A flexible Object-Oriented First Order 3-D Finite-Difference algorithm Chorin-Temam based solver for Brinkman Equation

Generated by Doxygen 1.9.1

Chapter 1

Finite Differences Navier-Stokes Solver

This project implements a solver based on finite differences for the Navier-Stokes equations. The solver can be used both on a default cubic domain as well as on an input original mesh which exploits the brinkman penalization method.

1.1 Requirements

To compile and run the project, make sure you have the following tools and libraries installed and configured:

- **Compiler**: GCC with C++20 support
- **Libraries**:
  - PETSc
  - VTK
  - Eigen

1.2 Installation

1. **Load the required modules**:
   Before compiling or running the program, load the necessary modules. Ensure that your environment is correctly set up by running:

~~~
   source /u/sw/etc/bash.bashrc
   module load gcc-glibc
   module load eigen
   module load vtk
   module load petsc
2. **Compile the project**:
    After loading the modules, compile the project by running:
    ```bash
    make
3. **Usage**
    To run the solver, execute the following command:
    ```bash
    ./bin/main
~~~

   For the brinkman solver the name of the .stl has to be indicated. An Example one is given, to run the solver on the example mesh execute the following command: ```bash ./bin/main caroitd.stl ``` The program will compute the solution and store the results in the results directory

Generated by Doxygen

Chapter 2

Namespace Index

2.1 Namespace List

Here is a list of all namespaces with brief descriptions:

Chapter 3

Class Index

3.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

Chapter 4

File Index

4.1 File List

Here is a list of all files with brief descriptions:

Chapter 5

Namespace Documentation

5.1 problem_setting Namespace Reference

Functions

- constexpr PetscReal uxRef (PetscReal const &x, PetscReal const &y, PetscReal const &z, PetscReal const &theta)

    Computes the reference solution for the problem in the x-direction.
- constexpr PetscReal uyRef (PetscReal const &x, PetscReal const &y, PetscReal const &z, PetscReal const &theta)

    Computes the reference solution for the problem in the y-direction.
- constexpr PetscReal uzRef (PetscReal const &x, PetscReal const &y, PetscReal const &z, PetscReal const &theta)

    Computes the reference solution for the problem in the z-direction.
- constexpr PetscReal pRef (PetscReal const &x, PetscReal const &y, PetscReal const &z, PetscReal const &theta)

Variables

- constexpr const char ∗ problem_type = "navier_stokes"

    Set the problem type. Possible values are "navier_stokes", "stokes", "euler", "advection_diffusion", "parabolic_x", "parabolic_y", "parabolic_z", "transport_x", "transport_y", "transport_z".
- constexpr const char ∗ base_path = "results/"

    Set this as base path to store results. Default is "results/".
- constexpr bool brinkman {false}

    Set flag to (dis)able brinkman penalization. Required for complex geometry handling.
- constexpr bool monitor_convergence {true}

    Set flag to (dis)able convergence error of KSP solver.
- constexpr bool check_convergence {true}

    Set flag to (dis)able convergence error of variable. Only implemented for NAvier-Stokes and parabolic problems.
- constexpr PetscInt nx {32}

    Set the number of elements in x-direction.
- constexpr PetscInt ny {32}

    Set the number of elements in y-direction.
- constexpr PetscInt nz {32}

    Set the number of elements in z-direction.
- constexpr PetscReal Lx_0 {-0.5}

    Set the domain limits in x, y and z directions.
- constexpr PetscReal Ly_0 {-0.5}
- constexpr PetscReal Lz_0 {-0.5}
- constexpr PetscReal Lx {0.5}

- constexpr PetscReal Ly {0.5}
- constexpr PetscReal Lz {0.5}
- constexpr PetscReal dt {0.00625/2}

  Set time-step.
- constexpr PetscReal iter {32}

  Set final time.
- PetscReal theta

  Set starting time.
- constexpr PetscReal Re {1}

  Set Reynolds number. For non advective problems, set mu = 1/Re (adimensional framework)
- constexpr PetscReal a = pi / 4

  Set flow parameters. You can declare as many constexpr variables as you need.
- constexpr PetscReal d = 1.5 ∗ pi

5.1.1 Function Documentation

5.1.1.1 pRef()

```
constexpr PetscReal problem_setting::pRef (
            PetscReal const & x,
            PetscReal const & y,
            PetscReal const & z,
            PetscReal const & theta )  [constexpr]
```

5.1.1.2 uxRef()

```
constexpr PetscReal problem_setting::uxRef (
            PetscReal const & x,
            PetscReal const & y,
            PetscReal const & z,
            PetscReal const & theta )  [constexpr]
```

Computes the reference solution for the problem in the x-direction.

This function provides an analytical reference solution for the given problem in the x-direction. It is time-dependent and useful for benchmarking numerical methods.

Parameters

x	X-coordinate.
y	Y-coordinate.
z	Z-coordinate.
theta	Time-dependent parameter.

Returns

Computed reference solution in the x-direction.

5.1.1.3 uyRef()

```
constexpr PetscReal problem_setting::uyRef (
            PetscReal const & x,
            PetscReal const & y,
```

```
            PetscReal const & z,
            PetscReal const & theta )  [constexpr]
```

Computes the reference solution for the problem in the y-direction.
This function provides an analytical reference solution for the given problem in the y-direction. It is used for validation and testing of numerical simulations.

Parameters

x	X-coordinate.
y	Y-coordinate.
z	Z-coordinate.
theta	Time-dependent parameter.

Returns

Computed reference solution in the y-direction.

5.1.1.4 uzRef()

```
constexpr PetscReal problem_setting::uzRef (
            PetscReal const & x,
            PetscReal const & y,
            PetscReal const & z,
            PetscReal const & theta )  [constexpr]
```

Computes the reference solution for the problem in the z-direction.
This function provides an analytical reference solution for the given problem in the z-direction. It is useful for testing the consistency of numerical solvers.

Parameters

x	X-coordinate.
y	Y-coordinate.
z	Z-coordinate.
theta	Time-dependent parameter.

Returns

Computed reference solution in the z-direction.

5.1.2 Variable Documentation

5.1.2.1 a

```
constexpr PetscReal problem_setting::a = pi / 4  [constexpr]
```

Set flow parameters. You can declare as many constexpr variables as you need.

5.1.2.2 base_path

```
constexpr const char* problem_setting::base_path = "results/"  [constexpr]
```

Set this as base path to store results. Default is "results/".

5.1.2.3 brinkman

`constexpr bool problem_setting::brinkman {false} [constexpr]`

Set flag to (dis)able brinkman penalization. Required for complex geometry handling.

5.1.2.4 check_convergence

`constexpr bool problem_setting::check_convergence {true} [constexpr]`

Set flag to (dis)able convergence error of variable. Only implemented for NAvier-Stokes and parabolic problems.

5.1.2.5 d

`constexpr PetscReal problem_setting::d = 1.5 * pi [constexpr]`

5.1.2.6 dt

`constexpr PetscReal problem_setting::dt {0.00625/2} [constexpr]`

Set time-step.

5.1.2.7 iter

`constexpr PetscReal problem_setting::iter {32} [constexpr]`

Set final time.

5.1.2.8 Lx

`constexpr PetscReal problem_setting::Lx {0.5} [constexpr]`

5.1.2.9 Lx_0

`constexpr PetscReal problem_setting::Lx_0 {-0.5} [constexpr]`

Set the domain limits in x, y and z directions.

5.1.2.10 Ly

`constexpr PetscReal problem_setting::Ly {0.5} [constexpr]`

5.1.2.11 Ly_0

`constexpr PetscReal problem_setting::Ly_0 {-0.5} [constexpr]`

5.1.2.12 Lz

`constexpr PetscReal problem_setting::Lz {0.5} [constexpr]`

5.1.2.13 Lz_0

`constexpr PetscReal problem_setting::Lz_0 {-0.5} [constexpr]`

5.1.2.14 monitor_convergence

`constexpr bool problem_setting::monitor_convergence {true} [constexpr]`

Set flag to (dis)able convergence error of KSP solver.

5.1.2.15 nx

`constexpr PetscInt problem_setting::nx {32} [constexpr]`

Set the number of elements in x-direction.

5.1.2.16 ny

`constexpr PetscInt problem_setting::ny {32} [constexpr]`

Set the number of elements in y-direction.

5.1.2.17 nz

`constexpr PetscInt problem_setting::nz {32} [constexpr]`

Set the number of elements in z-direction.

5.1.2.18 problem_type

`constexpr const char* problem_setting::problem_type = "navier_stokes" [constexpr]`

Set the problem type. Possible values are "navier_stokes", "stokes", "euler", "advection_diffusion", "parabolic_x", "parabolic_y", "parabolic_z", "transport_x", "transport_y", "transport_z".

5.1.2.19 Re

`constexpr PetscReal problem_setting::Re {1} [constexpr]`

Set Reynolds number. For non advective problems, set mu = 1/Re (adimensional framework)

5.1.2.20 theta

`PetscReal problem_setting::theta [inline]`

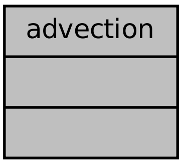
Set starting time.

Chapter 6

Class Documentation

6.1 advection Class Reference

Solves the Advection Diffusion evolutionary incompressible equations. It consists of a transport problem for each velocity component and a parabolic problem for each velocity component. Current implementation allows Dirichlet bc's only. Boundary conditions are accessed from reference solution, which is a function of space and time. Current implementation allows for Brinkamn penalty method.
Collaboration diagram for advection:



6.1.1 Detailed Description

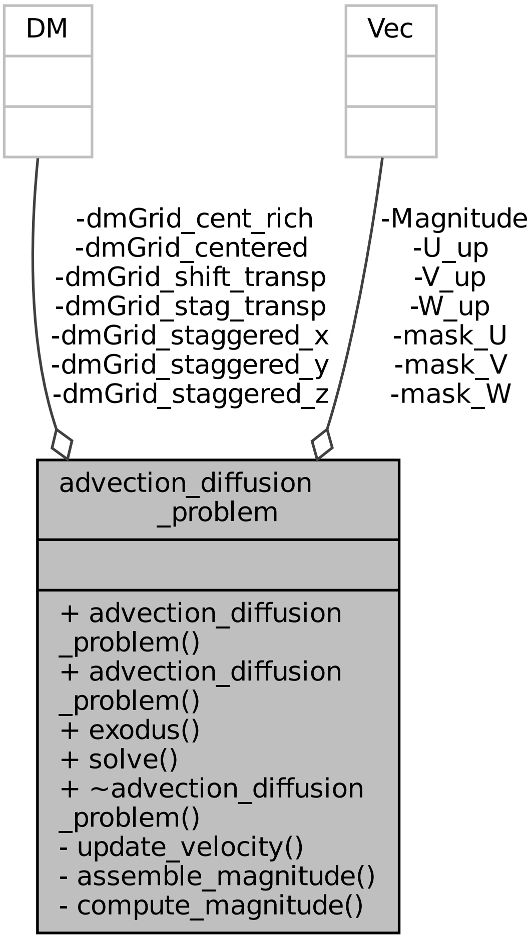
Solves the Advection Diffusion evolutionary incompressible equations. It consists of a transport problem for each velocity component and a parabolic problem for each velocity component. Current implementation allows Dirichlet bc's only. Boundary conditions are accessed from reference solution, which is a function of space and time. Current implementation allows for Brinkamn penalty method.
The documentation for this class was generated from the following file:

- include/advection_diffusion.hpp

6.2 advection_diffusion_problem Class Reference

```
#include <advection_diffusion.hpp>
```

Collaboration diagram for advection_diffusion_problem:



Public Member Functions

- advection_diffusion_problem (DM const &dmGrid_staggered_x, DM const &dmGrid_staggered_y, DM const &dmGrid_staggered_z, DM const &dmGrid_centered, DM const &dmGrid_cent_rich, DM const &dmGrid_stag_transp, DM const dmGrid_shift_transp, Vec const &U_up, Vec const &V_up, Vec const W_up)

    Constructor that initializes the Advection-Diffusion problem with given grids and velocity fields. This costructor has been defined for consistency and if future implementations will require solving Advection-Diffusion in a broader context. For our applications only a stand-alone constructor is used.

- advection_diffusion_problem ()

    Default constructor that initializes stand-alone Advection-Diffusion problem with automatically created grids.

- PetscErrorCode exodus (size_t i)

    Exports simulation in .vtk format format for visualization of x,y,z-componets, pressure and magnitude.

- PetscErrorCode const solve ()

    Solves the Advection-Diffusion equations leveraging parabolic_problem_x, y, z, transport_problem_x, y, z, and poisson_problem classes.

- ∼advection_diffusion_problem ()

Destructor to clean up allocated resources. Automatically calls sub-problems destructors. After destruction, a message is printed.

Private Member Functions

- PetscErrorCode const update_velocity (PetscReal const &theta)

  Updates the velocity field, opearating final pressure correction for CT scheme.
- PetscErrorCode const assemble_magnitude (Vec &Magnitude_Shifted, Vec const &U, Vec const &V, Vec const &W)

  Post-processing function: assembles the magnitude of velocity vectors, locating a new vector in the cell-centers.
- PetscErrorCode const compute_magnitude ()

  Final assembly of magnitude vector on cell-centers.

Private Attributes

- DM dmGrid_staggered_x

  Discretized grid for the staggered x-direction.
- DM dmGrid_staggered_y

  Discretized grid for the staggered y-direction.
- DM dmGrid_staggered_z

  Discretized grid for the staggered z-direction.
- DM dmGrid_centered

  Discretized grid for magnitude.
- DM dmGrid_cent_rich

  Discretized grid for shifted quantities.
- DM dmGrid_stag_transp

  Staggered grid for transport equations.
- DM dmGrid_shift_transp

  Shifted grid for transport computations.
- Vec Magnitude

  Magnitude of velocity vectors.
- Vec U_up
- Vec V_up
- Vec W_up

  Velocity fields in the x, y, and z directions.
- Vec mask_U
- Vec mask_V
- Vec mask_W

  Mask vectors for boundary conditions.

6.2.1 Constructor & Destructor Documentation

6.2.1.1 advection_diffusion_problem() [1/2]

```
advection_diffusion_problem::advection_diffusion_problem (
            DM const & dmGrid_staggered_x,
            DM const & dmGrid_staggered_y,
            DM const & dmGrid_staggered_z,
            DM const & dmGrid_centered,
            DM const & dmGrid_cent_rich,
            DM const & dmGrid_stag_transp,
            DM const dmGrid_shift_transp,
```

```
            Vec const & U_up,
            Vec const & V_up,
            Vec const W_up )  [inline]
```

Constructor that initializes the Advection-Diffusion problem with given grids and velocity fields. This costructor has been defined for consistency and if future implementations will require solving Advection-Diffusion in a broader context. For our applications only a stand-alone constructor is used.

6.2.1.2 advection_diffusion_problem() [2/2]

```
advection_diffusion_problem::advection_diffusion_problem ( )  [inline]
```

Default constructor that initializes stand-alone Advection-Diffusion problem with automatically created grids.

6.2.1.3 ∼advection_diffusion_problem()

```
advection_diffusion_problem::∼advection_diffusion_problem ( )  [inline]
```

Destructor to clean up allocated resources. Automatically calls sub-problems destructors. After destruction, a message is printed.

6.2.2 Member Function Documentation

6.2.2.1 assemble_magnitude()

```
PetscErrorCode const advection_diffusion_problem::assemble_magnitude (
            Vec & Magnitude_Shifted,
            Vec const & U,
            Vec const & V,
            Vec const & W )  [private]
```

Post-processing function: assembles the magnitude of velocity vectors, locating a new vector in the cell-centers.

Parameters

Magnitude_Shifted	Output shifted magnitude vector on dmGrid_cent_rich (dofs on faces and cell=centers.)
U	Velocity component in the x-direction.
V	Velocity component in the y-direction.
W	Velocity component in the z-direction.

6.2.2.2 compute_magnitude()

```
PetscErrorCode const advection_diffusion_problem::compute_magnitude ( )  [private]
```

Final assembly of magnitude vector on cell-centers.

6.2.2.3 exodus()

```
PetscErrorCode advection_diffusion_problem::exodus (
            size_t i )
```

Exports simulation in .vtk format format for visualization of x,y,z-componets, pressure and magnitude.

6.2.2.4 solve()

```
PetscErrorCode const advection_diffusion_problem::solve ( )
```

Solves the Advection-Diffusion equations leveraging parabolic_problem_x, y, z, transport_problem_x, y, z, and poisson_problem classes.

6.2.2.5 update_velocity()

```
PetscErrorCode const advection_diffusion_problem::update_velocity (
             PetscReal const & theta )  [private]
```

Updates the velocity field, opearating final pressure correction for CT scheme.

6.2.3 Member Data Documentation

6.2.3.1 dmGrid_cent_rich

```
DM advection_diffusion_problem::dmGrid_cent_rich  [private]
```

Discretized grid for shifted quantities.

6.2.3.2 dmGrid_centered

```
DM advection_diffusion_problem::dmGrid_centered  [private]
```

Discretized grid for magnitude.

6.2.3.3 dmGrid_shift_transp

```
DM advection_diffusion_problem::dmGrid_shift_transp  [private]
```

Shifted grid for transport computations.

6.2.3.4 dmGrid_stag_transp

```
DM advection_diffusion_problem::dmGrid_stag_transp  [private]
```

Staggered grid for transport equations.

6.2.3.5 dmGrid_staggered_x

```
DM advection_diffusion_problem::dmGrid_staggered_x  [private]
```

Discretized grid for the staggered x-direction.

6.2.3.6 dmGrid_staggered_y

```
DM advection_diffusion_problem::dmGrid_staggered_y  [private]
```

Discretized grid for the staggered y-direction.

6.2.3.7 dmGrid_staggered_z

```
DM advection_diffusion_problem::dmGrid_staggered_z  [private]
```

Discretized grid for the staggered z-direction.

6.2.3.8 Magnitude

`Vec advection_diffusion_problem::Magnitude [private]`

Magnitude of velocity vectors.

6.2.3.9 mask_U

`Vec advection_diffusion_problem::mask_U [private]`

6.2.3.10 mask_V

`Vec advection_diffusion_problem::mask_V [private]`

6.2.3.11 mask_W

`Vec advection_diffusion_problem::mask_W [private]`

Mask vectors for boundary conditions.

6.2.3.12 U_up

`Vec advection_diffusion_problem::U_up [private]`

6.2.3.13 V_up

`Vec advection_diffusion_problem::V_up [private]`

6.2.3.14 W_up

`Vec advection_diffusion_problem::W_up [private]`

Velocity fields in the x, y, and z directions.

The documentation for this class was generated from the following files:

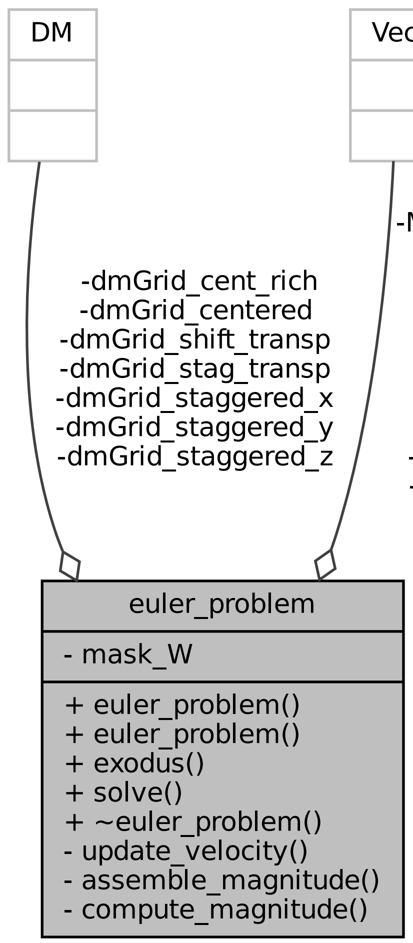
- include/advection_diffusion.hpp
- src/advection_diffusion.cpp

6.3 euler_problem Class Reference

Solves the Euler evolutionary incompressible equations, applying a first order Chorin-Temam algorithm. It consists of a transport problem for each velocity component and a Poisson problem for the pressure. Current implementation allows Dirichlet bc's only. Boundary conditions are accessed from reference solution, which is a function of space and time. Current implementation DOES NOT ALLOW for Brinkamn penalty method.

`#include <inviscid_euler.hpp>`

Collaboration diagram for euler_problem:



Public Member Functions

- euler_problem (DM const &dmGrid_staggered_x, DM const &dmGrid_staggered_y, DM const &dmGrid_staggered_z, DM const &dmGrid_centered, DM const &dmGrid_cent_rich, DM const &dmGrid_stag_transp, DM const dmGrid_shift_transp, Vec const &U_up, Vec const &V_up, Vec const W_up)

  Constructor that initializes the Euler problem with given grids and velocity fields. This costructor has been defined for consistency and if future implementations will require solving Euler in a broader context. For our applications only a stand-alone constructor is used.
- euler_problem ()

  Default constructor that initializes stand-alone Euler problem with automatically created grids.
- PetscErrorCode exodus (size_t i)

  Exports simulation in .vtk format format for visualization of x,y,z-componets, pressure and magnitude.
- PetscErrorCode const solve ()

  Solves the Euler equations leveraging parabolic_problem_x, y, z, transport_problem_x, y, z, and poisson_problem classes.
- ∼euler_problem ()

  Destructor to clean up allocated resources. Automatically calls sub-problems destructors. After destruction, a message is printed.

Private Member Functions

- PetscErrorCode const update_velocity (PetscReal const &theta)

    Updates the velocity field, opearating final pressure correction for CT scheme.
- PetscErrorCode const assemble_magnitude (Vec &Magnitude_Shifted, Vec const &U, Vec const &V, Vec const &W)

    Post-processing function: assembles the magnitude of velocity vectors, locating a new vector in the cell-centers.
- PetscErrorCode const compute_magnitude ()

    Final assembly of magnitude vector on cell-centers.

Private Attributes

- DM dmGrid_staggered_x

    Discretized grid for the staggered x-direction.
- DM dmGrid_staggered_y

    Discretized grid for the staggered y-direction.
- DM dmGrid_staggered_z

    Discretized grid for the staggered z-direction.
- DM dmGrid_centered

    Discretized grid for the centered formulation.
- DM dmGrid_cent_rich

    Refined centered grid for pressure computation.
- DM dmGrid_stag_transp

    Staggered grid for transport equations.
- DM dmGrid_shift_transp

    Shifted grid for transport computations.
- Vec P

    Pressure field.
- Vec P_x

    Pressure derivative in the x-direction.
- Vec P_y

    Pressure derivative in the y-direction.
- Vec P_z

    Pressure derivative in the z-direction.
- Vec Magnitude

    Magnitude of velocity vectors.
- Vec U_up
- Vec V_up
- Vec W_up

    Velocity fields in the x, y, and z directions.
- Vec mask_U
- Vec mask_V
- Vec mask_W

    Mask vectors for boundary conditions.

6.3.1 Detailed Description

Solves the Euler evolutionary incompressible equations, applying a first order Chorin-Temam algorithm. It consists of a transport problem for each velocity component and a Poisson problem for the pressure. Current implementation allows Dirichlet bc's only. Boundary conditions are accessed from reference solution, which is a function of space and time. Current implementation DOES NOT ALLOW for Brinkamn penalty method.

6.3.2 Constructor & Destructor Documentation

6.3.2.1 euler_problem() [1/2]

```
euler_problem::euler_problem (
            DM const & dmGrid_staggered_x,
            DM const & dmGrid_staggered_y,
            DM const & dmGrid_staggered_z,
            DM const & dmGrid_centered,
            DM const & dmGrid_cent_rich,
            DM const & dmGrid_stag_transp,
            DM const dmGrid_shift_transp,
            Vec const & U_up,
            Vec const & V_up,
            Vec const W_up )  [inline]
```

Constructor that initializes the Euler problem with given grids and velocity fields. This costructor has been defined for consistency and if future implementations will require solving Euler in a broader context. For our applications only a stand-alone constructor is used.

6.3.2.2 euler_problem() [2/2]

```
euler_problem::euler_problem ( )  [inline]
```

Default constructor that initializes stand-alone Euler problem with automatically created grids.

6.3.2.3 ∼euler_problem()

```
euler_problem::∼euler_problem ( )  [inline]
```

Destructor to clean up allocated resources. Automatically calls sub-problems destructors. After destruction, a message is printed.

6.3.3 Member Function Documentation

6.3.3.1 assemble_magnitude()

```
PetscErrorCode const euler_problem::assemble_magnitude (
            Vec & Magnitude_Shifted,
            Vec const & U,
            Vec const & V,
            Vec const & W )  [private]
```

Post-processing function: assembles the magnitude of velocity vectors, locating a new vector in the cell-centers.

Parameters

Magnitude_Shifted	Output shifted magnitude vector on dmGrid_cent_rich (dofs on faces and cell=centers.)
U	Velocity component in the x-direction.
V	Velocity component in the y-direction.
W	Velocity component in the z-direction.

6.3.3.2 compute_magnitude()

```
PetscErrorCode const euler_problem::compute_magnitude ( )  [private]
```

Final assembly of magnitude vector on cell-centers.

6.3.3.3 exodus()

```
PetscErrorCode euler_problem::exodus (
             size_t i )
```

Exports simulation in .vtk format format for visualization of x,y,z-componets, pressure and magnitude.

6.3.3.4 solve()

```
PetscErrorCode const euler_problem::solve ( )
```

Solves the Euler equations leveraging parabolic_problem_x, y, z, transport_problem_x, y, z, and poisson_problem classes.

6.3.3.5 update_velocity()

```
PetscErrorCode const euler_problem::update_velocity (
             PetscReal const & theta )  [private]
```

Updates the velocity field, opearating final pressure correction for CT scheme.

6.3.4 Member Data Documentation

6.3.4.1 dmGrid_cent_rich

```
DM euler_problem::dmGrid_cent_rich  [private]
```

Refined centered grid for pressure computation.

6.3.4.2 dmGrid_centered

```
DM euler_problem::dmGrid_centered  [private]
```

Discretized grid for the centered formulation.

6.3.4.3 dmGrid_shift_transp

```
DM euler_problem::dmGrid_shift_transp  [private]
```

Shifted grid for transport computations.

6.3.4.4 dmGrid_stag_transp

```
DM euler_problem::dmGrid_stag_transp  [private]
```

Staggered grid for transport equations.

6.3.4.5 dmGrid_staggered_x

```
DM euler_problem::dmGrid_staggered_x  [private]
```

Discretized grid for the staggered x-direction.

6.3.4.6 dmGrid_staggered_y

`DM euler_problem::dmGrid_staggered_y [private]`

Discretized grid for the staggered y-direction.

6.3.4.7 dmGrid_staggered_z

`DM euler_problem::dmGrid_staggered_z [private]`

Discretized grid for the staggered z-direction.

6.3.4.8 Magnitude

`Vec euler_problem::Magnitude [private]`

Magnitude of velocity vectors.

6.3.4.9 mask_U

`Vec euler_problem::mask_U [private]`

6.3.4.10 mask_V

`Vec euler_problem::mask_V [private]`

6.3.4.11 mask_W

`Vec euler_problem::mask_W [private]`

Mask vectors for boundary conditions.

6.3.4.12 P

`Vec euler_problem::P [private]`

Pressure field.

6.3.4.13 P_x

`Vec euler_problem::P_x [private]`

Pressure derivative in the x-direction.

6.3.4.14 P_y

`Vec euler_problem::P_y [private]`

Pressure derivative in the y-direction.

6.3.4.15 P_z

`Vec euler_problem::P_z [private]`

Pressure derivative in the z-direction.

6.3.4.16 U_up

`Vec euler_problem::U_up [private]`

6.3.4.17 V_up

`Vec euler_problem::V_up [private]`

6.3.4.18 W_up

`Vec euler_problem::W_up [private]`

Velocity fields in the x, y, and z directions.

The documentation for this class was generated from the following files:

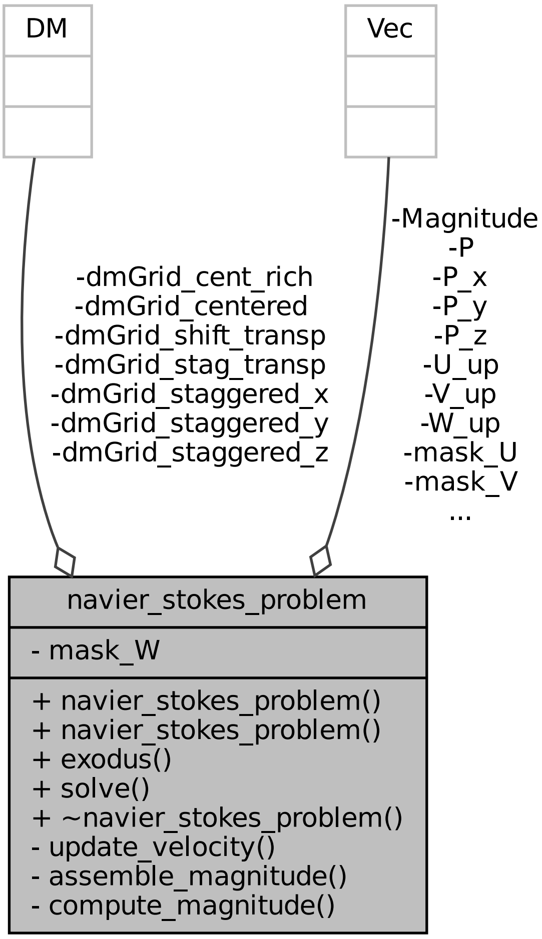
- include/inviscid_euler.hpp
- src/inviscid_euler.cpp

6.4 navier_stokes_problem Class Reference

Solves the Navier-Stokes evolutionary incompressible Navier-Stokes equations, applying a first order Chorin-↩ Temam algorithm. It consists of a transport problem for each velocity component, a parabolic problem for each velocity component, and a Poisson problem for the pressure. Current implementation allows Dirichlet bc's only. Boundary conditions are accessed from reference solution, which is a function of space and time. Current implementation allows for Brinkamn penalty method.

`#include <navier_stokes.hpp>`

Collaboration diagram for navier_stokes_problem:



Public Member Functions

- navier_stokes_problem (DM const &dmGrid_staggered_x, DM const &dmGrid_staggered_y, DM const &dmGrid_staggered_z, DM const &dmGrid_centered, DM const &dmGrid_cent_rich, DM const &dmGrid_stag_transp, DM const dmGrid_shift_transp, Vec const &U_up, Vec const &V_up, Vec const W_up)

    Constructor that initializes the Navier-Stokes problem with given grids and velocity fields. This costructor has been defined for consistency and if future implementations will require solving Navier-Stokes in a broader context. For our applications only a stand-alone constructor is used.

- navier_stokes_problem ()

    Default constructor that initializes stand-alone Navier-Stokes problem with automatically created grids.

- PetscErrorCode exodus (size_t i)

    Exports simulation in .vtk format format for visualization of x,y,z-componets, pressure and magnitude.

- PetscErrorCode const solve ()

    Solves the Navier-Stokes equations leveraging parabolic_problem_x, y, z, transport_problem_x, y, z, and poisson_problem classes.

- ∼navier_stokes_problem ()

Destructor to clean up allocated resources. Automatically calls sub-problems destructors. After destruction, a message is printed.

Private Member Functions

- PetscErrorCode const update_velocity (PetscReal const &theta)

  Updates the velocity field, opearating final pressure correction for CT scheme.
- PetscErrorCode const assemble_magnitude (Vec &Magnitude_Shifted, Vec const &U, Vec const &V, Vec const &W)

  Post-processing function: assembles the magnitude of velocity vectors, locating a new vector in the cell-centers.
- PetscErrorCode const compute_magnitude ()

  Final assembly of magnitude vector on cell-centers.

Private Attributes

- DM dmGrid_staggered_x

  Discretized grid for the staggered x-direction.
- DM dmGrid_staggered_y

  Discretized grid for the staggered y-direction.
- DM dmGrid_staggered_z

  Discretized grid for the staggered z-direction.
- DM dmGrid_centered

  Discretized grid for the centered formulation.
- DM dmGrid_cent_rich

  Refined centered grid for pressure computation.
- DM dmGrid_stag_transp

  Staggered grid for transport equations.
- DM dmGrid_shift_transp

  Shifted grid for transport computations.
- Vec P

  Pressure field.
- Vec P_x

  Pressure derivative in the x-direction.
- Vec P_y

  Pressure derivative in the y-direction.
- Vec P_z

  Pressure derivative in the z-direction.
- Vec Magnitude

  Magnitude of velocity vectors.
- Vec U_up
- Vec V_up
- Vec W_up

  Velocity fields in the x, y, and z directions.
- Vec mask_U
- Vec mask_V
- Vec mask_W

  Mask vectors for boundary conditions.

6.4.1 Detailed Description

Solves the Navier-Stokes evolutionary incompressible Navier-Stokes equations, applying a first order Chorin-↩ Temam algorithm. It consists of a transport problem for each velocity component, a parabolic problem for each velocity component, and a Poisson problem for the pressure. Current implementation allows Dirichlet bc's only. Boundary conditions are accessed from reference solution, which is a function of space and time. Current implementation allows for Brinkamn penalty method.

6.4.2 Constructor & Destructor Documentation

6.4.2.1 navier_stokes_problem() [1/2]

```
navier_stokes_problem::navier_stokes_problem (
            DM const & dmGrid_staggered_x,
            DM const & dmGrid_staggered_y,
            DM const & dmGrid_staggered_z,
            DM const & dmGrid_centered,
            DM const & dmGrid_cent_rich,
            DM const & dmGrid_stag_transp,
            DM const dmGrid_shift_transp,
            Vec const & U_up,
            Vec const & V_up,
            Vec const W_up )  [inline]
```

Constructor that initializes the Navier-Stokes problem with given grids and velocity fields. This costructor has been defined for consistency and if future implementations will require solving Navier-Stokes in a broader context. For our applications only a stand-alone constructor is used.

6.4.2.2 navier_stokes_problem() [2/2]

```
navier_stokes_problem::navier_stokes_problem ( )  [inline]
```

Default constructor that initializes stand-alone Navier-Stokes problem with automatically created grids.

6.4.2.3 ∼navier_stokes_problem()

```
navier_stokes_problem::∼navier_stokes_problem ( )  [inline]
```

Destructor to clean up allocated resources. Automatically calls sub-problems destructors. After destruction, a message is printed.

6.4.3 Member Function Documentation

6.4.3.1 assemble_magnitude()

```
PetscErrorCode const navier_stokes_problem::assemble_magnitude (
            Vec & Magnitude_Shifted,
            Vec const & U,
            Vec const & V,
            Vec const & W )  [private]
```

Post-processing function: assembles the magnitude of velocity vectors, locating a new vector in the cell-centers.

Parameters

Magnitude_Shifted	Output shifted magnitude vector on dmGrid_cent_rich (dofs on faces and cell=centers.)
U	Velocity component in the x-direction.
V	Velocity component in the y-direction.
W	Velocity component in the z-direction.

6.4.3.2 compute_magnitude()

```
PetscErrorCode const navier_stokes_problem::compute_magnitude ( )  [private]
```

Final assembly of magnitude vector on cell-centers.

6.4.3.3 exodus()

```
PetscErrorCode navier_stokes_problem::exodus (
             size_t i )
```

Exports simulation in .vtk format format for visualization of x,y,z-componets, pressure and magnitude.

6.4.3.4 solve()

```
PetscErrorCode const navier_stokes_problem::solve ( )
```

Solves the Navier-Stokes equations leveraging parabolic_problem_x, y, z, transport_problem_x, y, z, and poisson_problem classes.

6.4.3.5 update_velocity()

```
PetscErrorCode const navier_stokes_problem::update_velocity (
             PetscReal const & theta )  [private]
```

Updates the velocity field, opearating final pressure correction for CT scheme.

6.4.4 Member Data Documentation

6.4.4.1 dmGrid_cent_rich

```
DM navier_stokes_problem::dmGrid_cent_rich  [private]
```

Refined centered grid for pressure computation.

6.4.4.2 dmGrid_centered

```
DM navier_stokes_problem::dmGrid_centered  [private]
```

Discretized grid for the centered formulation.

6.4.4.3 dmGrid_shift_transp

```
DM navier_stokes_problem::dmGrid_shift_transp  [private]
```

Shifted grid for transport computations.

6.4.4.4 dmGrid_stag_transp

```
DM navier_stokes_problem::dmGrid_stag_transp  [private]
```

Staggered grid for transport equations.

6.4.4.5 dmGrid_staggered_x

```
DM navier_stokes_problem::dmGrid_staggered_x  [private]
```

Discretized grid for the staggered x-direction.

6.4.4.6 dmGrid_staggered_y

`DM navier_stokes_problem::dmGrid_staggered_y [private]`

Discretized grid for the staggered y-direction.

6.4.4.7 dmGrid_staggered_z

`DM navier_stokes_problem::dmGrid_staggered_z [private]`

Discretized grid for the staggered z-direction.

6.4.4.8 Magnitude

`Vec navier_stokes_problem::Magnitude [private]`

Magnitude of velocity vectors.

6.4.4.9 mask_U

`Vec navier_stokes_problem::mask_U [private]`

6.4.4.10 mask_V

`Vec navier_stokes_problem::mask_V [private]`

6.4.4.11 mask_W

`Vec navier_stokes_problem::mask_W [private]`

Mask vectors for boundary conditions.

6.4.4.12 P

`Vec navier_stokes_problem::P [private]`

Pressure field.

6.4.4.13 P_x

`Vec navier_stokes_problem::P_x [private]`

Pressure derivative in the x-direction.

6.4.4.14 P_y

`Vec navier_stokes_problem::P_y [private]`

Pressure derivative in the y-direction.

6.4.4.15 P_z

`Vec navier_stokes_problem::P_z [private]`

Pressure derivative in the z-direction.

6.4.4.16 U_up

```
Vec navier_stokes_problem::U_up [private]
```

6.4.4.17 V_up

```
Vec navier_stokes_problem::V_up [private]
```

6.4.4.18 W_up

```
Vec navier_stokes_problem::W_up [private]
```

Velocity fields in the x, y, and z directions.

The documentation for this class was generated from the following files:

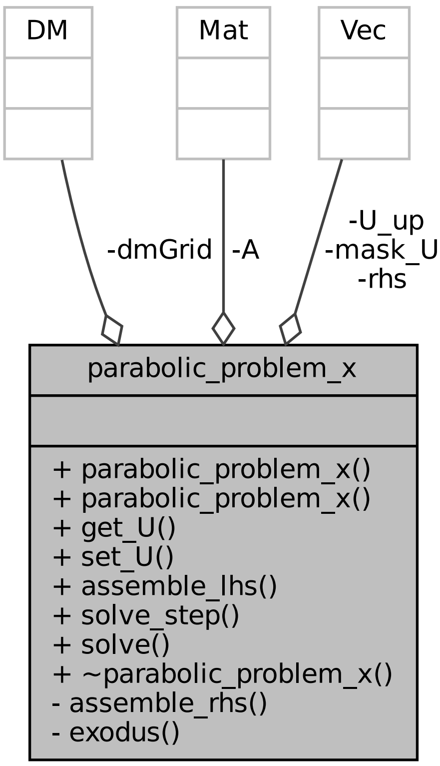
- include/navier_stokes.hpp
- src/navier_stokes.cpp

6.5 parabolic_problem_x Class Reference

Represents a parabolic problem in the x-direction.

```
#include <parabolic.hpp>
```

Collaboration diagram for parabolic_problem_x:



Public Member Functions

- parabolic_problem_x (DM const &dmGrid)

    Constructor that initializes the problem with a given grid. Use when parabolic problem is just a step of a bigger problem, like in Chorin-Temam method.
- parabolic_problem_x ()

    Default constructor for stand-alone problem.
- Vec get_U ()
- void set_U (Vec const &U)
- PetscErrorCode assemble_lhs ()

    Assembles the left-hand side (LHS) matrix.
- PetscErrorCode solve_step (PetscReal const &theta, std::optional< std::reference_wrapper< Vec >> U_↩ up_opt=std::nullopt)

    Performs a single time step of the numerical solution.
- PetscErrorCode solve ()

    Solves the entire parabolic problem in the x-direction.
- ∼parabolic_problem_x ()

    Destructor to clean up allocated resources. Fundamental in PETSc implementation lo avoid leaks and unexpected RAM overhead.

Private Member Functions

- const PetscErrorCode assemble_rhs (PetscReal const &theta, Vec const &U_up)

    Assembles the right-hand side (RHS) vector.
- PetscErrorCode exodus (size_t const &i)

    Exports results in .vtk format for post-processing.

Private Attributes

- DM dmGrid

    Discretized grid for the problem.
- Mat A

    Matrix representing the left-hand side of the system.
- Vec rhs

    Right-hand side vector.
- Vec U_up

    Solution vector for the x-direction. If not provided, it must be passed as reference in solve_step(...)
- Vec mask_U

    Mask vector used for Brinkman flow.

6.5.1 Detailed Description

Represents a parabolic problem in the x-direction.
This class solves a generic evolutionary diffusive problem in the x-direction with fully Dirichlet bc's. Boundary conditions are imposed by means of a reference solution. Discretization is performed on a staggered grid and in x-direction only, meaning that variables are located in position LEFT and RIGHT. Linear problem is solved by means of a PETSc KSP solver, with GMRES and Jacobi preconditioner.

6.5.2 Constructor & Destructor Documentation

6.5.2.1 parabolic_problem_x() [1/2]

```
parabolic_problem_x::parabolic_problem_x (
            DM const & dmGrid )  [inline]
```

Constructor that initializes the problem with a given grid. Use when parabolic problem is just a step of a bigger problem, like in Chorin-Temam method.

Parameters

dmGrid	staggered grid petsc-object must be already be defined.

6.5.2.2 parabolic_problem_x() [2/2]

```
parabolic_problem_x::parabolic_problem_x ( )  [inline]
```

Default constructor for stand-alone problem.

6.5.2.3 ∼parabolic_problem_x()

```
parabolic_problem_x::~parabolic_problem_x ( )  [inline]
```

Destructor to clean up allocated resources. Fundamental in PETSc implementation lo avoid leaks and unexpected RAM overhead.

6.5.3 Member Function Documentation

6.5.3.1 assemble_lhs()

```
PetscErrorCode parabolic_problem_x::assemble_lhs ( )
```

Assembles the left-hand side (LHS) matrix.

6.5.3.2 assemble_rhs()

```
const PetscErrorCode parabolic_problem_x::assemble_rhs (
            PetscReal const & theta,
            Vec const & U_up )  [private]
```

Assembles the right-hand side (RHS) vector.

6.5.3.3 exodus()

```
PetscErrorCode parabolic_problem_x::exodus (
            size_t const & i )  [private]
```

Exports results in .vtk format for post-processing.

6.5.3.4 get_U()

```
Vec parabolic_problem_x::get_U ( )
```

6.5.3.5 set_U()

```
void parabolic_problem_x::set_U (
            Vec const & U )
```

6.5.3.6 solve()

```
PetscErrorCode parabolic_problem_x::solve ( )
```

Solves the entire parabolic problem in the x-direction.

6.5.3.7 solve_step()

```
PetscErrorCode parabolic_problem_x::solve_step (
            PetscReal const & theta,
            std::optional< std::reference_wrapper< Vec >> U_up_opt = std::nullopt )
```

Performs a single time step of the numerical solution.

6.5.4 Member Data Documentation

6.5.4.1 A

```
Mat parabolic_problem_x::A [private]
```

Matrix representing the left-hand side of the system.

6.5.4.2 dmGrid

```
DM parabolic_problem_x::dmGrid [private]
```

Discretized grid for the problem.

6.5.4.3 mask_U

```
Vec parabolic_problem_x::mask_U [private]
```

Mask vector used for Brinkman flow.

6.5.4.4 rhs

```
Vec parabolic_problem_x::rhs [private]
```

Right-hand side vector.

6.5.4.5 U_up

```
Vec parabolic_problem_x::U_up [private]
```

Solution vector for the x-direction. If not provided, it must be passed as reference in solve_step(...)
The documentation for this class was generated from the following files:

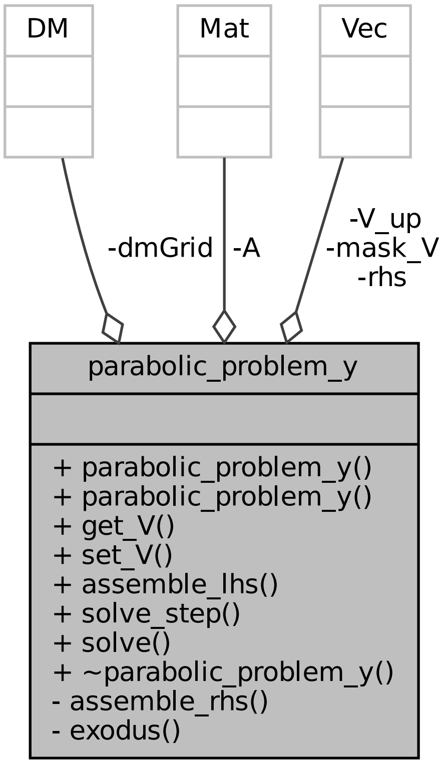
- include/parabolic.hpp
- src/parabolic.cpp

6.6 parabolic_problem_y Class Reference

Represents a parabolic problem in the y-direction.

```
#include <parabolic.hpp>
```

Collaboration diagram for parabolic_problem_y:



Public Member Functions

- parabolic_problem_y (DM const &dmGrid)

    Constructor that initializes the problem with a given grid. Use when parabolic problem is just a step of a bigger problem, like in Chorin-Temam method.
- parabolic_problem_y ()

    Default constructor for stand-alone problem.
- Vec get_V ()
- void set_V (Vec const &V)
- PetscErrorCode assemble_lhs ()

    Assembles the left-hand side (LHS) matrix.
- PetscErrorCode solve_step (PetscReal const &theta, std::optional< std::reference_wrapper< Vec >> V_↩ up_opt=std::nullopt)

    Performs a single time step of the numerical solution.
- PetscErrorCode solve ()

    Solves the entire parabolic problem in the Y-direction.
- ∼parabolic_problem_y ()

    Destructor to clean up allocated resources. Fundamental in PETSc implementation lo avoid leaks and unexpected RAM overhead.

Private Member Functions

- const PetscErrorCode assemble_rhs (PetscReal const &theta, Vec const &V_up)

  Assembles the right-hand side (RHS) vector.
- PetscErrorCode exodus (size_t const &i)

  Exports results in .vtk format for post-processing.

Private Attributes

- DM dmGrid

  Discretized grid for the problem.
- Mat A

  Matrix representing the left-hand side of the system.
- Vec rhs

  Right-hand side vector.
- Vec V_up

  Solution vector for the y-direction. If not provided, it must be passed as reference in solve_step(...)
- Vec mask_V

  Mask vector used for Brinkman flow.

6.6.1 Detailed Description

Represents a parabolic problem in the y-direction.
This class solves a generic evolutionary diffusive problem in the y-direction with fully Dirichlet bc's. Boundary conditions are imposed by means of a reference solution. Discretization is performed on a staggered grid and in x-direction only, meaning that variables are located in position DOWN and UP. Linear problem is solved by means of a PETSc KSP solver, with GMRES and Jacobi preconditioner.

6.6.2 Constructor & Destructor Documentation

6.6.2.1 parabolic_problem_y() [1/2]

```
parabolic_problem_y::parabolic_problem_y (
            DM const & dmGrid )  [inline]
```

Constructor that initializes the problem with a given grid. Use when parabolic problem is just a step of a bigger problem, like in Chorin-Temam method.

Parameters

dmGrid	staggered grid petsc-object must be already be defined.

6.6.2.2 parabolic_problem_y() [2/2]

```
parabolic_problem_y::parabolic_problem_y ( )  [inline]
```

Default constructor for stand-alone problem.

6.6.2.3 ∼parabolic_problem_y()

```
parabolic_problem_y::~parabolic_problem_y ( )  [inline]
```

Destructor to clean up allocated resources. Fundamental in PETSc implementation lo avoid leaks and unexpected RAM overhead.

6.6.3 Member Function Documentation

6.6.3.1 assemble_lhs()

```
PetscErrorCode parabolic_problem_y::assemble_lhs ( )
```
Assembles the left-hand side (LHS) matrix.

6.6.3.2 assemble_rhs()

```
const PetscErrorCode parabolic_problem_y::assemble_rhs (
            PetscReal const & theta,
            Vec const & V_up )  [private]
```
Assembles the right-hand side (RHS) vector.

6.6.3.3 exodus()

```
PetscErrorCode parabolic_problem_y::exodus (
            size_t const & i )  [private]
```
Exports results in .vtk format for post-processing.

6.6.3.4 get_V()

```
Vec parabolic_problem_y::get_V ( )
```

6.6.3.5 set_V()

```
void parabolic_problem_y::set_V (
            Vec const & V )
```

6.6.3.6 solve()

```
PetscErrorCode parabolic_problem_y::solve ( )
```
Solves the entire parabolic problem in the Y-direction.

6.6.3.7 solve_step()

```
PetscErrorCode parabolic_problem_y::solve_step (
            PetscReal const & theta,
            std::optional< std::reference_wrapper< Vec >> V_up_opt = std::nullopt )
```
Performs a single time step of the numerical solution.

6.6.4 Member Data Documentation

6.6.4.1 A

```
Mat parabolic_problem_y::A  [private]
```
Matrix representing the left-hand side of the system.

6.6.4.2 dmGrid

`DM parabolic_problem_y::dmGrid [private]`

Discretized grid for the problem.

6.6.4.3 mask_V

`Vec parabolic_problem_y::mask_V [private]`

Mask vector used for Brinkman flow.

6.6.4.4 rhs

`Vec parabolic_problem_y::rhs [private]`

Right-hand side vector.

6.6.4.5 V_up

`Vec parabolic_problem_y::V_up [private]`

Solution vector for the y-direction. If not provided, it must be passed as reference in solve_step(...)

The documentation for this class was generated from the following files:

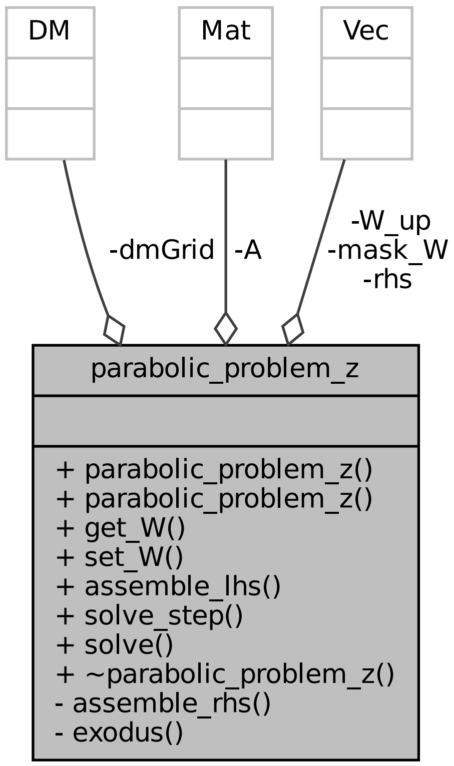
- include/parabolic.hpp
- src/parabolic.cpp

6.7 parabolic_problem_z Class Reference

Represents a parabolic problem in the z-direction.

`#include <parabolic.hpp>`

Collaboration diagram for parabolic_problem_z:



Public Member Functions

- parabolic_problem_z (DM const &dmGrid)

    Constructor that initializes the problem with a given grid. Use when parabolic problem is just a step of a bigger problem, like in Chorin-Temam method.
- parabolic_problem_z ()

    Default constructor for stand-alone problem.
- Vec get_W ()
- void set_W (Vec const &W)
- PetscErrorCode assemble_lhs ()

    Assembles the left-hand side (LHS) matrix.
- PetscErrorCode solve_step (PetscReal const &theta, std::optional< std::reference_wrapper< Vec >> W_up_opt=std::nullopt)

    Performs a single time step of the numerical solution.
- PetscErrorCode solve ()

    Solves the entire parabolic problem in the Z-direction.
- ∼parabolic_problem_z ()

    Destructor to clean up allocated resources. Fundamental in PETSc implementation lo avoid leaks and unexpected RAM overhead.

Private Member Functions

- PetscErrorCode const assemble_rhs (PetscReal const &theta, Vec const &W_up)

    Assembles the right-hand side (RHS) vector.
- PetscErrorCode exodus (size_t const &i)

    Exports results in .vtk format for post-processing.

Private Attributes

- DM dmGrid

    Discretized grid for the problem.
- Mat A

    Matrix representing the left-hand side of the system.
- Vec rhs

    Right-hand side vector.
- Vec W_up

    Solution vector for the x-direction. If not provided, it must be passed as reference in solve_step(...)
- Vec mask_W

    Mask vector used for Brinkman flow.

6.7.1 Detailed Description

Represents a parabolic problem in the z-direction.
This class solves a generic evolutionary diffusive problem in the z-direction with fully Dirichlet bc's. Boundary conditions are imposed by means of a reference solution. Discretization is performed on a staggered grid and in x-direction only, meaning that variables are located in position BACK and FRONT. Linear problem is solved by means of a PETSc KSP solver, with GMRES and Jacobi preconditioner.

6.7.2 Constructor & Destructor Documentation

6.7.2.1 parabolic_problem_z() [1/2]

```
parabolic_problem_z::parabolic_problem_z (
            DM const & dmGrid )  [inline]
```

Constructor that initializes the problem with a given grid. Use when parabolic problem is just a step of a bigger problem, like in Chorin-Temam method.

Parameters

dmGrid	staggered grid petsc-object must be already be defined.

6.7.2.2 parabolic_problem_z() [2/2]

```
parabolic_problem_z::parabolic_problem_z ( )  [inline]
```

Default constructor for stand-alone problem.

6.7.2.3 ∼parabolic_problem_z()

```
parabolic_problem_z::~parabolic_problem_z ( )  [inline]
```

Destructor to clean up allocated resources. Fundamental in PETSc implementation lo avoid leaks and unexpected RAM overhead.

6.7.3 Member Function Documentation

6.7.3.1 assemble_lhs()

```
PetscErrorCode parabolic_problem_z::assemble_lhs ( )
```
Assembles the left-hand side (LHS) matrix.

6.7.3.2 assemble_rhs()

```
PetscErrorCode const parabolic_problem_z::assemble_rhs (
             PetscReal const & theta,
             Vec const & W_up )  [private]
```
Assembles the right-hand side (RHS) vector.

6.7.3.3 exodus()

```
PetscErrorCode parabolic_problem_z::exodus (
             size_t const & i )  [private]
```
Exports results in .vtk format for post-processing.

6.7.3.4 get_W()

```
Vec parabolic_problem_z::get_W ( )
```

6.7.3.5 set_W()

```
void parabolic_problem_z::set_W (
             Vec const & W )
```

6.7.3.6 solve()

```
PetscErrorCode parabolic_problem_z::solve ( )
```
Solves the entire parabolic problem in the Z-direction.

6.7.3.7 solve_step()

```
PetscErrorCode parabolic_problem_z::solve_step (
             PetscReal const & theta,
             std::optional< std::reference_wrapper< Vec >> W_up_opt = std::nullopt )
```
Performs a single time step of the numerical solution.

6.7.4 Member Data Documentation

6.7.4.1 A

```
Mat parabolic_problem_z::A  [private]
```
Matrix representing the left-hand side of the system.

6.7.4.2 dmGrid

`DM parabolic_problem_z::dmGrid [private]`

Discretized grid for the problem.

6.7.4.3 mask_W

`Vec parabolic_problem_z::mask_W [private]`

Mask vector used for Brinkman flow.

6.7.4.4 rhs

`Vec parabolic_problem_z::rhs [private]`

Right-hand side vector.

6.7.4.5 W_up

`Vec parabolic_problem_z::W_up [private]`

Solution vector for the x-direction. If not provided, it must be passed as reference in solve_step(...)

The documentation for this class was generated from the following files:

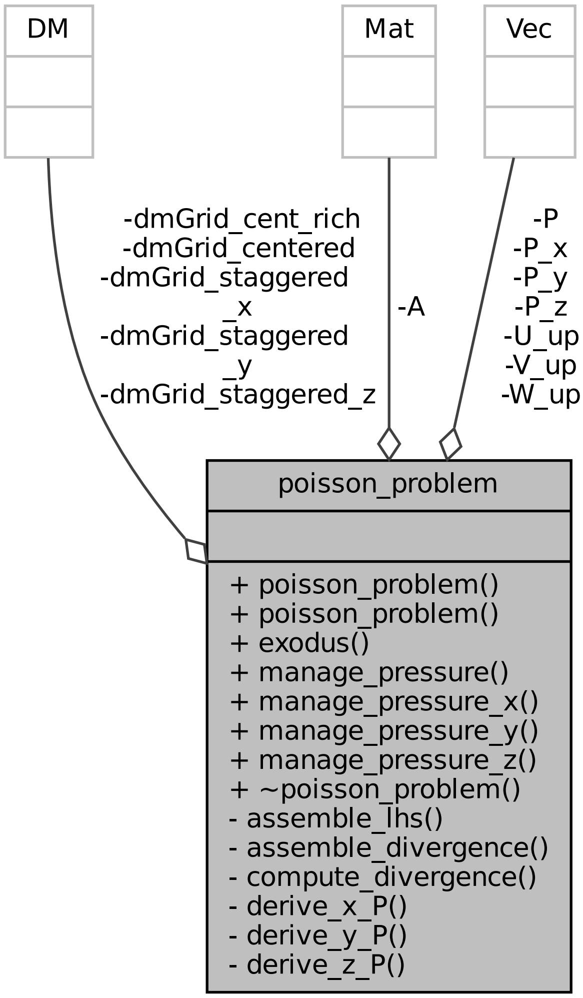
- include/parabolic.hpp
- src/parabolic.cpp

6.8 poisson_problem Class Reference

Represents a Poisson equation solver for pressure correction in fluid simulations.

`#include <poisson.hpp>`

Collaboration diagram for poisson_problem:



Public Member Functions

- poisson_problem (DM const &dmGrid_staggered_x, DM const &dmGrid_staggered_y, DM const &dmGrid_staggered_z, DM const &dmGrid_centered, DM const &dmGrid_cent_rich)

    Constructor to initialize the Poisson problem with pre-allocated grids.
- poisson_problem ()
- PetscErrorCode const exodus (size_t i)

    Exports simulation results in .vtk format for visualization.
- PetscErrorCode const manage_pressure (std::optional< std::reference_wrapper< Vec >> U_opt=std::nullopt, std::optional< std::reference_wrapper< Vec >> V_up_opt=std::nullopt, std::optional< std::reference_wrapper< Vec >> W_up_opt=std::nullopt, std::optional< std::reference_wrapper< Vec >> P_opt=std::nullopt)

    Solves the elliptic Poisson equation with GMRES and multigrid preconditioner.
- PetscErrorCode const manage_pressure_x (std::optional< std::reference_wrapper< Vec >> P_opt=std::nullopt, std::optional< std::reference_wrapper< Vec >> P_x_opt=std::nullopt)

    Assembles the pressure derivative in the x-direction on the staggered grid.

- PetscErrorCode const manage_pressure_y (std::optional< std::reference_wrapper< Vec >> P_opt=std↩ ::nullopt, std::optional< std::reference_wrapper< Vec >> P_y_opt=std::nullopt)

  Assembles the pressure derivative in the y-direction on the staggered grid.
- PetscErrorCode const manage_pressure_z (std::optional< std::reference_wrapper< Vec >> P_opt=std↩ ::nullopt, std::optional< std::reference_wrapper< Vec >> P_z_opt=std::nullopt)

  Assembles the pressure derivative in the z-direction on the staggered grid.
- ∼poisson_problem ()

  Destructor to clean up allocated resources. required by PETSc management of native objects.

Private Member Functions

- PetscErrorCode const assemble_lhs ()

  Assembles the left-hand side (LHS) matrix for the Poisson problem.
- PetscErrorCode const assemble_divergence (Vec &div, Vec const &U, Vec const &V, Vec const &W)

  Computes the divergence term for velocity fields and outputs on dmGrid_centered_rich grid.
- PetscErrorCode const compute_divergence (Vec &div, Vec const &U_n, Vec const &V_n, Vec const &W_n)

  Assemble routines for a previously found divergence of the given velocity field and migrates it on the correct dm↩ Grid_centered grid.
- PetscErrorCode const derive_x_P (Vec &P_x_shifted, Vec const &vec)

  Computes the derivative of the pressure field in the x-direction and outputes on dmGrid_centered_rich grid.
- PetscErrorCode const derive_y_P (Vec &P_y_shifted, Vec const &vec)

  Computes the derivative of the pressure field in the y-direction and outputes on dmGrid_centered_rich grid.
- PetscErrorCode const derive_z_P (Vec &P_z_shifted, Vec const &vec)

  Computes the derivative of the pressure field in the z-direction and outputes on dmGrid_centered_rich grid.

Private Attributes

- DM dmGrid_staggered_x

  Discretized grid for staggered x-direction.
- DM dmGrid_staggered_y

  Discretized grid for staggered y-direction.
- DM dmGrid_staggered_z

  Discretized grid for staggered z-direction.
- DM dmGrid_centered

  Discretized grid for centered formulation.
- DM dmGrid_cent_rich

  Refined centered grid for pressure computation.
- Vec P

  Pressure field.
- Vec P_x

  Pressure derivative in x-direction.
- Vec P_y

  Pressure derivative in y-direction.
- Vec P_z

  Pressure derivative in z-direction.
- Vec U_up

  Velocity component in the x-direction.
- Vec V_up

  Velocity component in the y-direction.
- Vec W_up

  Velocity component in the z-direction.
- Mat A

  Matrix for the discretized Poisson equation.

6.8.1 Detailed Description

Represents a Poisson equation solver for pressure correction in fluid simulations.
This class solves the Poisson equation for a variabble like pressure, with homogeneous Neumann boundary conditions. It manages the assembly of matrices, calculation of divergence. In our framework, it is used to solve the pressure correction in the Navier-Stokes equations. For our purposes, enforcing compatibility condition was not required. Beware that for a stand-alone problem, compatible-to-null-bc's source must be provided.

6.8.2 Constructor & Destructor Documentation

6.8.2.1 poisson_problem() [1/2]

```
poisson_problem::poisson_problem (
            DM const & dmGrid_staggered_x,
            DM const & dmGrid_staggered_y,
            DM const & dmGrid_staggered_z,
            DM const & dmGrid_centered,
            DM const & dmGrid_cent_rich )  [inline]
```

Constructor to initialize the Poisson problem with pre-allocated grids.

Parameters

dmGrid_staggered←_x	Grid for staggered x-direction.
dmGrid_staggered←_y	Grid for staggered y-direction.
dmGrid_staggered←_z	Grid for staggered z-direction.
dmGrid_centered	Grid for centered formulation.
dmGrid_cent_rich	Grid for refined pressure computation.

6.8.2.2 poisson_problem() [2/2]

```
poisson_problem::poisson_problem ( )  [inline]
```

6.8.2.3 ∼poisson_problem()

```
poisson_problem::∼poisson_problem ( )  [inline]
```

Destructor to clean up allocated resources. required by PETSc management of native objects.

6.8.3 Member Function Documentation

6.8.3.1 assemble_divergence()

```
PetscErrorCode const poisson_problem::assemble_divergence (
            Vec & div,
            Vec const & U,
            Vec const & V,
            Vec const & W )  [private]
```

Computes the divergence term for velocity fields and outputs on dmGrid_centered_rich grid.

Parameters

div	Output divergence vector.
U	Velocity component in the x-direction.
V	Velocity component in the y-direction.
W	Velocity component in the z-direction.

6.8.3.2 assemble_lhs()

```
PetscErrorCode const poisson_problem::assemble_lhs ( )  [private]
```

Assembles the left-hand side (LHS) matrix for the Poisson problem.

6.8.3.3 compute_divergence()

```
PetscErrorCode const poisson_problem::compute_divergence (
            Vec & div,
            Vec const & U_n,
            Vec const & V_n,
            Vec const & W_n )  [private]
```

Assemble routines for a previously found divergence of the given velocity field and migrates it on the correct dm↩
Grid_centered grid.

Parameters

div	Output divergence vector.
U	Velocity component in the x-direction.
V	Velocity component in the y-direction.
W	Velocity component in the z-direction.

6.8.3.4 derive_x_P()

```
PetscErrorCode const poisson_problem::derive_x_P (
            Vec & P_x_shifted,
            Vec const & vec )  [private]
```

Computes the derivative of the pressure field in the x-direction and outputes on dmGrid_centered_rich grid.

Parameters

P_x_shifted	Output shifted pressure derivative.
vec	Input pressure field.

6.8.3.5 derive_y_P()

```
PetscErrorCode const poisson_problem::derive_y_P (
            Vec & P_y_shifted,
            Vec const & vec )  [private]
```

Computes the derivative of the pressure field in the y-direction and outputes on dmGrid_centered_rich grid.

Parameters

P_y_shifted	Output shifted pressure derivative.
vec	Input pressure field.

6.8.3.6 derive_z_P()

```
PetscErrorCode const poisson_problem::derive_z_P (
            Vec & P_z_shifted,
            Vec const & vec )  [private]
```

Computes the derivative of the pressure field in the z-direction and outputes on dmGrid_centered_rich grid.

Parameters

P_z_shifted	Output shifted pressure derivative.
vec	Input vector.

6.8.3.7 exodus()

```
PetscErrorCode const poisson_problem::exodus (
            size_t i )
```

Exports simulation results in .vtk format for visualization.

6.8.3.8 manage_pressure()

```
PetscErrorCode const poisson_problem::manage_pressure (
            std::optional< std::reference_wrapper< Vec >> U_opt = std::nullopt,
            std::optional< std::reference_wrapper< Vec >> V_up_opt = std::nullopt,
            std::optional< std::reference_wrapper< Vec >> W_up_opt = std::nullopt,
            std::optional< std::reference_wrapper< Vec >> P_opt = std::nullopt )
```

Solves the elliptic Poisson equation with GMRES and multigrid preconditioner.

Parameters

U_up	Velocity field in the x-direction.
V_up	Velocity field in the y-direction.
W_up	Velocity field in the z-direction.
P	Pressure field.

6.8.3.9 manage_pressure_x()

```
PetscErrorCode const poisson_problem::manage_pressure_x (
            std::optional< std::reference_wrapper< Vec >> P_opt = std::nullopt,
            std::optional< std::reference_wrapper< Vec >> P_x_opt = std::nullopt )
```

Assembles the pressure derivative in the x-direction on the staggered grid.

Parameters

P	Pressure field.
P_x	Updated pressure derivative in the x-direction.

6.8.3.10 manage_pressure_y()

```
PetscErrorCode const poisson_problem::manage_pressure_y (
            std::optional< std::reference_wrapper< Vec >> P_opt = std::nullopt,
            std::optional< std::reference_wrapper< Vec >> P_y_opt = std::nullopt )
```

Assembles the pressure derivative in the y-direction on the staggered grid.

Parameters

P	Pressure field.
P_y	Updated pressure derivative in the y-direction.

6.8.3.11 manage_pressure_z()

```
PetscErrorCode const poisson_problem::manage_pressure_z (
            std::optional< std::reference_wrapper< Vec >> P_opt = std::nullopt,
            std::optional< std::reference_wrapper< Vec >> P_z_opt = std::nullopt )
```

Assembles the pressure derivative in the z-direction on the staggered grid.

Parameters

P	Pressure field.
P_z	Updated pressure derivative in the z-direction.

6.8.4 Member Data Documentation

6.8.4.1 A

`Mat poisson_problem::A [private]`

Matrix for the discretized Poisson equation.

6.8.4.2 dmGrid_cent_rich

`DM poisson_problem::dmGrid_cent_rich [private]`

Refined centered grid for pressure computation.

6.8.4.3 dmGrid_centered

`DM poisson_problem::dmGrid_centered [private]`

Discretized grid for centered formulation.

6.8.4.4 dmGrid_staggered_x

`DM poisson_problem::dmGrid_staggered_x [private]`

Discretized grid for staggered x-direction.

6.8.4.5 dmGrid_staggered_y

`DM poisson_problem::dmGrid_staggered_y [private]`

Discretized grid for staggered y-direction.

6.8.4.6 dmGrid_staggered_z

`DM poisson_problem::dmGrid_staggered_z [private]`

Discretized grid for staggered z-direction.

6.8.4.7 P

`Vec poisson_problem::P [private]`

Pressure field.

6.8.4.8 P_x

`Vec poisson_problem::P_x [private]`

Pressure derivative in x-direction.

6.8.4.9 P_y

`Vec poisson_problem::P_y [private]`

Pressure derivative in y-direction.

6.8.4.10 P_z

`Vec poisson_problem::P_z [private]`

Pressure derivative in z-direction.

6.8.4.11 U_up

`Vec poisson_problem::U_up [private]`

Velocity component in the x-direction.

6.8.4.12 V_up

`Vec poisson_problem::V_up [private]`

Velocity component in the y-direction.

6.8.4.13 W_up

`Vec poisson_problem::W_up [private]`

Velocity component in the z-direction.

The documentation for this class was generated from the following files:

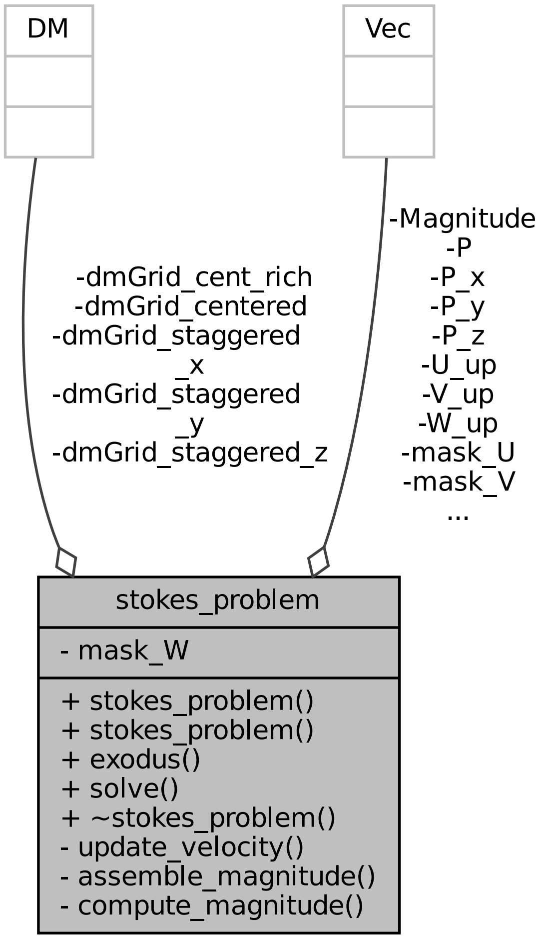
- include/poisson.hpp
- src/poisson.cpp

6.9 stokes_problem Class Reference

Solves the Stokes evolutionary incompressible Stokes equations, applying a first order Chorin-Temam algorithm. It consists of a parabolic problem for each velocity component, and a Poisson problem for the pressure. Current implementation allows Dirichlet bc's only. Boundary conditions are accessed from reference solution, which is a function of space and time. Current implementation allows for Brinkamn penalty method.

`#include <stokes.hpp>`

Collaboration diagram for stokes_problem:



Public Member Functions

- stokes_problem (DM const &dmGrid_staggered_x, DM const &dmGrid_staggered_y, DM const &dmGrid_staggered_z, DM const &dmGrid_centered, DM const &dmGrid_cent_rich, Vec const &U_up, Vec const &V_up, Vec const W_up)

  Constructor that initializes the Stokes problem with given grids and velocity fields. This costructor has been defined for consistency and if future implementations will require solving Stokes in a broader context. For our applications only a stand-alone constructor is used.

- stokes_problem ()

  Default constructor that initializes stand-alone Stokes problem with automatically created grids.

- PetscErrorCode exodus (size_t i)

Exports simulation in .vtk format format for visualization of x,y,z-componets, pressure and magnitude.
- PetscErrorCode const solve ()

  Solves the Stokes equations leveraging parabolic_problem_x, y, z, transport_problem_x, y, z, and poisson_problem classes.
- ∼stokes_problem ()

  Destructor to clean up allocated resources. Automatically calls sub-problems destructors. After destruction, a message is printed.

Private Member Functions

- PetscErrorCode const update_velocity (PetscReal const &theta)

  Updates the velocity field, opearating final pressure correction for CT scheme.
- PetscErrorCode const assemble_magnitude (Vec &Magnitude_Shifted, Vec const &U, Vec const &V, Vec const &W)

  Post-processing function: assembles the magnitude of velocity vectors, locating a new vector in the cell-centers.
- PetscErrorCode const compute_magnitude ()

  Final assembly of magnitude vector on cell-centers.

Private Attributes

- DM dmGrid_staggered_x

  Discretized grid for the staggered x-direction.
- DM dmGrid_staggered_y

  Discretized grid for the staggered y-direction.
- DM dmGrid_staggered_z

  Discretized grid for the staggered z-direction.
- DM dmGrid_centered

  Discretized grid for the centered formulation.
- DM dmGrid_cent_rich

  Refined centered grid for pressure computation.
- Vec P

  Pressure field.
- Vec P_x

  Pressure derivative in the x-direction.
- Vec P_y

  Pressure derivative in the y-direction.
- Vec P_z

  Pressure derivative in the z-direction.
- Vec Magnitude

  Magnitude of velocity vectors.
- Vec U_up
- Vec V_up
- Vec W_up

  Velocity fields in the x, y, and z directions.
- Vec mask_U
- Vec mask_V
- Vec mask_W

  Mask vectors for boundary conditions.

6.9.1 Detailed Description

Solves the Stokes evolutionary incompressible Stokes equations, applying a first order Chorin-Temam algorithm. It consists of a parabolic problem for each velocity component, and a Poisson problem for the pressure. Current implementation allows Dirichlet bc's only. Boundary conditions are accessed from reference solution, which is a function of space and time. Current implementation allows for Brinkamn penalty method.

6.9.2 Constructor & Destructor Documentation

6.9.2.1 stokes_problem() [1/2]

```
stokes_problem::stokes_problem (
            DM const & dmGrid_staggered_x,
            DM const & dmGrid_staggered_y,
            DM const & dmGrid_staggered_z,
            DM const & dmGrid_centered,
            DM const & dmGrid_cent_rich,
            Vec const & U_up,
            Vec const & V_up,
            Vec const W_up )  [inline]
```

Constructor that initializes the Stokes problem with given grids and velocity fields. This costructor has been defined for consistency and if future implementations will require solving Stokes in a broader context. For our applications only a stand-alone constructor is used.

6.9.2.2 stokes_problem() [2/2]

```
stokes_problem::stokes_problem ( )  [inline]
```

Default constructor that initializes stand-alone Stokes problem with automatically created grids.

6.9.2.3 ∼stokes_problem()

```
stokes_problem::∼stokes_problem ( )  [inline]
```

Destructor to clean up allocated resources. Automatically calls sub-problems destructors. After destruction, a message is printed.

6.9.3 Member Function Documentation

6.9.3.1 assemble_magnitude()

```
PetscErrorCode const stokes_problem::assemble_magnitude (
            Vec & Magnitude_Shifted,
            Vec const & U,
            Vec const & V,
            Vec const & W )  [private]
```

Post-processing function: assembles the magnitude of velocity vectors, locating a new vector in the cell-centers.

Parameters

Magnitude_Shifted	Output shifted magnitude vector on dmGrid_cent_rich (dofs on faces and cell=centers.)
U	Velocity component in the x-direction.
V	Velocity component in the y-direction.
W	Velocity component in the z-direction.

6.9.3.2 compute_magnitude()

```
PetscErrorCode const stokes_problem::compute_magnitude ( )  [private]
```

Final assembly of magnitude vector on cell-centers.

6.9.3.3 exodus()

```
PetscErrorCode stokes_problem::exodus (
            size_t i )
```

Exports simulation in .vtk format format for visualization of x,y,z-componets, pressure and magnitude.

6.9.3.4 solve()

```
PetscErrorCode const stokes_problem::solve ( )
```

Solves the Stokes equations leveraging parabolic_problem_x, y, z, transport_problem_x, y, z, and poisson_problem classes.

6.9.3.5 update_velocity()

```
PetscErrorCode const stokes_problem::update_velocity (
            PetscReal const & theta )  [private]
```

Updates the velocity field, opearating final pressure correction for CT scheme.

6.9.4 Member Data Documentation

6.9.4.1 dmGrid_cent_rich

```
DM stokes_problem::dmGrid_cent_rich  [private]
```

Refined centered grid for pressure computation.

6.9.4.2 dmGrid_centered

```
DM stokes_problem::dmGrid_centered  [private]
```

Discretized grid for the centered formulation.

6.9.4.3 dmGrid_staggered_x

```
DM stokes_problem::dmGrid_staggered_x  [private]
```

Discretized grid for the staggered x-direction.

6.9.4.4 dmGrid_staggered_y

```
DM stokes_problem::dmGrid_staggered_y  [private]
```

Discretized grid for the staggered y-direction.

6.9.4.5 dmGrid_staggered_z

```
DM stokes_problem::dmGrid_staggered_z  [private]
```

Discretized grid for the staggered z-direction.

6.9.4.6 Magnitude

```
Vec stokes_problem::Magnitude  [private]
```

Magnitude of velocity vectors.

6.9.4.7 mask_U

`Vec stokes_problem::mask_U [private]`

6.9.4.8 mask_V

`Vec stokes_problem::mask_V [private]`

6.9.4.9 mask_W

`Vec stokes_problem::mask_W [private]`

Mask vectors for boundary conditions.

6.9.4.10 P

`Vec stokes_problem::P [private]`

Pressure field.

6.9.4.11 P_x

`Vec stokes_problem::P_x [private]`

Pressure derivative in the x-direction.

6.9.4.12 P_y

`Vec stokes_problem::P_y [private]`

Pressure derivative in the y-direction.

6.9.4.13 P_z

`Vec stokes_problem::P_z [private]`

Pressure derivative in the z-direction.

6.9.4.14 U_up

`Vec stokes_problem::U_up [private]`

6.9.4.15 V_up

`Vec stokes_problem::V_up [private]`

6.9.4.16 W_up

`Vec stokes_problem::W_up [private]`

Velocity fields in the x, y, and z directions.

The documentation for this class was generated from the following files:

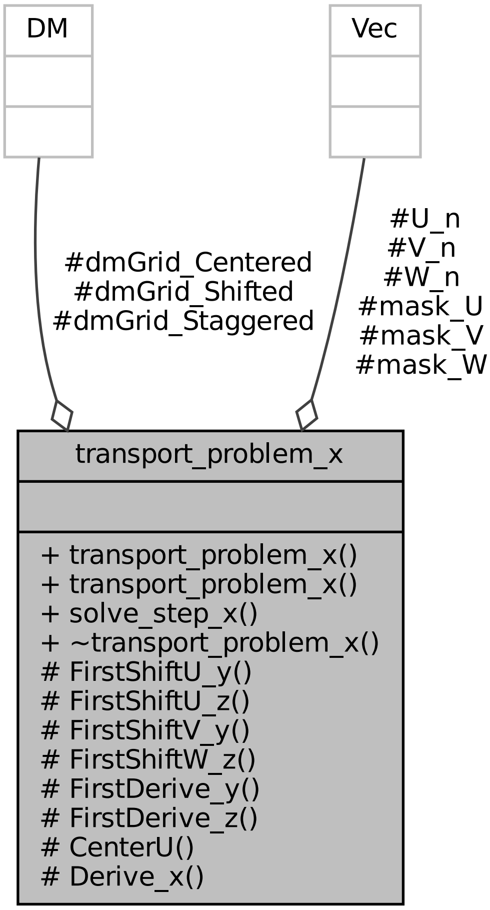
- include/stokes.hpp
- src/stokes.cpp

6.10 transport_problem_x Class Reference

Represents a transport problem in the x-direction.

`#include <transport.hpp>`

Collaboration diagram for transport_problem_x:



Public Member Functions

- transport_problem_x (DM const &dmGrid_Shifted, DM const &dmGrid_Staggered, DM const &dmGrid_Centered)

    Constructor initializing the transport problem with given grids.
- transport_problem_x ()

    Default constructor for stand-alone transport problem.
- PetscErrorCode const solve_step_x (PetscScalar const &theta, std::optional< std::reference_wrapper< Vec >> U_n_opt=std::nullopt, std::optional< std::reference_wrapper< Vec >> V_n_opt=std::nullopt, std↩ ::optional< std::reference_wrapper< Vec >> W_n_opt=std::nullopt)

    Performs a single time step for solving the transport equation.
- ~transport_problem_x ()

    Destructor to clean up allocated resources.

Protected Member Functions

- PetscErrorCode FirstShiftU_y (Vec &UShifted, Vec const &vec, PetscScalar const &theta)

  Performs the shift for x-component in a 3D transport non-linear problem in the y-direction. Interpolates velocity component on edges.
- PetscErrorCode FirstShiftU_z (Vec &UShifted, Vec const &vec, PetscScalar const &theta)

  Performs the shift for x-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.
- PetscErrorCode FirstShiftV_y (Vec &VShifted, Vec const &vec, PetscScalar const &theta)

  Performs the shift for y-component in a 3D transport non-linear problem in the y-direction. Interpolates velocity component on edges.
- PetscErrorCode FirstShiftW_z (Vec &WShifted, Vec const &vec, PetscScalar const &theta)

  Performs the shift for z-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.
- PetscErrorCode FirstDerive_y (Vec &AB_y, Vec const &AB)

  Computes the first derivative in the y-direction, placing the result on faces.
- PetscErrorCode FirstDerive_z (Vec &AB_z, Vec const &AB)

  Computes the first derivative in the z-direction, placing the result on faces.
- PetscErrorCode CenterU (Vec &UCenter, Vec const &vec, PetscReal const &theta)

  Centers the x-velocity component in cell-centers.
- PetscErrorCode Derive_x (Vec &U2_x, Vec const &vec, PetscReal const &theta)

  Computes the first derivative in the x-direction, placing the result on faces.

Protected Attributes

- DM dmGrid_Shifted

  DMGrid with dofs on faces and edges.
- DM dmGrid_Staggered

  DMGrid with dofs of faces.
- DM dmGrid_Centered

  DMGrid with dofs of faces and centers.
- Vec U_n
- Vec V_n
- Vec W_n

  Velocity fields at the current time step.
- Vec mask_U
- Vec mask_V
- Vec mask_W

  Mask vectors for boundary conditions.

6.10.1 Detailed Description

Represents a transport problem in the x-direction.
This class solves an advection-transport problem in the x-direction using 2nd order centered differences and a fully explicit approach.

6.10.2 Constructor & Destructor Documentation

6.10.2.1 transport_problem_x() [1/2]

```
transport_problem_x::transport_problem_x (
            DM const & dmGrid_Shifted,
            DM const & dmGrid_Staggered,
            DM const & dmGrid_Centered ) [inline]
```

Constructor initializing the transport problem with given grids.

6.10.2.2 transport_problem_x() [2/2]

```
transport_problem_x::transport_problem_x ( ) [inline]
```

Default constructor for stand-alone transport problem.

6.10.2.3 ∼transport_problem_x()

```
transport_problem_x::∼transport_problem_x ( ) [inline]
```

Destructor to clean up allocated resources.

6.10.3 Member Function Documentation

6.10.3.1 CenterU()

```
PetscErrorCode transport_problem_x::CenterU (
            Vec & UCenter,
            Vec const & vec,
            PetscReal const & theta ) [protected]
```

Centers the x-velocity component in cell-centers.

6.10.3.2 Derive_x()

```
PetscErrorCode transport_problem_x::Derive_x (
            Vec & U2_x,
            Vec const & vec,
            PetscReal const & theta ) [protected]
```

Computes the first derivative in the x-direction, placing the result on faces.

6.10.3.3 FirstDerive_y()

```
PetscErrorCode transport_problem_x::FirstDerive_y (
            Vec & AB_y,
            Vec const & AB ) [protected]
```

Computes the first derivative in the y-direction, placing the result on faces.

6.10.3.4 FirstDerive_z()

```
PetscErrorCode transport_problem_x::FirstDerive_z (
            Vec & AB_z,
            Vec const & AB ) [protected]
```

Computes the first derivative in the z-direction, placing the result on faces.

6.10.3.5 FirstShiftU_y()

```
PetscErrorCode transport_problem_x::FirstShiftU_y (
            Vec & UShifted,
            Vec const & vec,
            PetscScalar const & theta ) [protected]
```

Performs the shift for x-component in a 3D transport non-linear problem in the y-direction. Interpolates velocity component on edges.

6.10.3.6 FirstShiftU_z()

```
PetscErrorCode transport_problem_x::FirstShiftU_z (
            Vec & UShifted,
            Vec const & vec,
            PetscScalar const & theta ) [protected]
```

Performs the shift for x-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.

6.10.3.7 FirstShiftV_y()

```
PetscErrorCode transport_problem_x::FirstShiftV_y (
            Vec & VShifted,
            Vec const & vec,
            PetscScalar const & theta ) [protected]
```

Performs the shift for y-component in a 3D transport non-linear problem in the y-direction. Interpolates velocity component on edges.

6.10.3.8 FirstShiftW_z()

```
PetscErrorCode transport_problem_x::FirstShiftW_z (
            Vec & WShifted,
            Vec const & vec,
            PetscScalar const & theta ) [protected]
```

Performs the shift for z-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.

6.10.3.9 solve_step_x()

```
PetscErrorCode const transport_problem_x::solve_step_x (
            PetscScalar const & theta,
            std::optional< std::reference_wrapper< Vec >> U_n_opt = std::nullopt,
            std::optional< std::reference_wrapper< Vec >> V_n_opt = std::nullopt,
            std::optional< std::reference_wrapper< Vec >> W_n_opt = std::nullopt )
```

Performs a single time step for solving the transport equation.

6.10.4 Member Data Documentation

6.10.4.1 dmGrid_Centered

```
DM transport_problem_x::dmGrid_Centered [protected]
```

DMGrid with dofs of faces and centers.

6.10.4.2 dmGrid_Shifted

`DM transport_problem_x::dmGrid_Shifted [protected]`

DMGrid with dofs on faces and edges.

6.10.4.3 dmGrid_Staggered

`DM transport_problem_x::dmGrid_Staggered [protected]`

DMGrid with dofs of faces.

6.10.4.4 mask_U

`Vec transport_problem_x::mask_U [protected]`

6.10.4.5 mask_V

`Vec transport_problem_x::mask_V [protected]`

6.10.4.6 mask_W

`Vec transport_problem_x::mask_W [protected]`

Mask vectors for boundary conditions.

6.10.4.7 U_n

`Vec transport_problem_x::U_n [protected]`

6.10.4.8 V_n

`Vec transport_problem_x::V_n [protected]`

6.10.4.9 W_n

`Vec transport_problem_x::W_n [protected]`

Velocity fields at the current time step.

The documentation for this class was generated from the following files:

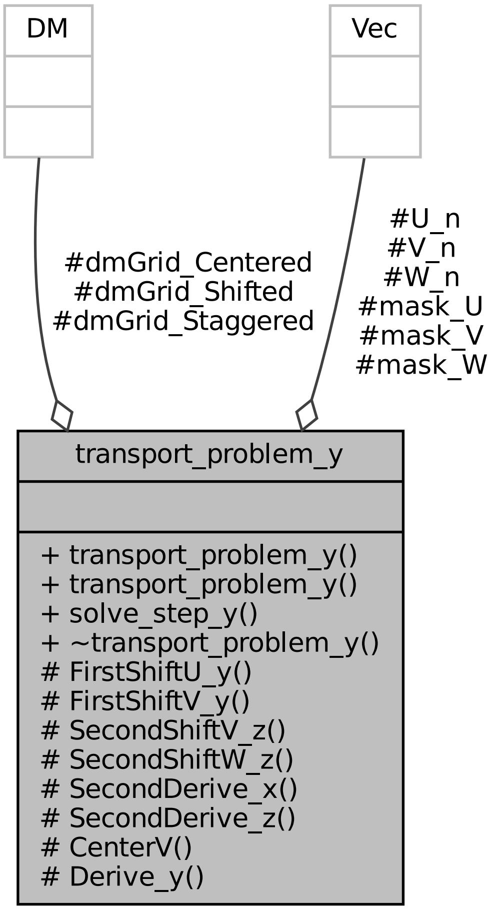
- include/transport.hpp
- src/transport.cpp

6.11 transport_problem_y Class Reference

Represents a transport problem in the y-direction.

`#include <transport.hpp>`

Collaboration diagram for transport_problem_y:



Public Member Functions

- transport_problem_y (DM const &dmGrid_Shifted, DM const &dmGrid_Staggered, DM const &dmGrid_Centered)

    Constructor initializing the transport problem with given grids.
- transport_problem_y ()

    Default constructor for stand-alone transport problem.
- PetscErrorCode const solve_step_y (PetscScalar const &theta, std::optional< std::reference_wrapper< Vec >> U_n_opt=std::nullopt, std::optional< std::reference_wrapper< Vec >> V_n_opt=std::nullopt, std↵::optional< std::reference_wrapper< Vec >> W_n_opt=std::nullopt)

    Performs a single time step for solving the transport equation.
- ∼transport_problem_y ()

    Destructor to clean up allocated resources.

Protected Member Functions

- PetscErrorCode FirstShiftU_y (Vec &UShifted, Vec const &vec, PetscScalar const &theta)

    Performs the shift for x-component in a 3D transport non-linear problem in the y-direction. Interpolates velocity component on edges.

- PetscErrorCode FirstShiftV_y (Vec &VShifted, Vec const &vec, PetscScalar const &theta)

  Performs the shift for y-component in a 3D transport non-linear problem in the y-direction. Interpolates velocity component on edges.
- PetscErrorCode SecondShiftV_z (Vec &VShifted, Vec const &vec, PetscScalar const &theta)

  Performs the shift for y-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.
- PetscErrorCode SecondShiftW_z (Vec &WShifted, Vec const &vec, PetscScalar const &theta)

  Performs the shift for z-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.
- PetscErrorCode SecondDerive_x (Vec &AB_x, Vec const &AB)

  Computes the first derivative in the x-direction, placing the result on faces.
- PetscErrorCode SecondDerive_z (Vec &AB_z, Vec const &AB)

  Computes the first derivative in the z-direction, placing the result on faces.
- PetscErrorCode CenterV (Vec &VCenter, Vec const &vec, PetscReal const &theta)

  Centers the y-velocity component in cell-centers.
- PetscErrorCode Derive_y (Vec &V2_y, Vec const &vec, PetscReal const &theta)

  Computes the first derivative in the y-direction, placing the result on faces.

Protected Attributes

- DM dmGrid_Shifted

  DMGrid with dofs on faces and edges.
- DM dmGrid_Staggered

  DMGrid with dofs of faces.
- DM dmGrid_Centered

  DMGrid with dofs of faces and centers.
- Vec U_n
- Vec V_n
- Vec W_n

  Velocity fields at the current time step.
- Vec mask_U
- Vec mask_V
- Vec mask_W

  Mask vectors for boundary conditions.

6.11.1 Detailed Description

Represents a transport problem in the y-direction.
This class solves an advection-transport problem in the y-direction using 2nd order centered differences and a fully explicit approach.

6.11.2 Constructor & Destructor Documentation

6.11.2.1 transport_problem_y() [1/2]

```
transport_problem_y::transport_problem_y (
            DM const & dmGrid_Shifted,
            DM const & dmGrid_Staggered,
            DM const & dmGrid_Centered )  [inline]
```

Constructor initializing the transport problem with given grids.

6.11.2.2 transport_problem_y() [2/2]

```
transport_problem_y::transport_problem_y ( ) [inline]
```
Default constructor for stand-alone transport problem.

6.11.2.3 ∼transport_problem_y()

```
transport_problem_y::∼transport_problem_y ( ) [inline]
```
Destructor to clean up allocated resources.

6.11.3 Member Function Documentation

6.11.3.1 CenterV()

```
PetscErrorCode transport_problem_y::CenterV (
            Vec & VCenter,
            Vec const & vec,
            PetscReal const & theta ) [protected]
```
Centers the y-velocity component in cell-centers.

6.11.3.2 Derive_y()

```
PetscErrorCode transport_problem_y::Derive_y (
            Vec & V2_y,
            Vec const & vec,
            PetscReal const & theta ) [protected]
```
Computes the first derivative in the y-direction, placing the result on faces.

6.11.3.3 FirstShiftU_y()

```
PetscErrorCode transport_problem_y::FirstShiftU_y (
            Vec & UShifted,
            Vec const & vec,
            PetscScalar const & theta ) [protected]
```
Performs the shift for x-component in a 3D transport non-linear problem in the y-direction. Interpolates velocity component on edges.

6.11.3.4 FirstShiftV_y()

```
PetscErrorCode transport_problem_y::FirstShiftV_y (
            Vec & VShifted,
            Vec const & vec,
            PetscScalar const & theta ) [protected]
```
Performs the shift for y-component in a 3D transport non-linear problem in the y-direction. Interpolates velocity component on edges.

6.11.3.5 SecondDerive_x()

```
PetscErrorCode transport_problem_y::SecondDerive_x (
            Vec & AB_x,
            Vec const & AB ) [protected]
```
Computes the first derivative in the x-direction, placing the result on faces.

6.11.3.6 SecondDerive_z()

```
PetscErrorCode transport_problem_y::SecondDerive_z (
            Vec & AB_z,
            Vec const & AB ) [protected]
```

Computes the first derivative in the z-direction, placing the result on faces.

6.11.3.7 SecondShiftV_z()

```
PetscErrorCode transport_problem_y::SecondShiftV_z (
            Vec & VShifted,
            Vec const & vec,
            PetscScalar const & theta ) [protected]
```

Performs the shift for y-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.

6.11.3.8 SecondShiftW_z()

```
PetscErrorCode transport_problem_y::SecondShiftW_z (
            Vec & WShifted,
            Vec const & vec,
            PetscScalar const & theta ) [protected]
```

Performs the shift for z-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.

6.11.3.9 solve_step_y()

```
PetscErrorCode const transport_problem_y::solve_step_y (
            PetscScalar const & theta,
            std::optional< std::reference_wrapper< Vec >> U_n_opt = std::nullopt,
            std::optional< std::reference_wrapper< Vec >> V_n_opt = std::nullopt,
            std::optional< std::reference_wrapper< Vec >> W_n_opt = std::nullopt )
```

Performs a single time step for solving the transport equation.

6.11.4 Member Data Documentation

6.11.4.1 dmGrid_Centered

```
DM transport_problem_y::dmGrid_Centered [protected]
```

DMGrid with dofs of faces and centers.

6.11.4.2 dmGrid_Shifted

```
DM transport_problem_y::dmGrid_Shifted [protected]
```

DMGrid with dofs on faces and edges.

6.11.4.3 dmGrid_Staggered

```
DM transport_problem_y::dmGrid_Staggered [protected]
```

DMGrid with dofs of faces.

6.11.4.4 mask_U

`Vec transport_problem_y::mask_U [protected]`

6.11.4.5 mask_V

`Vec transport_problem_y::mask_V [protected]`

6.11.4.6 mask_W

`Vec transport_problem_y::mask_W [protected]`

Mask vectors for boundary conditions.

6.11.4.7 U_n

`Vec transport_problem_y::U_n [protected]`

6.11.4.8 V_n

`Vec transport_problem_y::V_n [protected]`

6.11.4.9 W_n

`Vec transport_problem_y::W_n [protected]`

Velocity fields at the current time step.

The documentation for this class was generated from the following files:

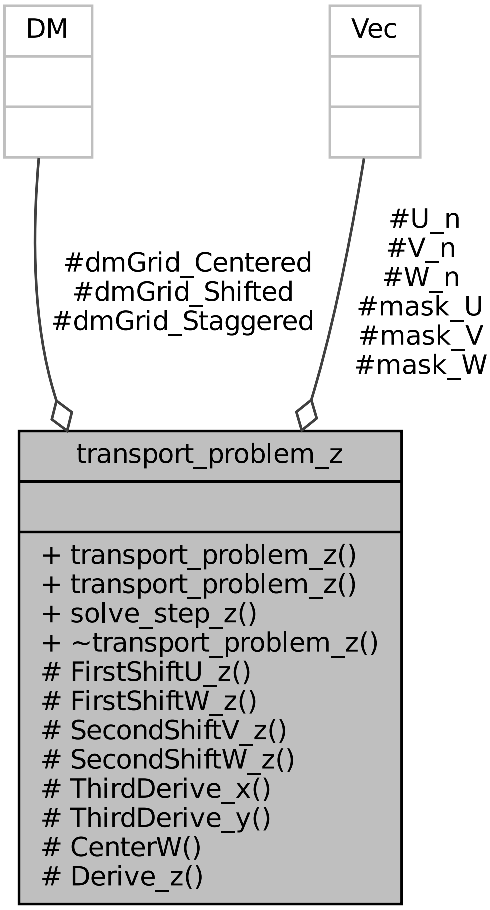
- include/transport.hpp
- src/transport.cpp

6.12 transport_problem_z Class Reference

Represents a transport problem in the z-direction.

`#include <transport.hpp>`

Collaboration diagram for transport_problem_z:



Public Member Functions

- transport_problem_z (DM const &dmGrid_Shifted, DM const &dmGrid_Staggered, DM const &dmGrid_Centered)

    Constructor initializing the transport problem with given grids.
- transport_problem_z ()

    Default constructor for stand-alone transport problem.
- PetscErrorCode const solve_step_z (PetscScalar const &theta, std::optional< std::reference_wrapper< Vec >> U_n_opt=std::nullopt, std::optional< std::reference_wrapper< Vec >> V_n_opt=std::nullopt, std::optional< std::reference_wrapper< Vec >> W_n_opt=std::nullopt)

    Performs a single time step for solving the transport equation.
- ~transport_problem_z ()

    Destructor to clean up allocated resources.

Protected Member Functions

- PetscErrorCode FirstShiftU_z (Vec &UShifted, Vec const &vec, PetscScalar const &theta)

    Performs the shift for x-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.

- PetscErrorCode FirstShiftW_z (Vec &WShifted, Vec const &vec, PetscScalar const &theta)

  Performs the shift for z-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.
- PetscErrorCode SecondShiftV_z (Vec &VShifted, Vec const &vec, PetscScalar const &theta)

  Performs the shift for y-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.
- PetscErrorCode SecondShiftW_z (Vec &WShifted, Vec const &vec, PetscScalar const &theta)

  Performs the shift for z-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.
- PetscErrorCode ThirdDerive_x (Vec &AB_x, Vec const &AB)

  Computes the first derivative in the x-direction, placing the result on faces.
- PetscErrorCode ThirdDerive_y (Vec &AB_y, Vec const &AB)

  Computes the first derivative in the y-direction, placing the result on faces.
- PetscErrorCode CenterW (Vec &WCenter, Vec const &vec, PetscReal const &theta)

  Centers the z-velocity component in cell-centers.
- PetscErrorCode Derive_z (Vec &W2_z, Vec const &vec, PetscReal const &theta)

  Computes the first derivative in the z-direction, placing the result on faces.

Protected Attributes

- DM dmGrid_Shifted

  DMGrid with dofs on faces and edges.
- DM dmGrid_Staggered

  DMGrid with dofs of faces.
- DM dmGrid_Centered

  DMGrid with dofs of faces and centers.
- Vec U_n
- Vec V_n
- Vec W_n

  Velocity fields at the current time step.
- Vec mask_U
- Vec mask_V
- Vec mask_W

  Mask vectors for boundary conditions.

6.12.1 Detailed Description

Represents a transport problem in the z-direction.
This class solves an advection-transport problem in the z-direction using 2nd order centered differences and a fully explicit approach.

6.12.2 Constructor & Destructor Documentation

6.12.2.1 transport_problem_z() [1/2]

```
transport_problem_z::transport_problem_z (
            DM const & dmGrid_Shifted,
            DM const & dmGrid_Staggered,
            DM const & dmGrid_Centered )  [inline]
```

Constructor initializing the transport problem with given grids.

6.12.2.2 transport_problem_z() [2/2]

```
transport_problem_z::transport_problem_z ( ) [inline]
```

Default constructor for stand-alone transport problem.

6.12.2.3 ∼transport_problem_z()

```
transport_problem_z::~transport_problem_z ( ) [inline]
```

Destructor to clean up allocated resources.

6.12.3 Member Function Documentation

6.12.3.1 CenterW()

```
PetscErrorCode transport_problem_z::CenterW (
            Vec & WCenter,
            Vec const & vec,
            PetscReal const & theta ) [protected]
```

Centers the z-velocity component in cell-centers.

6.12.3.2 Derive_z()

```
PetscErrorCode transport_problem_z::Derive_z (
            Vec & W2_z,
            Vec const & vec,
            PetscReal const & theta ) [protected]
```

Computes the first derivative in the z-direction, placing the result on faces.

6.12.3.3 FirstShiftU_z()

```
PetscErrorCode transport_problem_z::FirstShiftU_z (
            Vec & UShifted,
            Vec const & vec,
            PetscScalar const & theta ) [protected]
```

Performs the shift for x-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.

6.12.3.4 FirstShiftW_z()

```
PetscErrorCode transport_problem_z::FirstShiftW_z (
            Vec & WShifted,
            Vec const & vec,
            PetscScalar const & theta ) [protected]
```

Performs the shift for z-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.

6.12.3.5 SecondShiftV_z()

```
PetscErrorCode transport_problem_z::SecondShiftV_z (
            Vec & VShifted,
            Vec const & vec,
            PetscScalar const & theta ) [protected]
```

Performs the shift for y-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.

6.12.3.6 SecondShiftW_z()

```
PetscErrorCode transport_problem_z::SecondShiftW_z (
            Vec & WShifted,
            Vec const & vec,
            PetscScalar const & theta ) [protected]
```

Performs the shift for z-component in a 3D transport non-linear problem in the z-direction. Interpolates velocity component on edges.

6.12.3.7 solve_step_z()

```
PetscErrorCode const transport_problem_z::solve_step_z (
            PetscScalar const & theta,
            std::optional< std::reference_wrapper< Vec >> U_n_opt = std::nullopt,
            std::optional< std::reference_wrapper< Vec >> V_n_opt = std::nullopt,
            std::optional< std::reference_wrapper< Vec >> W_n_opt = std::nullopt )
```

Performs a single time step for solving the transport equation.

6.12.3.8 ThirdDerive_x()

```
PetscErrorCode transport_problem_z::ThirdDerive_x (
            Vec & AB_x,
            Vec const & AB ) [protected]
```

Computes the first derivative in the x-direction, placing the result on faces.

6.12.3.9 ThirdDerive_y()

```
PetscErrorCode transport_problem_z::ThirdDerive_y (
            Vec & AB_y,
            Vec const & AB ) [protected]
```

Computes the first derivative in the y-direction, placing the result on faces.

6.12.4 Member Data Documentation

6.12.4.1 dmGrid_Centered

```
DM transport_problem_z::dmGrid_Centered [protected]
```

DMGrid with dofs of faces and centers.

6.12.4.2 dmGrid_Shifted

```
DM transport_problem_z::dmGrid_Shifted [protected]
```

DMGrid with dofs on faces and edges.

6.12.4.3 dmGrid_Staggered

```
DM transport_problem_z::dmGrid_Staggered [protected]
```

DMGrid with dofs of faces.

6.12.4.4 mask_U

```
Vec transport_problem_z::mask_U [protected]
```

6.12.4.5 mask_V

```
Vec transport_problem_z::mask_V [protected]
```

6.12.4.6 mask_W

```
Vec transport_problem_z::mask_W [protected]
```

Mask vectors for boundary conditions.

6.12.4.7 U_n

```
Vec transport_problem_z::U_n [protected]
```

6.12.4.8 V_n

```
Vec transport_problem_z::V_n [protected]
```

6.12.4.9 W_n

```
Vec transport_problem_z::W_n [protected]
```

Velocity fields at the current time step.

The documentation for this class was generated from the following files:

- include/transport.hpp
- src/transport.cpp

Chapter 7

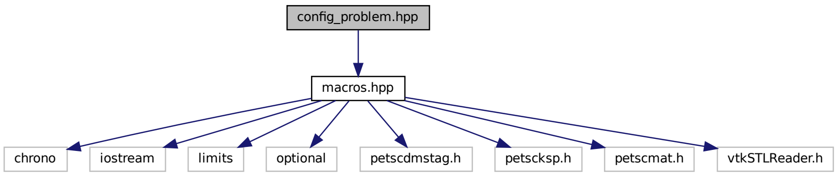
File Documentation

7.1 config_problem.hpp File Reference

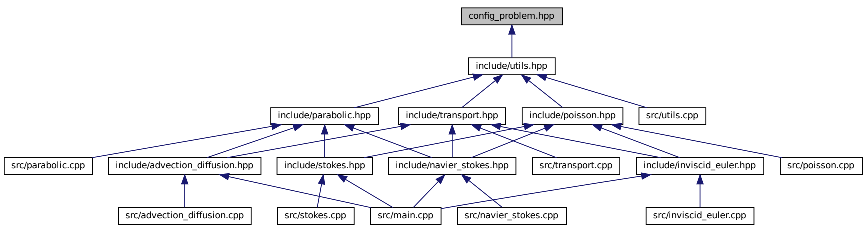
Configuration file for setting up problem parameters.

`#include "macros.hpp"`

Include dependency graph for config_problem.hpp:



This graph shows which files directly or indirectly include this file:



Namespaces

- problem_setting

Functions

- constexpr PetscReal problem_setting::uxRef (PetscReal const &x, PetscReal const &y, PetscReal const &z, PetscReal const &theta)

    Computes the reference solution for the problem in the x-direction.
- constexpr PetscReal problem_setting::uyRef (PetscReal const &x, PetscReal const &y, PetscReal const &z, PetscReal const &theta)

    Computes the reference solution for the problem in the y-direction.

- constexpr PetscReal problem_setting::uzRef (PetscReal const &x, PetscReal const &y, PetscReal const &z, PetscReal const &theta)

  Computes the reference solution for the problem in the z-direction.
- constexpr PetscReal problem_setting::pRef (PetscReal const &x, PetscReal const &y, PetscReal const &z, PetscReal const &theta)

Variables

- constexpr const char ∗ problem_setting::problem_type = "navier_stokes"

  Set the problem type. Possible values are "navier_stokes", "stokes", "euler", "advection_diffusion", "parabolic_x", "parabolic_y", "parabolic_z", "transport_x", "transport_y", "transport_z".
- constexpr const char ∗ problem_setting::base_path = "results/"

  Set this as base path to store results. Default is "results/".
- constexpr bool problem_setting::brinkman {false}

  Set flag to (dis)able brinkman penalization. Required for complex geometry handling.
- constexpr bool problem_setting::monitor_convergence {true}

  Set flag to (dis)able convergence error of KSP solver.
- constexpr bool problem_setting::check_convergence {true}

  Set flag to (dis)able convergence error of variable. Only implemented for NAvier-Stokes and parabolic problems.
- constexpr PetscInt problem_setting::nx {32}

  Set the number of elements in x-direction.
- constexpr PetscInt problem_setting::ny {32}

  Set the number of elements in y-direction.
- constexpr PetscInt problem_setting::nz {32}

  Set the number of elements in z-direction.
- constexpr PetscReal problem_setting::Lx_0 {-0.5}

  Set the domain limits in x, y and z directions.
- constexpr PetscReal problem_setting::Ly_0 {-0.5}
- constexpr PetscReal problem_setting::Lz_0 {-0.5}
- constexpr PetscReal problem_setting::Lx {0.5}
- constexpr PetscReal problem_setting::Ly {0.5}
- constexpr PetscReal problem_setting::Lz {0.5}
- constexpr PetscReal problem_setting::dt {0.00625/2}

  Set time-step.
- constexpr PetscReal problem_setting::iter {32}

  Set final time.
- PetscReal problem_setting::theta

  Set starting time.
- constexpr PetscReal problem_setting::Re {1}

  Set Reynolds number. For non advective problems, set mu = 1/Re (adimensional framework)
- constexpr PetscReal problem_setting::a = pi / 4

  Set flow parameters. You can declare as many constexpr variables as you need.
- constexpr PetscReal problem_setting::d = 1.5 ∗ pi

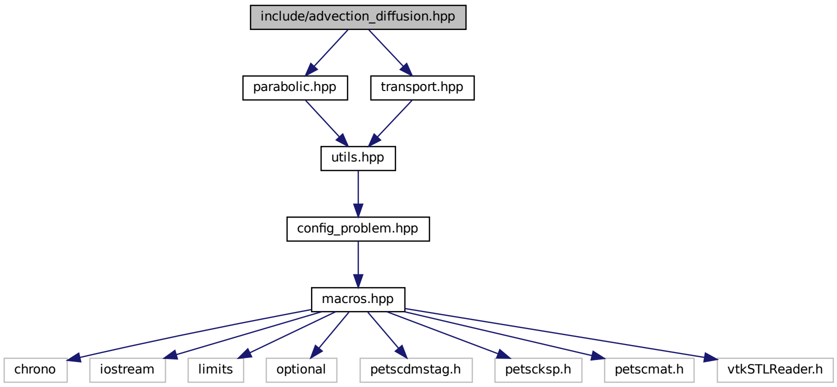
7.1.1 Detailed Description

Configuration file for setting up problem parameters.
This file defines the parameters for simulations. Before starting any simulation, careful consideration of the parameters is required. It is recommended to work in a dimensionless framework.

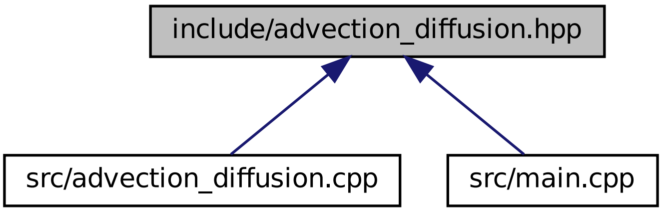
7.2 include/advection_diffusion.hpp File Reference

```
#include "parabolic.hpp"
#include "transport.hpp"
```

Include dependency graph for advection_diffusion.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- class advection_diffusion_problem

Macros

- #define ADVECTION_DIFFUSION_PROBLEM_HPP

7.2.1 Macro Definition Documentation

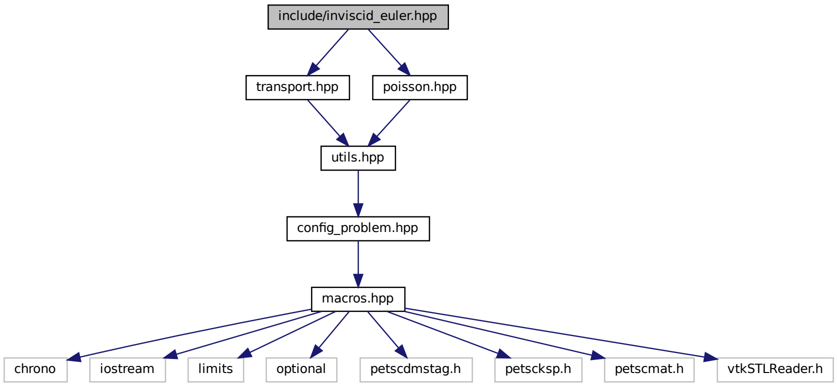
7.2.1.1 ADVECTION_DIFFUSION_PROBLEM_HPP

```
#define ADVECTION_DIFFUSION_PROBLEM_HPP
```

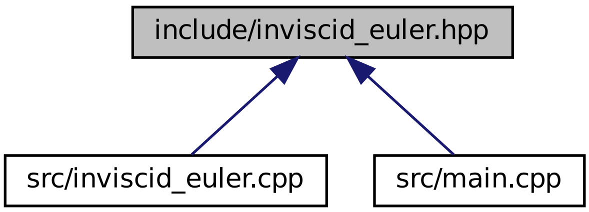
7.3 include/inviscid_euler.hpp File Reference

```
#include "transport.hpp"
#include "poisson.hpp"
```

Include dependency graph for inviscid_euler.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- class euler_problem

  Solves the Euler evolutionary incompressible equations, applying a first order Chorin-Temam algorithm. It consists of a transport problem for each velocity component and a Poisson problem for the pressure. Current implementation allows Dirichlet bc's only. Boundary conditions are accessed from reference solution, which is a function of space and time. Current implementation DOES NOT ALLOW for Brinkamn penalty method.

Macros

- #define EULER_PROBLEM_HPP

7.3.1 Macro Definition Documentation

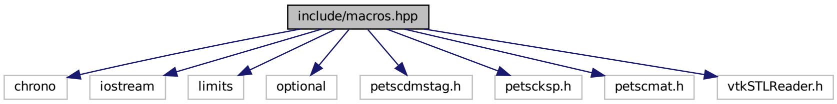
7.3.1.1 EULER_PROBLEM_HPP

```
#define EULER_PROBLEM_HPP
```

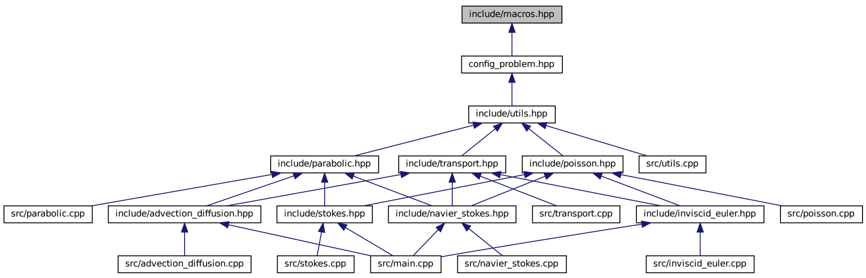
7.4 include/macros.hpp File Reference

```
#include <chrono>
#include <iostream>
#include <limits>
#include <optional>
#include <petscdmstag.h>
#include <petscksp.h>
#include <petscmat.h>
#include <vtkSTLReader.h>
```

Include dependency graph for macros.hpp:



This graph shows which files directly or indirectly include this file:



Macros

- #define BACK_DOWN DMSTAG_BACK_DOWN
- #define BACK_LEFT DMSTAG_BACK_LEFT
- #define BACK DMSTAG_BACK
- #define BACK_RIGHT DMSTAG_BACK_RIGHT
- #define BACK_UP DMSTAG_BACK_UP
- #define DOWN_LEFT DMSTAG_DOWN_LEFT
- #define DOWN DMSTAG_DOWN
- #define DOWN_RIGHT DMSTAG_DOWN_RIGHT
- #define LEFT DMSTAG_LEFT
- #define ELEMENT DMSTAG_ELEMENT
- #define RIGHT DMSTAG_RIGHT
- #define UP_LEFT DMSTAG_UP_LEFT
- #define UP DMSTAG_UP
- #define UP_RIGHT DMSTAG_UP_RIGHT
- #define FRONT_DOWN DMSTAG_FRONT_DOWN
- #define FRONT_LEFT DMSTAG_FRONT_LEFT
- #define FRONT DMSTAG_FRONT
- #define FRONT_RIGHT DMSTAG_FRONT_RIGHT
- #define FRONT_UP DMSTAG_FRONT_UP

Variables

- constexpr PetscReal pi = 3.14159265358979323846

    The mathematical constant pi.
- constexpr PetscReal eps =1e6

    A large numerical value used as an approximation for Brinkman flow penalization parameter.

7.4.1 Macro Definition Documentation

7.4.1.1 BACK

```
#define BACK DMSTAG_BACK
```

7.4.1.2 BACK_DOWN

```
#define BACK_DOWN DMSTAG_BACK_DOWN
```

7.4.1.3 BACK_LEFT

```
#define BACK_LEFT DMSTAG_BACK_LEFT
```

7.4.1.4 BACK_RIGHT

```
#define BACK_RIGHT DMSTAG_BACK_RIGHT
```

7.4.1.5 BACK_UP

```
#define BACK_UP DMSTAG_BACK_UP
```

7.4.1.6 DOWN

```
#define DOWN DMSTAG_DOWN
```

7.4.1.7 DOWN_LEFT

```
#define DOWN_LEFT DMSTAG_DOWN_LEFT
```

7.4.1.8 DOWN_RIGHT

```
#define DOWN_RIGHT DMSTAG_DOWN_RIGHT
```

7.4.1.9 ELEMENT

```
#define ELEMENT DMSTAG_ELEMENT
```

7.4.1.10 FRONT

```
#define FRONT DMSTAG_FRONT
```

7.4.1.11 FRONT_DOWN

```
#define FRONT_DOWN DMSTAG_FRONT_DOWN
```

7.4.1.12 FRONT_LEFT

```
#define FRONT_LEFT DMSTAG_FRONT_LEFT
```

7.4.1.13 FRONT_RIGHT

```
#define FRONT_RIGHT DMSTAG_FRONT_RIGHT
```

7.4.1.14 FRONT_UP

```
#define FRONT_UP DMSTAG_FRONT_UP
```

7.4.1.15 LEFT

```
#define LEFT DMSTAG_LEFT
```

7.4.1.16 RIGHT

```
#define RIGHT DMSTAG_RIGHT
```

7.4.1.17 UP

```
#define UP DMSTAG_UP
```

7.4.1.18 UP_LEFT

```
#define UP_LEFT DMSTAG_UP_LEFT
```

7.4.1.19 UP_RIGHT

```
#define UP_RIGHT DMSTAG_UP_RIGHT
```

7.4.2 Variable Documentation

7.4.2.1 eps

```
constexpr PetscReal eps =1e6  [constexpr]
```

A large numerical value used as an approximation for Brinkman flow penalization parameter.

7.4.2.2 pi

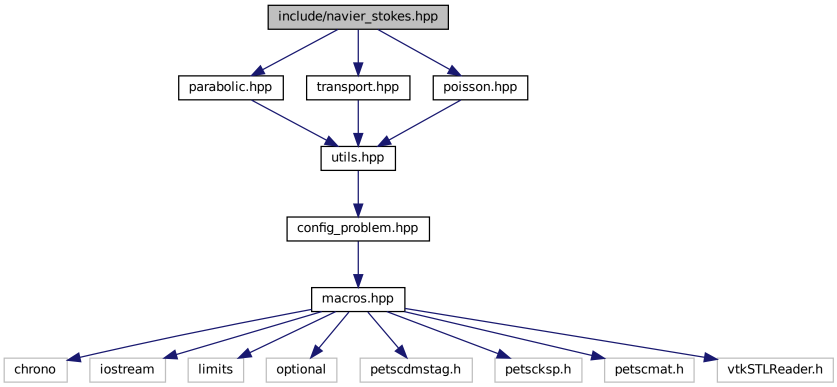
```
constexpr PetscReal pi = 3.14159265358979323846  [constexpr]
```

The mathematical constant pi.

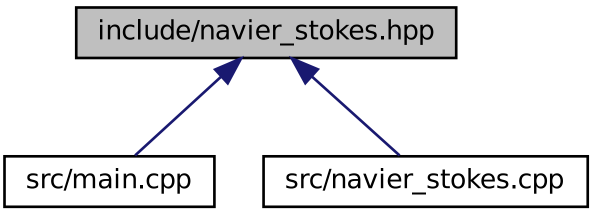
7.5 include/navier_stokes.hpp File Reference

```
#include "parabolic.hpp"
#include "transport.hpp"
#include "poisson.hpp"
```

Include dependency graph for navier_stokes.hpp:



This graph shows which files directly or indirectly include this file:



Classes

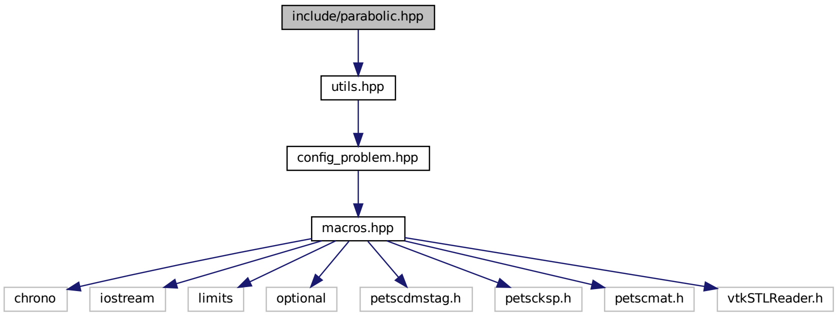
- class navier_stokes_problem

  Solves the Navier-Stokes evolutionary incompressible Navier-Stokes equations, applying a first order Chorin-Temam algorithm. It consists of a transport problem for each velocity component, a parabolic problem for each velocity component, and a Poisson problem for the pressure. Current implementation allows Dirichlet bc's only. Boundary conditions are accessed from reference solution, which is a function of space and time. Current implementation allows for Brinkamn penalty method.

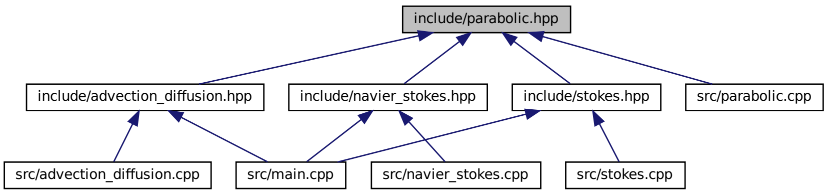
7.6 include/parabolic.hpp File Reference

```
#include "utils.hpp"
```

Include dependency graph for parabolic.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- class parabolic_problem_x

    Represents a parabolic problem in the x-direction.
- class parabolic_problem_y

    Represents a parabolic problem in the y-direction.
- class parabolic_problem_z

    Represents a parabolic problem in the z-direction.

Macros

- #define PARABOLIC_PROBLEM_Y_HPP
- #define PARABOLIC_PROBLEM_Z_HPP

7.6.1 Macro Definition Documentation

7.6.1.1 PARABOLIC_PROBLEM_Y_HPP

```
#define PARABOLIC_PROBLEM_Y_HPP
```

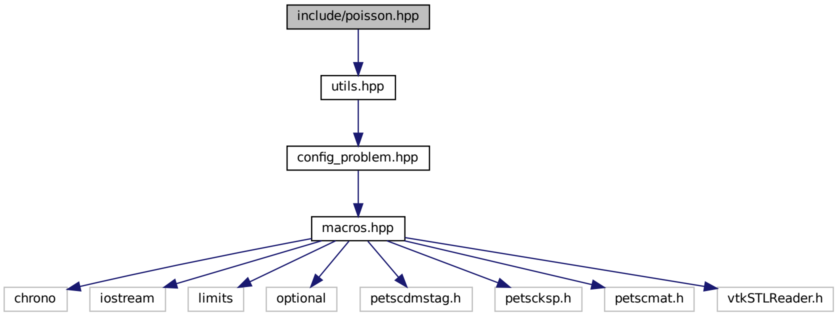
7.6.1.2 PARABOLIC_PROBLEM_Z_HPP

```
#define PARABOLIC_PROBLEM_Z_HPP
```

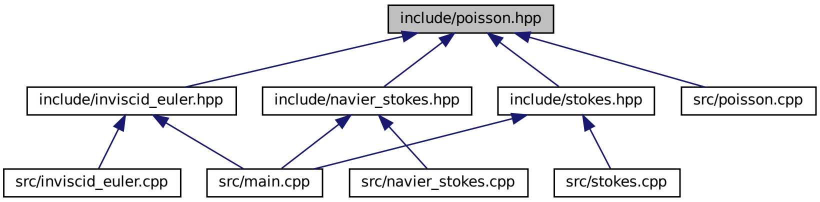
7.7 include/poisson.hpp File Reference

```
#include "utils.hpp"
```

Include dependency graph for poisson.hpp:



This graph shows which files directly or indirectly include this file:



Classes

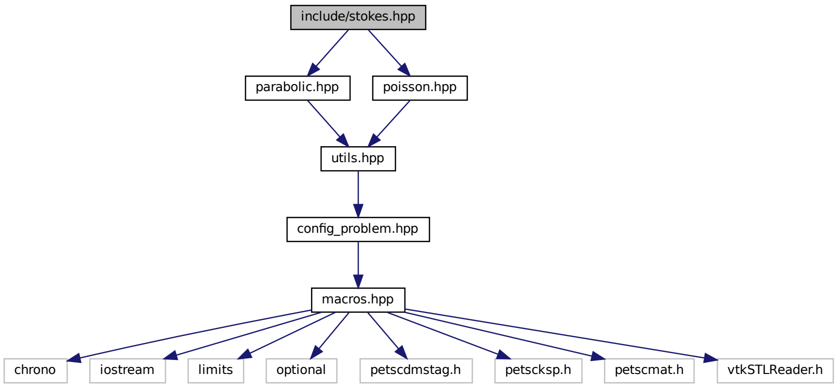
- class poisson_problem

  Represents a Poisson equation solver for pressure correction in fluid simulations.

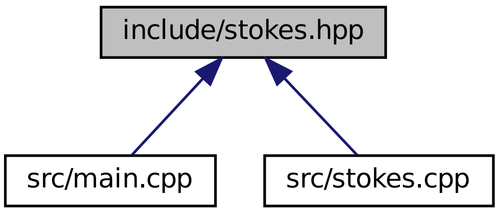
7.8 include/stokes.hpp File Reference

```
#include "parabolic.hpp"
#include "poisson.hpp"
```

Include dependency graph for stokes.hpp:



This graph shows which files directly or indirectly include this file:



Classes

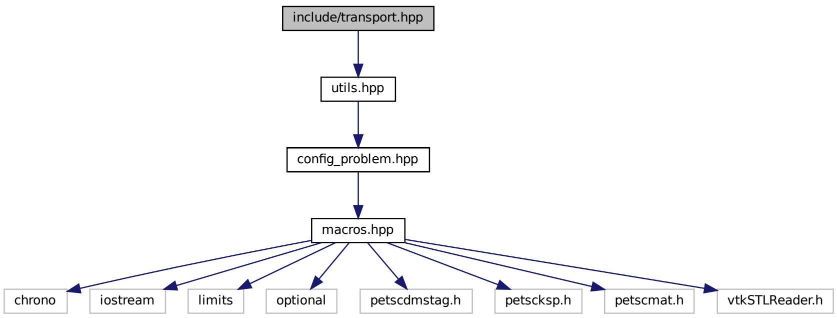
- class stokes_problem

    Solves the Stokes evolutionary incompressible Stokes equations, applying a first order Chorin-Temam algorithm. It consists of a parabolic problem for each velocity component, and a Poisson problem for the pressure. Current implementation allows Dirichlet bc's only. Boundary conditions are accessed from reference solution, which is a function of space and time. Current implementation allows for Brinkamn penalty method.

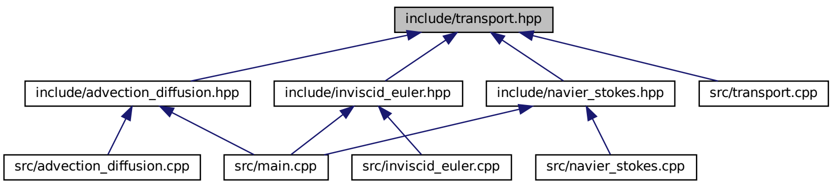
7.9 include/transport.hpp File Reference

```
#include "utils.hpp"
```

Include dependency graph for transport.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- class transport_problem_x

    Represents a transport problem in the x-direction.
- class transport_problem_y

    Represents a transport problem in the y-direction.
- class transport_problem_z

    Represents a transport problem in the z-direction.

Macros

- #define TRANSPORT_PROBLEM_Y_HPP
- #define TRANSPORT_PROBLEM_Z_HPP

7.9.1 Macro Definition Documentation

7.9.1.1 TRANSPORT_PROBLEM_Y_HPP

```
#define TRANSPORT_PROBLEM_Y_HPP
```

7.9.1.2 TRANSPORT_PROBLEM_Z_HPP

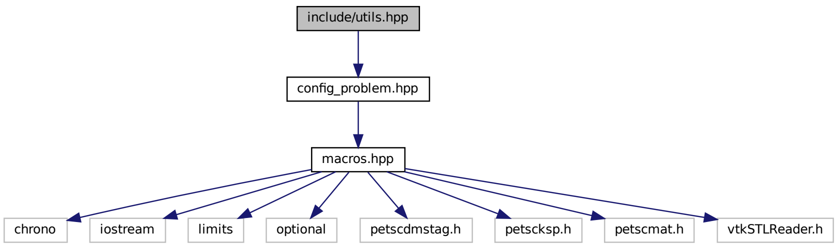
```
#define TRANSPORT_PROBLEM_Z_HPP
```

7.10 include/utils.hpp File Reference

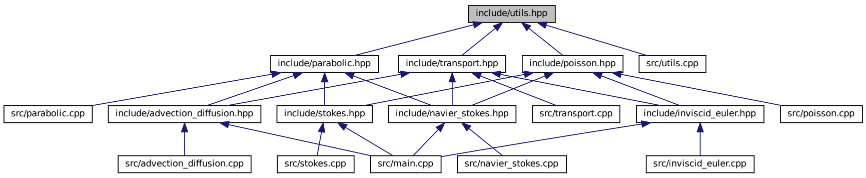
Utility functions for grid creation, analytical solutions, and geometric operations.

`#include "config_problem.hpp"`

Include dependency graph for utils.hpp:



This graph shows which files directly or indirectly include this file:



Functions

- PetscErrorCode CheckSolution (Vec const &sol, Vec const &solRef, std::string const &comp)

  Checks the difference between a computed solution and a reference solution and evaulates L2-norm.
- PetscErrorCode CreateAnalyticalU (DM const &dmGrid, Vec &vec, PetscReal const &theta)

  Creates an analytical solution on a staggered grid in the x-direction (dofs in position LEFT and RIGHT)
- PetscErrorCode CreateAnalyticalV (DM const &dmGrid, Vec &vec, PetscReal const &theta)

  Creates an analytical solution on a staggered grid in the y-direction (dofs in position DOWN and UP)
- PetscErrorCode CreateAnalyticalW (DM const &dmGrid, Vec &vec, PetscReal const &theta)

  Creates an analytical solution on a staggered grid in the z-direction (dofs in position BACK and FRONT)
- PetscErrorCode CreateGrid (DM *const dmGrid, PetscInt const &dof1, PetscInt const &dof2, PetscInt const &dof3)

  Creates a computational grid for simulation. Allows to specify dofs ONLY on edges, faces and cell-cenetrs. Pass 0 to not allow dofs in some position, 1 allocate dofs.
- PetscErrorCode CreateAnalyticalP (DM const &dmGrid, Vec &vec, PetscReal const &theta)
- void PrintSimulationParameters ()

  Prints the simulation parameters to the console.
- bool rayIntersectsTriangle (const std::array< double, 3 > &rayOrigin, const std::array< double, 3 > &rayVector, const std::array< double, 3 > &v0, const std::array< double, 3 > &v1, const std::array< double, 3 > &v2)

  Checks if a ray intersects with a triangle in 3D space (part of ray-casting algorithm to create Brinkman masks)
- bool isPointInsideMesh (const std::array< double, 3 > &point, const std::vector< std::array< double, 3 >> &vertices, const std::vector< std::array< int, 3 >> &faces)

  Determines if a point is inside a 3D mesh.
- void reader (const std::string &filename, std::vector< std::array< double, 3 >> &vertices, std::vector< std::array< int, 3 >> &faces)

Reads a mesh file and extracts vertices and faces.

- PetscErrorCode createMaskU (DM const &dmGrid, Vec &vec_stag, std::vector< std::array< double, 3 >> const &vertices, std::vector< std::array< int, 3 >> const &faces)

  Creates a mask for the x-component component.

- PetscErrorCode createMaskV (DM const &dmGrid, Vec &vec_stag, std::vector< std::array< double, 3 >> const &vertices, std::vector< std::array< int, 3 >> const &faces)

  Creates a mask for the y-component component.

- PetscErrorCode createMaskW (DM const &dmGrid, Vec &vec_stag, std::vector< std::array< double, 3 >> const &vertices, std::vector< std::array< int, 3 >> const &faces)

  Creates a mask for the z-component component.

Variables

- constexpr PetscReal D_x {Lx - Lx_0}

  Domain length in the x-direction.

- constexpr PetscReal D_y {Ly - Ly_0}

  Domain length in the y-direction.

- constexpr PetscReal D_z {Lz - Lz_0}

  Domain length in the z-direction.

- std::vector< std::array< double, 3 > > vertices

  List of mesh vertices.

- std::vector< std::array< int, 3 > > faces

  List of mesh faces.

- std::string filename

  Filename of the geometry file.

7.10.1 Detailed Description

Utility functions for grid creation, analytical solutions, and geometric operations.
This file contains various utility functions used in numerical simulations, including:

- Functions for generating analytical velocity solutions.
- Grid creation and setup.
- Mesh operations such as point-in-mesh checks and ray-triangle intersections.
- Functions for creating Brinkman masks.

7.10.2 Function Documentation

7.10.2.1 CheckSolution()

```
PetscErrorCode CheckSolution (
            Vec const & sol,
            Vec const & solRef,
            std::string const & comp )
```

Checks the difference between a computed solution and a reference solution and evaulates L2-norm.

Parameters

sol	Computed solution vector.
solRef	Reference solution vector.

7.10.2.2 CreateAnalyticalP()

```
PetscErrorCode CreateAnalyticalP (
            DM const & dmGrid,
            Vec & vec,
            PetscReal const & theta )
```

7.10.2.3 CreateAnalyticalU()

```
PetscErrorCode CreateAnalyticalU (
            DM const & dmGrid,
            Vec & vec,
            PetscReal const & theta )
```

Creates an analytical solution on a staggered grid in the x-direction (dofs in position LEFT and RIGHT)

Parameters

dmGrid	Discretized grid.
vec	Output velocity field.

7.10.2.4 CreateAnalyticalV()

```
PetscErrorCode CreateAnalyticalV (
            DM const & dmGrid,
            Vec & vec,
            PetscReal const & theta )
```

Creates an analytical solution on a staggered grid in the y-direction (dofs in position DOWN and UP)

Parameters

dmGrid	Discretized grid.
vec	Output velocity field.

7.10.2.5 CreateAnalyticalW()

```
PetscErrorCode CreateAnalyticalW (
            DM const & dmGrid,
            Vec & vec,
            PetscReal const & theta )
```

Creates an analytical solution on a staggered grid in the z-direction (dofs in position BACK and FRONT)

Parameters

dmGrid	Discretized grid.
vec	Output velocity field.

7.10.2.6 CreateGrid()

```
PetscErrorCode CreateGrid (
            DM *const dmGrid,
            PetscInt const & dof1,
```

```
            PetscInt const & dof2,
            PetscInt const & dof3 )
```

Creates a computational grid for simulation. Allows to specify dofs ONLY on edges, faces and cell-cenetrs. Pass 0 to not allow dofs in some position, 1 allocate dofs.

Parameters

dmGrid	Pointer to the grid.
dof1	Degrees of freedom on edges.
dof2	Degrees of freedom of faces.
dof3	Degrees of freedom at cell-ceneters.

7.10.2.7 createMaskU()

```
PetscErrorCode createMaskU (
            DM const & dmGrid,
            Vec & vec_stag,
            std::vector< std::array< double, 3 >> const & vertices,
            std::vector< std::array< int, 3 >> const & faces )
```

Creates a mask for the x-component component.

Parameters

dmGrid	Discretized grid.
vec_stag	Output mask vector.
vertices	List of mesh vertices.
faces	List of mesh faces.

7.10.2.8 createMaskV()

```
PetscErrorCode createMaskV (
            DM const & dmGrid,
            Vec & vec_stag,
            std::vector< std::array< double, 3 >> const & vertices,
            std::vector< std::array< int, 3 >> const & faces )
```

Creates a mask for the y-component component.

Parameters

dmGrid	Discretized grid.
vec_stag	Output mask vector.
vertices	List of mesh vertices.
faces	List of mesh faces.

7.10.2.9 createMaskW()

```
PetscErrorCode createMaskW (
            DM const & dmGrid,
            Vec & vec_stag,
            std::vector< std::array< double, 3 >> const & vertices,
```

```
            std::vector< std::array< int, 3 >> const & faces )
```

Creates a mask for the z-component component.

Parameters

dmGrid	Discretized grid.
vec_stag	Output mask vector.
vertices	List of mesh vertices.
faces	List of mesh faces.

7.10.2.10 isPointInsideMesh()

```
bool isPointInsideMesh (
            const std::array< double, 3 > & point,
            const std::vector< std::array< double, 3 >> & vertices,
            const std::vector< std::array< int, 3 >> & faces )
```

Determines if a point is inside a 3D mesh.

Parameters

point	The point to be checked.
vertices	List of vertices of the mesh.
faces	List of faces of the mesh.

Returns

True if the point is inside the mesh, false otherwise.

7.10.2.11 PrintSimulationParameters()

```
void PrintSimulationParameters ( )
```

Prints the simulation parameters to the console.

7.10.2.12 rayIntersectsTriangle()

```
bool rayIntersectsTriangle (
            const std::array< double, 3 > & rayOrigin,
            const std::array< double, 3 > & rayVector,
            const std::array< double, 3 > & v0,
            const std::array< double, 3 > & v1,
            const std::array< double, 3 > & v2 )
```

Checks if a ray intersects with a triangle in 3D space (part of ray-casting algorithm to create Brinkman masks)

Parameters

rayOrigin	Starting point of the ray.
rayVector	Direction of the ray.
v0	First vertex of the triangle.
v1	Second vertex of the triangle.
v2	Third vertex of the triangle.

Returns

True if the ray intersects the triangle, false otherwise.

7.10.2.13 reader()

```
void reader (
            const std::string & filename,
            std::vector< std::array< double, 3 >> & vertices,
            std::vector< std::array< int, 3 >> & faces )
```

Reads a mesh file and extracts vertices and faces.

Parameters

filename	The name of the mesh file.
vertices	Output list of vertices.
faces	Output list of faces.

7.10.3 Variable Documentation

7.10.3.1 D_x

```
constexpr PetscReal D_x {Lx - Lx_0}  [constexpr]
```

Domain length in the x-direction.

7.10.3.2 D_y

```
constexpr PetscReal D_y {Ly - Ly_0}  [constexpr]
```

Domain length in the y-direction.

7.10.3.3 D_z

```
constexpr PetscReal D_z {Lz - Lz_0}  [constexpr]
```

Domain length in the z-direction.

7.10.3.4 faces

```
std::vector<std::array<int, 3> > faces  [inline]
```

List of mesh faces.

7.10.3.5 filename

```
std::string filename  [inline]
```

Filename of the geometry file.

7.10.3.6 vertices

```
std::vector<std::array<double, 3> > vertices  [inline]
```

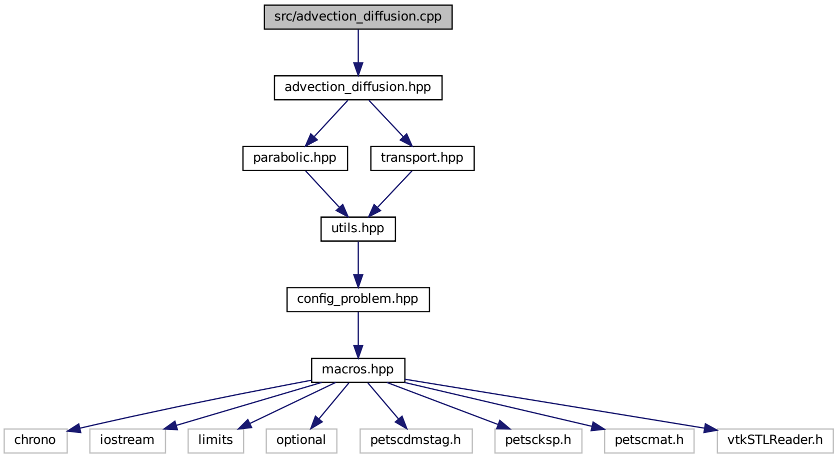
List of mesh vertices.

7.11 README.md File Reference

7.12 src/advection_diffusion.cpp File Reference

```
#include "advection_diffusion.hpp"
```

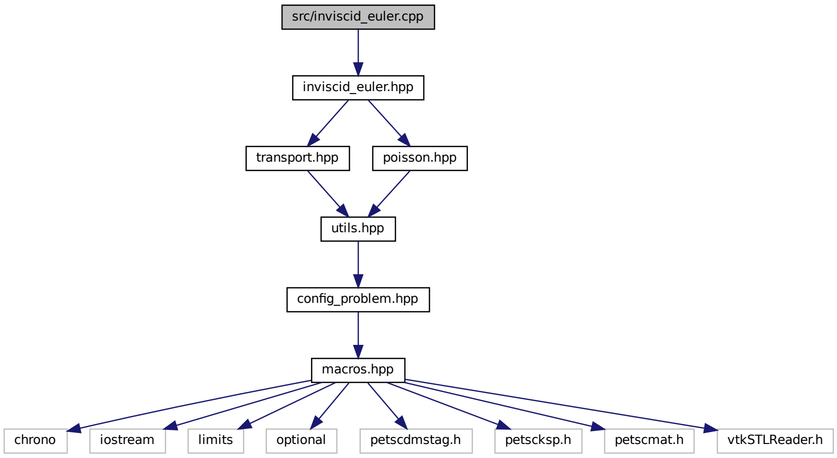
Include dependency graph for advection_diffusion.cpp:



7.13 src/inviscid_euler.cpp File Reference

```
#include "inviscid_euler.hpp"
```

Include dependency graph for inviscid_euler.cpp:

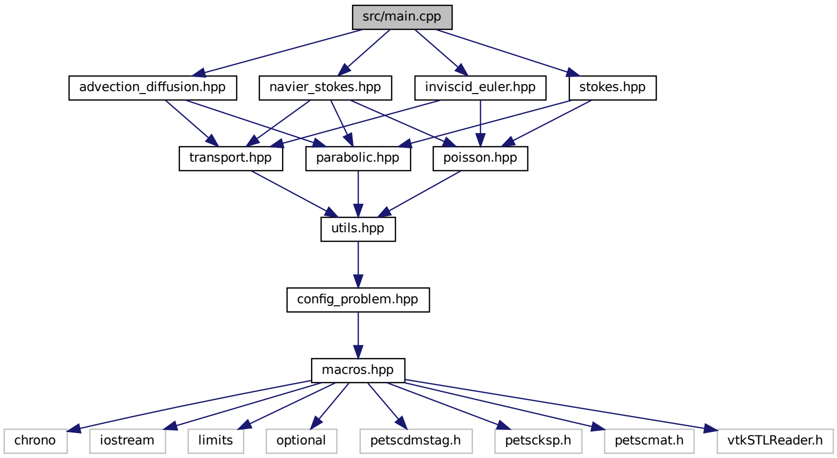


7.14 src/main.cpp File Reference

```
#include "navier_stokes.hpp"
#include "inviscid_euler.hpp"
#include "stokes.hpp"
```

```
#include "advection_diffusion.hpp"
```

Include dependency graph for main.cpp:



Functions

- int main (int argc, char **argv)

7.14.1 Function Documentation

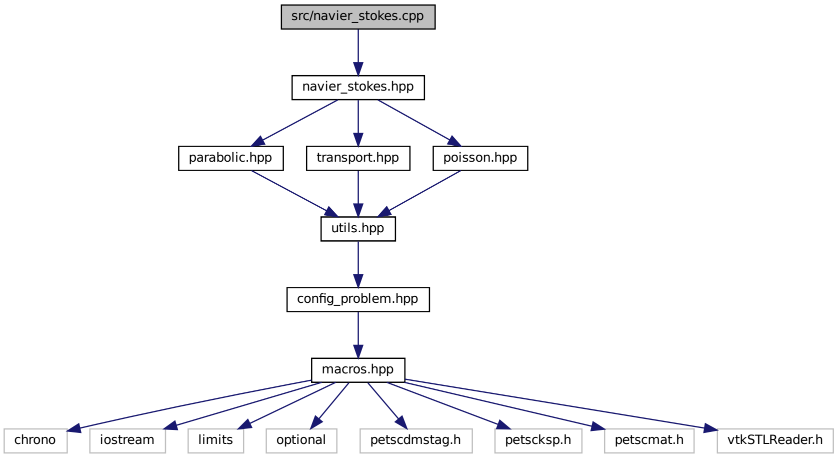
7.14.1.1 main()

```
int main (
            int argc,
            char ** argv )
```

7.15 src/navier_stokes.cpp File Reference

`#include "navier_stokes.hpp"`

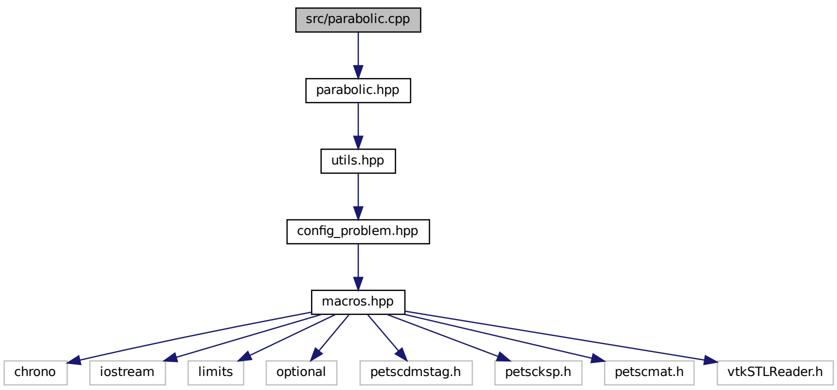
Include dependency graph for navier_stokes.cpp:



7.16 src/parabolic.cpp File Reference

`#include "parabolic.hpp"`

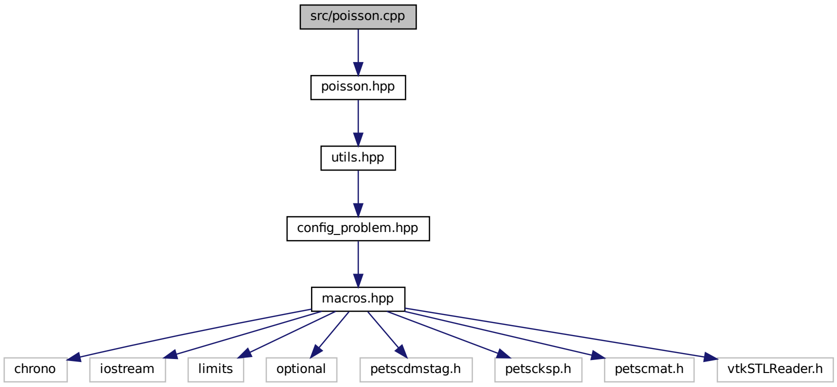
Include dependency graph for parabolic.cpp:



7.17 src/poisson.cpp File Reference

`#include "poisson.hpp"`

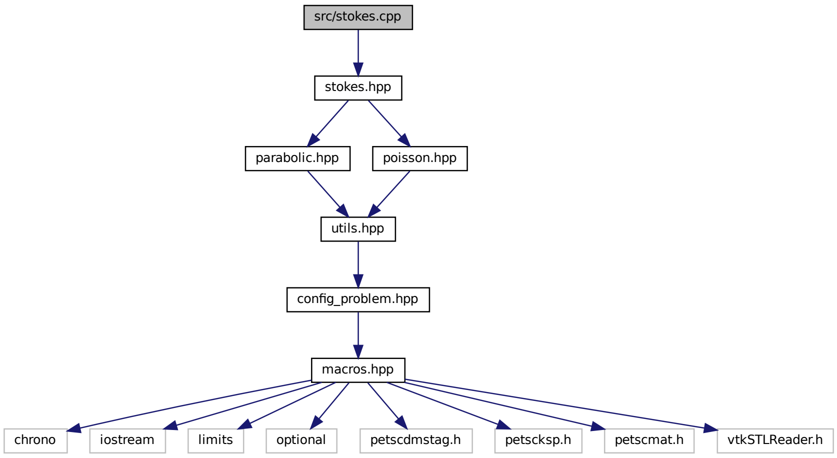
Include dependency graph for poisson.cpp:



7.18 src/stokes.cpp File Reference

`#include "stokes.hpp"`

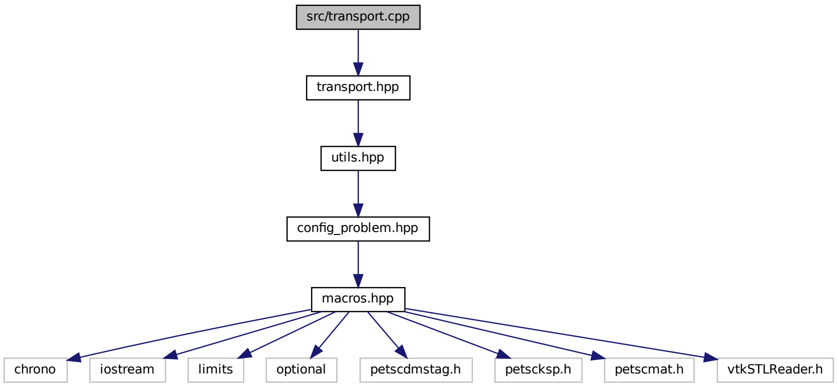
Include dependency graph for stokes.cpp:



7.19 src/transport.cpp File Reference

`#include "transport.hpp"`

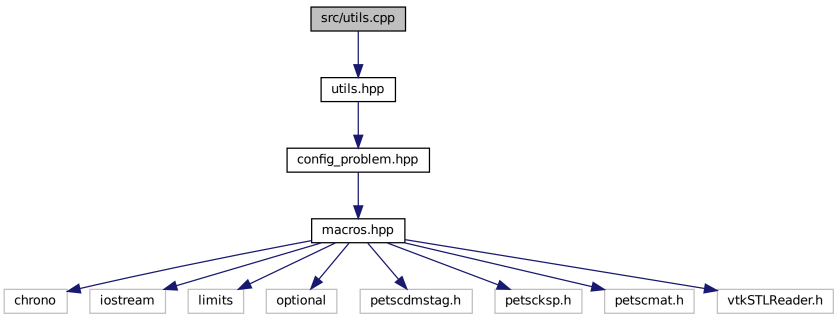
Include dependency graph for transport.cpp:



7.20 src/utils.cpp File Reference

`#include "utils.hpp"`

Include dependency graph for utils.cpp:



Functions

- PetscErrorCode CheckSolution (Vec const &sol, Vec const &solRef, std::string const &comp)

    Checks the difference between a computed solution and a reference solution and evaulates L2-norm.
- PetscErrorCode CreateAnalyticalU (DM const &dmGrid, Vec &vec, PetscReal const &theta)

    Creates an analytical solution on a staggered grid in the x-direction (dofs in position LEFT and RIGHT)
- PetscErrorCode CreateAnalyticalV (DM const &dmGrid, Vec &vec, PetscReal const &theta)

    Creates an analytical solution on a staggered grid in the y-direction (dofs in position DOWN and UP)
- PetscErrorCode CreateAnalyticalW (DM const &dmGrid, Vec &vec, PetscReal const &theta)

    Creates an analytical solution on a staggered grid in the z-direction (dofs in position BACK and FRONT)
- PetscErrorCode CreateAnalyticalP (DM const &dmGrid, Vec &vec, PetscReal const &theta)
- PetscErrorCode CreateGrid (DM ∗const dmGrid, PetscInt const &dof1, PetscInt const &dof2, PetscInt const &dof3)

    Creates a computational grid for simulation. Allows to specify dofs ONLY on edges, faces and cell-cenetrs. Pass 0 to not allow dofs in some position, 1 allocate dofs.

- void PrintSimulationParameters ()
  Prints the simulation parameters to the console.
- bool rayIntersectsTriangle (const std::array< double, 3 > &rayOrigin, const std::array< double, 3 > &ray↩ Vector, const std::array< double, 3 > &v0, const std::array< double, 3 > &v1, const std::array< double, 3 > &v2)
  Checks if a ray intersects with a triangle in 3D space (part of ray-casting algorithm to create Brinkman masks)
- bool isPointInsideMesh (const std::array< double, 3 > &point, const std::vector< std::array< double, 3 >> &vertices, const std::vector< std::array< int, 3 >> &faces)
  Determines if a point is inside a 3D mesh.
- void reader (const std::string &filename, std::vector< std::array< double, 3 >> &vertices, std::vector< std↩ ::array< int, 3 >> &faces)
  Reads a mesh file and extracts vertices and faces.
- PetscErrorCode createMaskU (DM const &dmGrid, Vec &vec_stag, std::vector< std::array< double, 3 >> const &vertices, std::vector< std::array< int, 3 >> const &faces)
  Creates a mask for the x-component component.
- PetscErrorCode createMaskV (DM const &dmGrid, Vec &vec_stag, std::vector< std::array< double, 3 >> const &vertices, std::vector< std::array< int, 3 >> const &faces)
  Creates a mask for the y-component component.
- PetscErrorCode createMaskW (DM const &dmGrid, Vec &vec_stag, std::vector< std::array< double, 3 >> const &vertices, std::vector< std::array< int, 3 >> const &faces)
  Creates a mask for the z-component component.

7.20.1 Function Documentation

7.20.1.1 CheckSolution()

```
PetscErrorCode CheckSolution (
            Vec const & sol,
            Vec const & solRef,
            std::string const & comp )
```

Checks the difference between a computed solution and a reference solution and evaulates L2-norm.

Parameters

sol	Computed solution vector.
solRef	Reference solution vector.

7.20.1.2 CreateAnalyticalP()

```
PetscErrorCode CreateAnalyticalP (
            DM const & dmGrid,
            Vec & vec,
            PetscReal const & theta )
```

7.20.1.3 CreateAnalyticalU()

```
PetscErrorCode CreateAnalyticalU (
            DM const & dmGrid,
            Vec & vec,
            PetscReal const & theta )
```

Creates an analytical solution on a staggered grid in the x-direction (dofs in position LEFT and RIGHT)

Parameters

dmGrid	Discretized grid.
vec	Output velocity field.

7.20.1.4 CreateAnalyticalV()

```
PetscErrorCode CreateAnalyticalV (
            DM const & dmGrid,
            Vec & vec,
            PetscReal const & theta )
```

Creates an analytical solution on a staggered grid in the y-direction (dofs in position DOWN and UP)

Parameters

dmGrid	Discretized grid.
vec	Output velocity field.

7.20.1.5 CreateAnalyticalW()

```
PetscErrorCode CreateAnalyticalW (
            DM const & dmGrid,
            Vec & vec,
            PetscReal const & theta )
```

Creates an analytical solution on a staggered grid in the z-direction (dofs in position BACK and FRONT)

Parameters

dmGrid	Discretized grid.
vec	Output velocity field.

7.20.1.6 CreateGrid()

```
PetscErrorCode CreateGrid (
            DM *const dmGrid,
            PetscInt const & dof1,
            PetscInt const & dof2,
            PetscInt const & dof3 )
```

Creates a computational grid for simulation. Allows to specify dofs ONLY on edges, faces and cell-cenetrs. Pass 0 to not allow dofs in some position, 1 allocate dofs.

Parameters

dmGrid	Pointer to the grid.
dof1	Degrees of freedom on edges.
dof2	Degrees of freedom of faces.
dof3	Degrees of freedom at cell-ceneters.

7.20.1.7 createMaskU()

```
PetscErrorCode createMaskU (
            DM const & dmGrid,
            Vec & vec_stag,
            std::vector< std::array< double, 3 >> const & vertices,
            std::vector< std::array< int, 3 >> const & faces )
```

Creates a mask for the x-component component.

Parameters

dmGrid	Discretized grid.
vec_stag	Output mask vector.
vertices	List of mesh vertices.
faces	List of mesh faces.

7.20.1.8 createMaskV()

```
PetscErrorCode createMaskV (
            DM const & dmGrid,
            Vec & vec_stag,
            std::vector< std::array< double, 3 >> const & vertices,
            std::vector< std::array< int, 3 >> const & faces )
```

Creates a mask for the y-component component.

Parameters

dmGrid	Discretized grid.
vec_stag	Output mask vector.
vertices	List of mesh vertices.
faces	List of mesh faces.

7.20.1.9 createMaskW()

```
PetscErrorCode createMaskW (
            DM const & dmGrid,
            Vec & vec_stag,
            std::vector< std::array< double, 3 >> const & vertices,
            std::vector< std::array< int, 3 >> const & faces )
```

Creates a mask for the z-component component.

Parameters

dmGrid	Discretized grid.
vec_stag	Output mask vector.
vertices	List of mesh vertices.
faces	List of mesh faces.

7.20.1.10 isPointInsideMesh()

```
bool isPointInsideMesh (
```

```
            const std::array< double, 3 > & point,
            const std::vector< std::array< double, 3 >> & vertices,
            const std::vector< std::array< int, 3 >> & faces )
```

Determines if a point is inside a 3D mesh.

Parameters

point	The point to be checked.
vertices	List of vertices of the mesh.
faces	List of faces of the mesh.

Returns

True if the point is inside the mesh, false otherwise.

7.20.1.11 PrintSimulationParameters()

```
void PrintSimulationParameters ( )
```

Prints the simulation parameters to the console.

7.20.1.12 rayIntersectsTriangle()

```
bool rayIntersectsTriangle (
            const std::array< double, 3 > & rayOrigin,
            const std::array< double, 3 > & rayVector,
            const std::array< double, 3 > & v0,
            const std::array< double, 3 > & v1,
            const std::array< double, 3 > & v2 )
```

Checks if a ray intersects with a triangle in 3D space (part of ray-casting algorithm to create Brinkman masks)

Parameters

rayOrigin	Starting point of the ray.
rayVector	Direction of the ray.
v0	First vertex of the triangle.
v1	Second vertex of the triangle.
v2	Third vertex of the triangle.

Returns

True if the ray intersects the triangle, false otherwise.

7.20.1.13 reader()

```
void reader (
            const std::string & filename,
            std::vector< std::array< double, 3 >> & vertices,
            std::vector< std::array< int, 3 >> & faces )
```

Reads a mesh file and extracts vertices and faces.

Parameters

filename	The name of the mesh file.

Parameters

vertices	Output list of vertices.
faces	Output list of faces.

Index