Provides pythonic interface to OpenFOAM's *Forces* function objects.

class caelus.post.funcobj.forces.**ForceCoeffs** (*name, obj_dict, *, casedir=None*)

Bases: *caelus.post.funcobj.funcobj.FunctionObject*

The class retrieves data from *coefficient.dat* file generated during a run.

Example

```
>>> post = PostProcessing()           # Get the post processing instance
>>> fcoeffs = post['forceCoeffs1']    # Retrieve force coefficients object
>>> df = fcoeffs()                   # Dataframe for latest time instance
>>> print(df.columns)                # Examine columns
```

Initialize object from input dictionary.

Parameters

- **name** (*str*) – User-defined name for this object (in functions)
- **obj_dict** (*CaelusDict*) – Input dictionary for this functionObject
- **casedir** (*path*) – Path to the case directory (default: cwd)

Aref**dragDir****lRef****liftDir**

magUInf**patches****pitchAxis****class** caelus.post.funcobj.forces.**Forces** (*name, obj_dict, *, casedir=None*)Bases: *caelus.post.funcobj.funcobj.FunctionObject*

The class retrieves data from `force.dat` and `moment.dat` files generated during a run and returns a single Pandas DataFrame containing the following columns.

Column	Value
Fx	Total force (x-direction)
Fy	Total force (y-direction)
Fz	Total force (z-direction)
Fpx	Pressure force (x-direction)
Fpy	Pressure force (y-direction)
Fpz	Pressure force (z-direction)
Fvx	Viscous force (x-direction)
Fvy	Viscous force (y-direction)
Fvz	Viscous force (z-direction)
Mx	Total moment (x-direction)
My	Total moment (y-direction)
Mz	Total moment (z-direction)
Mpx	Pressure moment (x-direction)
Mpy	Pressure moment (y-direction)
Mpz	Pressure moment (z-direction)
Mvx	Viscous moment (x-direction)
Mvy	Viscous moment (y-direction)
Mvz	Viscous moment (z-direction)

Example

```
>>> post = PostProcessing() # Get the post processing instance
>>> forces = post['forces1'] # Retrieve force coefficients object
>>> df = forces() # DataFrame for latest time instance
>>> print(df.columns) # Examine columns
```

Initialize object from input dictionary.

Parameters

- **name** (*str*) – User-defined name for this object (in functions)
- **obj_dict** (*CaelusDict*) – Input dictionary for this functionObject
- **casedir** (*path*) – Path to the case directory (default: cwd)

7.4.5 Caelus Log Analyzer

This module provides utilities to parse and extract information from solver outputs (log files) that can be used to monitor and analyze the convergence of runs. It implements the *SolverLog* class that can be used to access time histories of residuals for various fields of interest.

Example

```
>>> logs = SolverLog()
>>> print ("Available fields: ", logs.fields)
>>> ux_residuals = logs.residual("Ux")
```

The actual extraction of the logs is performed by *LogProcessor* which uses regular expressions to match lines of interest and convert them into tabular files suitable for loading with `numpy.loadtxt` or `pandas.read_table`.

class `caelus.post.logs.LogProcessor` (*logfile*, *case_dir=None*, *logs_dir='logs'*)

Bases: `object`

Process the log file and extract information for analysis.

This is a low-level utility to parse log files and extract information using regular expressions from the log file. Users should interact with solver output using the *SolverLog* class.

Parameters

- **logfile** (*str*) – Name of the Caelus log file
- **casedir** (*path*) – Path to the case directory (default: `cwd`)
- **logs_dir** (*path*) – Relative path to the directory where logs are written

add_rule (*regexp*, *actions*)

Add a user-defined rule for processing

Parameters

- **regexp** (*str*) – A string that can be compiled into a regexp
- **action** (*func*) – A coroutine that can consume matching patterns

bounding_processor ()

Process the bounding lines

completion_processor ()

Process End line indicating solver completion

continuity_processor ()

Process continuity error lines from log file

convergence_processor ()

Process convergence information (steady solvers only)

courant_processor ()

Process Courant Number lines

exec_time_processor ()

Process execution/clock time lines

exiting_processor ()

Process exiting option

extend_rule (*line_type*, *actions*)

Extend a pre-defined regexp with extra functions

The default action for *LogProcessor* is to output processed lines into files. Additional actions on pre-defined lines (e.g., “time”) can be hooked via this method.

Parameters

- **line_type** (*str*) – Pre-defined line type

- **actions** (*list*) – A list of coroutines that receive the matching lines

fatal_error_processor ()

Process CAELUS FATAL ERROR line

residual_processor ()

Process a residual line and output data to the relevant file.

time_processor ()

Processor for the Time line in log files

watch_file (*target=None, wait_time=0.1*)

Process a log file for an in-progress run.

This method takes one parameter, *target*, a coroutine that is called at the end of every timestep. See [LogWatcher](#) for an example of using *target* to plot residuals for monitoring the run.

Parameters

- **target** (*coroutine*) – A consumer acting on the data
- **wait_time** (*seconds*) – Wait time between checking the log file for updates

bound_files = None

Open file handles for bounding outputs

case_dir = None

Absolute path to the case directory

converged = None

Flag indicating convergence message in logs

converged_time = None

Timestep when the steady state solver converged

current_state

Return the current state of the logs processor

failed = None

Flag indicating whether the solver failed

logfile = None

User-supplied log file (relative to case directory)

logs_dir = None

Absolute path to the directory containing processed logs

res_files = None

Open file handles for the residual outputs

solve_completed = None

Flag indicating solver completion in logs (if End is found)

subiter_map = None

(variable, subIteration) pairs tracking the number of predictor subIterations for each flow variable

time = None

Track the latest time that was processed by the utility

time_str = None

Time as a string (for output)

class caelus.post.logs.SolverLog (*case_dir=None, logs_dir='logs', force_reload=False, logfile=None*)

Bases: object

Caelus solver log file interface.

`SolverLog` extracts information from solver outputs and allows interaction with the log data as `numpy.ndarray` or `pandas.DataFrame` objects.

Parameters

- **case_dir** (*path*) – Absolute path to case directory
- **logs_dir** (*path*) – Path to logs directory relative to case_dir
- **force_reload** (*bool*) – If True, force reread of the log file even if the logs were processed previously.
- **logfile** (*file*) – If force_reload, then log file to process

Raises `RuntimeError` – An error is raised if no logs directory is available and the user has not provided a logfile that can be processed on the fly during initialization.

bounding_var (*field*)

Return the bounding information for a field

continuity_errors ()

Return the time history of continuity errors

residual (*field, all_cols=False*)

Return the residual time-history for a field

7.4.6 Caelus Plotting Utilities

This module provides the capability to plot various quantities of interest using matplotlib through `CaelusPlot`.

class `caelus.post.plots.CaelusPlot` (*casedir=None, plotdir='results'*)

Bases: `object`

Caelus Data Plotting Interface

Currently implemented:

- Plot residual time history
- Plot convergence of forces and force coefficients

Parameters

- **casedir** (*path*) – Path to the case directory
- **plotdir** (*path*) – Directory where figures are saved

plot_force_coeffs_hist (*plotfile=None, dpi=300, **kwargs*)

Plot force coefficients

Parameters

- **func_object** (*str*) – The function object used in controlDict
- **plotfile** – File to save plot (e.g., residuals.png)
- **dpi** – Resolution for saving plots (default=300)

plot_forces_hist (*plotfile=None, dpi=300, **kwargs*)

Plot forces

Parameters

- **func_object** (*str*) – The function object used in controlDict
- **plotfile** – File to save plot (e.g., residuals.png)
- **dpi** – Resolution for saving plots (default=300)

plot_residuals_hist (*plotfile=None, dpi=300, **kwargs*)

Plot time-history of residuals for a Caelus run

Parameters

- **fields** (*list*) – Plot residuals only for the fields in this list
- **plotfile** – File to save plot (e.g., residuals.png)
- **dpi** – Resolution for saving plots (default=300)

casedir = None

Path to the case directory

plot_continuity_errors = None

Flag indicating whether continuity errors are plotted along with residuals

plotdir = None

Path to plots output directory

solver_log = None

Instance of *SolverLog*

class caelus.post.plots.**LogWatcher** (*logfile, case_dir=None*)

Bases: *object*

Real-time log monitoring utility

Parameters

- **logfile** (*str*) – Name of the Caelus log file
- **casedir** (*path*) – Path to the case directory (default: cwd)

continuity_processor ()

Capture continuity errors for plot updates

plot_residuals ()

Update plot for residuals

residual_processor ()

Capture residuals for plot updates

skip_field (*field*)

Helper function to determine if field must be processed

time_processor ()

Capture time array

plot_fields = None

List of fields to plot. If None, plots all available fields

skip_fields = None

List of fields to skip. If None, plots all available fields

time_array = None

Time array used for plotting data

class caelus.post.plots.PlotsMeta

Bases: `type`

Provide interactive and non-interactive versions of plot methods.

This metaclass automatically wraps methods starting with `_plot` such that these methods can be used in both interactive and non-interactive modes. Non-interactive modes are automatically enabled if the user provides a file name to save the resulting figure.

`caelus.post.plots.make_plot_method(func)`

Make a wrapper plot method

`caelus.post.plots.mpl_settings(backend='agg')`

Temporarily switch matplotlib settings for a plot

7.5 caelus.io – CML Input File Manipulation

7.5.1 Caelus/OpenFOAM Input File Interface

class caelus.io.dictfile.BlockMeshDict (*filename=None, populate_defaults=True*)

Bases: `caelus.io.dictfile.DictFile`

constant/polyMesh/blockMeshDict interface

Parameters `filename` (*path*) – Path to the input file

create_default_entries ()

Create defaults from property list

blocks

boundary

convertToMeters

edges

mergePatchPairs

vertices

class caelus.io.dictfile.ChangeDictionaryDict (*filename=None, populate_defaults=True*)

Bases: `caelus.io.dictfile.DictFile`

system/changeDictionaryDict interface

Parameters `filename` (*path*) – Path to the input file

create_default_entries ()

Create defaults from property list

dictionaryReplacement

class caelus.io.dictfile.CmlControls (*filename=None, populate_defaults=True*)

Bases: `caelus.io.dictfile.DictFile`

cmlControls interface

Parameters `filename` (*path*) – Path to the input file

```

class caelus.io.dictfile.ControlDict (filename=None, populate_defaults=True)
    Bases: caelus.io.dictfile.DictFile
    system/controlDict interface

        Parameters filename (path) – Path to the input file

    create_default_entries ()
        Create defaults from property list

    adjustTimeStep

    application

    deltaT

    endTime

    functions
        function object definitions in controlDict

    graphFormat

    maxCo

    purgeWrite

    runTimeModifiable

    startFrom

    startTime

    stopAt

    timeFormat

    timePrecision

    writeCompression

    writeControl

    writeFormat

    writeInterval

    writePrecision

class caelus.io.dictfile.DecomposeParDict (filename=None, populate_defaults=True)
    Bases: caelus.io.dictfile.DictFile
    system/decomposeParDict interface

        Parameters filename (path) – Path to the input file

    create_default_entries ()
        Create defaults from property list

    method

    numberOfSubdomains

class caelus.io.dictfile.DictFile (filename=None, populate_defaults=True)
    Bases: object
    Caelus/OpenFOAM input file reader/writer

```

The default constructor does not read a file, but instead creates a new input file object. If a property list is provided, this is used to initialize the default entries. To read an existing file, the use of `DictFile.read_if_present()` method is recommended.

Parameters `filename (path)` – Path to the input file

create_default_entries ()

Create default entries for this file

create_header ()

Create a default header

keys ()

Return list of variable names in the dictionary

classmethod load (filename=None, debug=False)

Load a Caelus input file from disk

Parameters

- **filename (path)** – Path to the input files
- **debug (bool)** – Turn on detailed errors

merge (*args)

Merge entries from one dictionary to another

classmethod read_if_present (casedir=None, filename=None, debug=False, populate_defaults=True)

Read the file if present, else create object with default values

Parameters

- **casedir (path)** – Path to the case directory
- **filename (path)** – Filename to read
- **debug (bool)** – Turn on detailed errors
- **populate_defaults (bool)** – Populate the defaults

write (casedir=None, filename=None, update_object=True, write_header=True)

Write a formatted Caelus input file

Parameters

- **casedir (path)** – Path to the case directory
- **filename (path)** – Filename to write
- **update_object (bool)** – Ensure object type is consistent
- **write_header (bool)** – Write header for the file

contents

Access entries within the Caelus CML dictionary

data = None

Contents of the file as a dictionary suitable for manipulation

filename = None

File to read/write data

header = None

Contents of the FoamFile sub-dictionary in the file

class caelus.io.dictfile.**DictMeta** (*name, bases, cdict*)

Bases: `type`

Create property methods and add validation for properties.

This metaclass implements the boilerplate code necessary to add getter/setters for various entries found in a Caelus input file. It expects a class variable `_dict_properties` that contains tuples for the various entries in the input file. The tuple can be of two forms:

- (name, default_value)
- (name, default_value, valid_values)

If the default_value is not None, then this value will be used to automatically initialize the particular entry by `create_default_entries()` method. If valid_values are provided, any attempt to set/modify this value will be checked to ensure that only the allowed values are used.

process_defaults (*proplist*)

Process default entries

process_properties (*proplist*)

Create getters/setters for properties

process_property (*plist*)

Process a property

class caelus.io.dictfile.**FvSchemes** (*filename=None, populate_defaults=True*)

Bases: `caelus.io.dictfile.DictFile`

system/fvSchemes interface

Parameters filename (*path*) – Path to the input file

create_default_entries ()

Create defaults from property list

ddtSchemes

divSchemes

fluxRequired

gradSchemes

interpolationSchemes

laplacianSchemes

snGradSchemes

class caelus.io.dictfile.**FvSolution** (*filename=None, populate_defaults=True*)

Bases: `caelus.io.dictfile.DictFile`

system/fvSolution interface

Parameters filename (*path*) – Path to the input file

create_default_entries ()

Create defaults from property list

PIMPLE

PISO

SIMPLE

potentialFlow

relaxationFactors

solvers

class caelus.io.dictfile.LESProperties (*filename=None, populate_defaults=True*)

Bases: *caelus.io.dictfile.TurbModelProps*

constant/LESProperties interface

Parameters filename (*path*) – Path to the input file

create_default_entries ()

Create the default turbulence model entries

In addition to the default options specified in turbulence properties class, this also triggers the default entries for delta.

delta

LES delta

class caelus.io.dictfile.PolyMeshBoundary (*filename=None, populate_defaults=True*)

Bases: *caelus.io.dictfile.DictFile*

constant/polyMesh/boundary interface

Parameters filename (*path*) – Path to the input file

class caelus.io.dictfile.RASProperties (*filename=None, populate_defaults=True*)

Bases: *caelus.io.dictfile.TurbModelProps*

constant/RASProperties interface

Parameters filename (*path*) – Path to the input file

class caelus.io.dictfile.TransportProperties (*filename=None, populate_defaults=True*)

Bases: *caelus.io.dictfile.DictFile*

constant/transportProperties interface

Parameters filename (*path*) – Path to the input file

create_default_entries ()

Create defaults from property list

transportModel

class caelus.io.dictfile.TurbModelProps (*filename=None, populate_defaults=True*)

Bases: *caelus.io.dictfile.DictFile*

Common interface for LES/RAS models

Parameters filename (*path*) – Path to the input file

create_default_entries ()

Create defaults from property list

coeffs

Turbulence model coefficients

This represents the sub-dictionary (e.g., kOmegaSSTCoeffs, SmagorinskyCoeffs) containing the additional parameters necessary for the turbulence model. The accessor automatically populates the right name when generating the dictionary depending on the turbulence model selected.

model

Turbulence model

Depending on the type (RANS or LES), this is the entry RASModel or LESModel respectively in the RASProperties and LESProperties file. To simplify access, it is simply named model here.

printCoeffs

turbulence

class caelus.io.dictfile.**TurbulenceProperties** (*filename=None*, *popu-*
late_defaults=True)

Bases: *caelus.io.dictfile.DictFile*

constant/turbulenceProperties interface

Parameters **filename** (*path*) – Path to the input file

create_default_entries ()

Create defaults from property list

get_turb_file ()

Return the appropriate RASProperties or LESProperties file

simulationType

caelus.io.dictfile.cml_std_files = {'LESProperties': <class 'caelus.io.dictfile.LESProperty

Mapping of standard files known to exist in a case directory

7.5.2 Caelus/OpenFOAM Dictionary Implementation

class caelus.io.caelusdict.**CaelusDict**

Bases: *caelus.utils.struct.Struct*

Caelus Input File Dictionary

yaml_decoder

alias of *caelus.utils.struct.gen_yaml_decoder.<locals>.StructYAMLLoader*

yaml_encoder

alias of *caelus.utils.struct.gen_yaml_encoder.<locals>.StructYAMLDumper*

Caelus/OpenFOAM Input File Datatypes

class caelus.io.dtypes.**BoundaryList** (*value*)

Bases: *caelus.io.dtypes.FoamType*

polyMesh/boundary file

write_value (*fh=<io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*, *in-*
dent_str="")

Write as a Caelus/OpenFOAM entry

This method is called by *DictPrinter* to format the data suitable for writing to a Caelus input file that can be read by the solvers.

Parameters

- **fh** (*file*) – A valid file handle
- **indent_str** (*str*) – Padding for indentation

class caelus.io.dtypes.**CalcDirective** (*directive, value*)

Bases: *caelus.io.dtypes.FoamType*

A #calc directive entry

Example:: radHalfAngle #calc “degToRad(\$halfAngle)”;

```
write_value (fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, in-
            dent_str=")
    Write out the dimensional value
```

```
class caelus.io.dtypes.CodeStream (value)
```

Bases: *caelus.io.dtypes.FoamType*

A codestream entry

Contains C++ code that can be compiled and executed to determine dictionary parameters.

```
write_value (fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, in-
            dent_str=")
    Write out the dimensional value
```

```
class caelus.io.dtypes.DimStr (units)
```

Bases: *caelus.io.dtypes.FoamType*

String dimensions

```
write_value (fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, in-
            dent_str=")
    Write as a Caelus/OpenFOAM entry
```

This method is called by *DictPrinter* to format the data suitable for writing to a Caelus input file that can be read by the solvers.

Parameters

- **fh** (*file*) – A valid file handle
- **indent_str** (*str*) – Padding for indentation

```
class caelus.io.dtypes.DimValue (name, dims, value)
```

Bases: *caelus.io.dtypes.FoamType*

A dimensioned value

A dimensioned value contains three parts: the name, units, and the value. Units are of type *Dimension* and value can be a scalar, vector, tensor or a symmetric tensor.

```
write_value (fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, in-
            dent_str=")
    Write out the dimensional value
```

```
class caelus.io.dtypes.Dimension (units=None, **kwargs)
```

Bases: *caelus.io.dtypes.FoamType*

Caelus dimensional units

Represents the units of a dimensional quantity as an array of seven integers that represent the powers of the fundamental units: mass, length, time, temperature, quantity, current, and luminous intensity.

Provide an array of individual units as keyword arguments

Parameters **units** (*list*) – A list of 5 or 7 entries

```
write_value (fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, in-
            dent_str=")
    Write out the dimensions
```

Parameters

- **fh** (*file*) – A valid file handle
- **indent_str** (*str*) – Padding for indentation

class caelus.io.dtypes.**Directive** (*directive, value*)

Bases: *caelus.io.dtypes.FoamType*

A Caelus directive type

Directives are keyword-less entries that indicate certain processing actions and begin with a hash (#) symbol. For example, the `#includeEtc` directive that can be used to include files from `foamEtc` directory.

write_value (*fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, indent_str=""*)
Write out the dimensional value

directive = None
Type of directive (str)

value = None
Value of the directive (e.g., file to be included)

class caelus.io.dtypes.**EvalDirective** (*directive, value*)

Bases: *caelus.io.dtypes.FoamType*

A `#eval` directive entry

Examples

```
timeStart #eval #{ 0.1 * ${/endTime} #}; r0CosT #eval{ $r0*cos(degToRad($t)) };
```

write_value (*fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, indent_str=""*)
Write as a Caelus/OpenFOAM entry

This method is called by *DictPrinter* to format the data suitable for writing to a Caelus input file that can be read by the solvers.

Parameters

- **fh** (*file*) – A valid file handle
- **indent_str** (*str*) – Padding for indentation

class caelus.io.dtypes.**Field** (*ftype, value*)

Bases: *caelus.io.dtypes.FoamType*

A field declaration

This class represents both uniform and non-uniform fields. The attribute `f_type` indicates the type of field and the `value` contains the value for the given field. Uniform fields can be scalar, vector, tensor, or symmetric tensors. Non-uniform fields are typically a *ListTemplate* entity.

write_nonuniform (*fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*)
Write a non-uniform field

write_uniform (*fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>*)
Write a uniform field

write_value (*fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, indent_str=""*)
Write value in OpenFOAM format

class caelus.io.dtypes.**FoamType**

Bases: *object*

Base class for a FOAM type

```
write_value (fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, in-
             dent_str="")
Write as a Caelus/OpenFOAM entry
```

This method is called by *DictPrinter* to format the data suitable for writing to a Caelus input file that can be read by the solvers.

Parameters

- **fh** (*file*) – A valid file handle
- **indent_str** (*str*) – Padding for indentation

```
class caelus.io.dtypes.ListTemplate (ltype, value)
```

Bases: *caelus.io.dtypes.FoamType*

List<T> type entries

```
write_value (fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, in-
             dent_str="")
Write out a List<T> value
```

```
class caelus.io.dtypes.MacroSubstitution (value, semi=True)
```

Bases: *caelus.io.dtypes.FoamType*

Macro substitution without keyword

```
write_value (fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, in-
             dent_str="")
Write standalone macro substitution
```

```
class caelus.io.dtypes.MultipleValues (value)
```

Bases: *caelus.io.dtypes.FoamType*

Multiple values for single keyword

Example:: laplacian(nuEff,U) Gauss linear corrected;

Here “Gauss linear corrected” is stored as an instance of this class to disambiguate between multi-valued entries and plain lists.

```
write_value (fh=<_io.TextIOWrapper name='<stdout>' mode='w' encoding='UTF-8'>, in-
             dent_str="")
Write as a Caelus/OpenFOAM entry
```

This method is called by *DictPrinter* to format the data suitable for writing to a Caelus input file that can be read by the solvers.

Parameters

- **fh** (*file*) – A valid file handle
- **indent_str** (*str*) – Padding for indentation

7.5.3 Caelus Input File Pretty-printer

```
class caelus.io.printer.DictPrinter (buf=<_io.TextIOWrapper name='<stdout>' mode='w'
                                     encoding='UTF-8'>, tab_width=4)
```

Bases: *object*

Caelus Input File Pretty-printer

Given a CaelusDict instance, this class will emit formatted data suitable for use with Caelus solvers

Parameters

- **buf** (*file handle*) – A valid buffer to output to
- **tab_width** (*int*) – Indentation width

write_dict (*value*)

Pretty-print a Caelus dictionary type

Parameters **value** (*Mapping*) – A valid python dict-like instance

write_dict_item (*key, value, nested=False*)

Pretty-print a dictionary entry

Parameters

- **key** (*str*) – Keyword for the parameter
- **value** (*object*) – Value for the keyword
- **nested** (*bool*) – Flag indicating whether the entries are nested

write_list (*value, recursive=False*)

Pretty-print a list entry

Lists are mixed-type data entries. Empty lists and short string lists are printed flat in the same line. All other lists have their entries printed on new lines.

Parameters

- **value** (*list*) – A list entry
- **recursive** (*bool*) – Flag indicating whether this list is part of another list or dict

write_ndarray (*value, recursive=False*)

Pretty-print a numeric list

Parameters

- **value** (*np.ndarray*) – Array object
- **recursive** (*bool*) – Flag indicating whether it is part of a list or dict

write_value (*value, recursive=False, indented=False*)

Pretty-print an RHS entry based on its type

Parameters

- **value** (*object*) – Value to be printed
- **recursive** (*bool*) – Flag indicating whether the value is part of a dictionary or a list
- **indented** (*bool*) – Flag indicating whether value must be indented

keyword_fmt = '%-20s'

Default width for keywords

class caelus.io.printer.**Indenter** (*tab_width=4*)

Bases: *object*

An indentation utility for use with DictPrinter

Parameters **tab_width** (*int*) – Default indentation width

dedent ()

Dedent the tab

emit (*fh*)

Emit the leading indentation

indent ()

Indent the tab

curr_indent = None

Current indentation column

indent_str

Return an indentation string

tab_width = None

Indentation width

`caelus.io.printer.foam_writer (filename, header=None)`

Caelus/OpenFOAM file writer

Parameters `header (CaelusDict)` – The FoamFile entries

Yields `printer (DictPrinter)` – A dictionary printer for printing data

7.6 caelus.scripts – CLI App Utilities

7.6.1 Basic CLI Interface

Defines the base classes that are used to build the CLI scripts.

class `caelus.scripts.core.CaelusScriptBase (name=None, args=None)`

Bases: `object`

Base class for all Caelus CLI applications.

Defines the common functionality for simple scripts and scripts with sub-commands that are used to access functionality from the library without writing additional python scripts.

Parameters

- **name** (`str`) – Custom name used in messages
- **args** (`str`) – Pass arguments instead of using `sys.argv`

cli_options ()

Setup the command line options and arguments

setup_logging (`log_to_file=True, log_file=None, verbose_level=0, quiet=False`)

Setup logging for the script.

Parameters

- **log_to_file** (`bool`) – If True, script will log to file
- **log_file** (`path`) – Filename to log
- **verbose_level** (`int`) – Level of verbosity

args = None

Arugments provided by user at the command line

description = 'Caelus CLI Application'

Description of the CLI app used in help messages

epilog = 'Caelus Python Library (CPL) v2.0.0'

Epilog for help messages

name = None

Custom name when invoked from a python interface instead of command line

parser = None

Instance of the ArgumentParser used to parse command line arguments

class caelus.scripts.core.CaelusSubCmdScript (*name=None, args=None*)

Bases: *caelus.scripts.core.CaelusScriptBase*

A CLI app with sub-commands.

Parameters

- **name** (*str*) – Custom name used in messages
- **args** (*str*) – Pass arguments instead of using sys.argv

cli_options ()

Setup sub-parsers.

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