Tutorial 42: Performing FEM Stress and Displacement Analysis and Structural Optimization of Solids

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Complete List of all Tutorials with Publishable MATLAB Files of this Solid-Geoemtries Toolbox

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Motivation for this tutorial: (Originally SolidGeometry 4.2 required)

Yinlun Sun of TU Munich has supplemented the SG-Library with functions that allow a structural and topological optimization of geometric bodies with surface representation.

List of function introduced in this tutorial

- pdemodelofSG - creates a pde tetrahedron mesh-model from a solid surface geometry
- pdeplot3D - Plot 3-D solution or surface mesh
- SGofpdemodel - returns a solid geometry surface model of a pde model
- SGremsurfpoints - returns a surface model without surface points that are inside of a surface - boundary/edge points are unchanged
- SGremsurfedgepoints - returns a surface model without edge points and surface points that are inside of a surface
- pdegplot - Plot PDE tetrahedron mesh geometry
- FSplot - plots the featureEdges of TR, SG or VLFL
- pdeplotfaces - simply plots the surfaces to select; similar as FSplot
- SGplotsurfaceload - plots the surface load of a solid geometry
- pdesolvesurfaceload - calculates the FEM analysis using pde for a pde mesh model
- pdestressstatic - returns the calculated static stress inside a SG based on a pde model by YINLUN SUN
- SGshapeOptiCAO - returns the optimized shape of a given structure based on biological growth

```
function VLFL_EXP42
```

```
% clear all; close all;
```

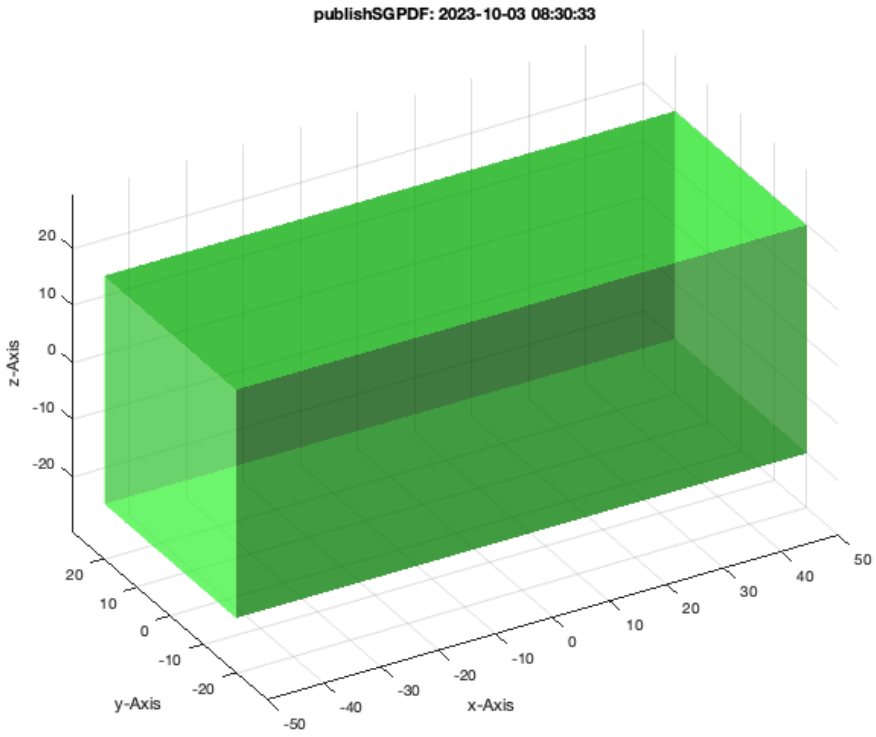
1. Conversion between triangle surface model and tetrahedon volumen model

1.1 Create a simple bar type link

```
A=SGbox([100,40,40])
SGfigure; h=SGplot(A); view(-30,30); setplotlight(h,'g',0.5);
```

```
A =
  struct with fields:
```

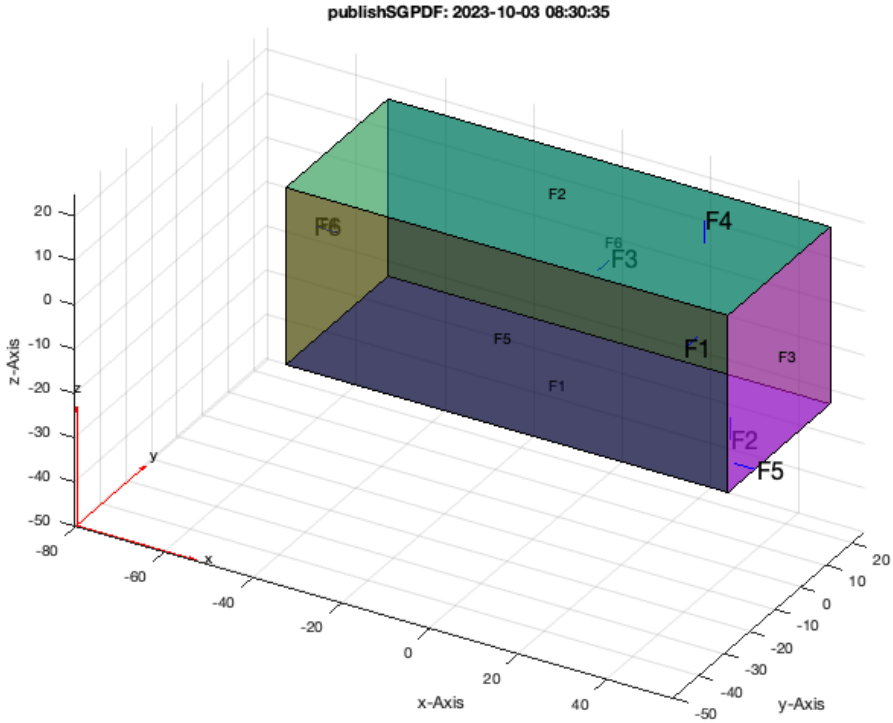
```
    VL: [8×3 double]
    FL: [12×3 double]
 Tname: {'B'  'F'  'X+'  'X-'  'Y+'  'Y-'}
     T: {1×6 cell}
  TFiL: {[]  []  []  []  []  []}
```



1.2 Create a pde mesh model of the simple bar with voxel size 5mm

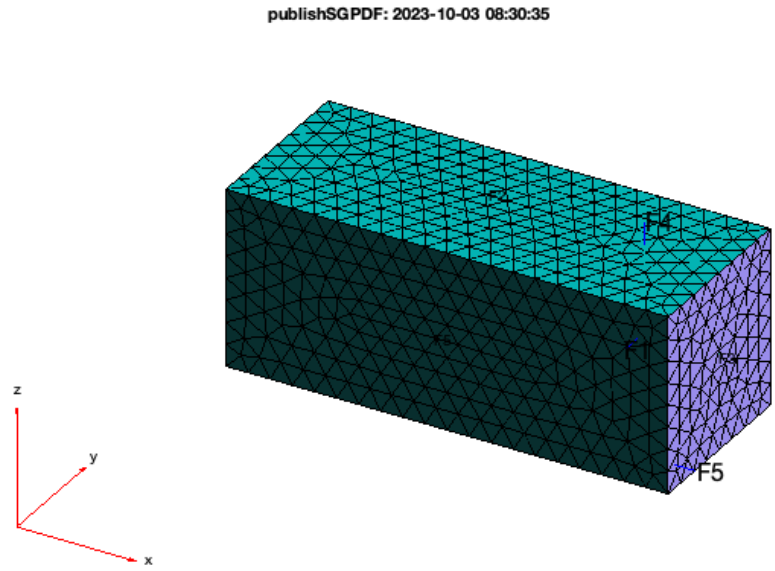
```
pdemodelofSG(A,5); model=ans
```

```
6 Feature Surfaces found! Only the largest 99.90% (4.000 .. 4000.0mm^2), i.e. 6 of 6 are shown.
model =
  PDEModel with properties:

          PDESystemSize: 3
        IsTimeDependent: 0
               Geometry: [1×1 DiscreteGeometry]
    EquationCoefficients: [1×1 CoefficientAssignmentRecords]
      BoundaryConditions: []
       InitialConditions: []
                    Mesh: [1×1 FEMesh]
           SolverOptions: [1×1 pde.PDESolverOptions]
```



1.3 Show the tetrahedron volume structure of the mesh

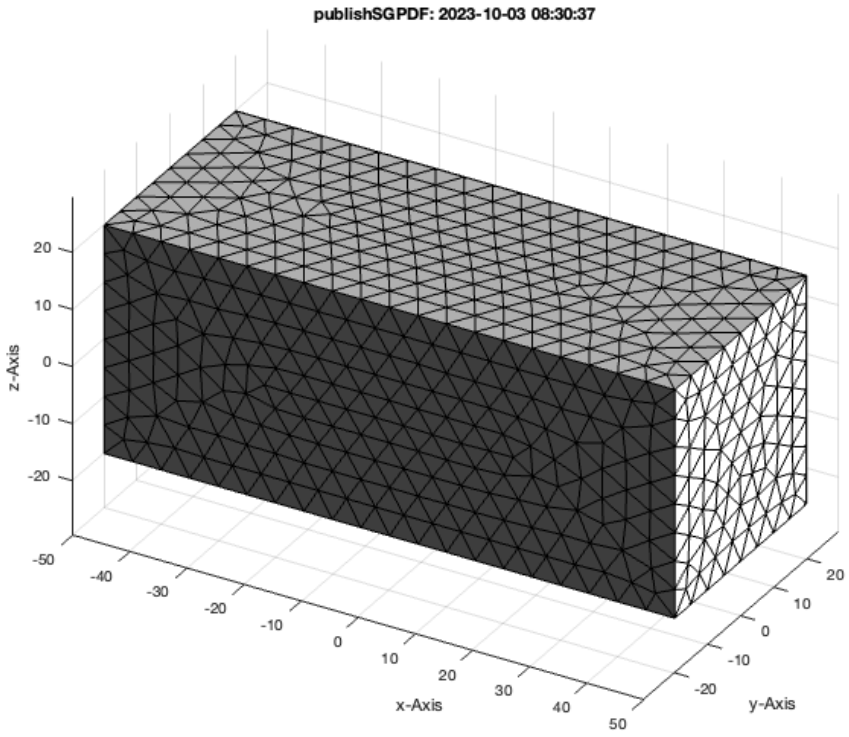
```
pdeplot3D(model);
```



1.4 Convert the tetrahedron volume into a surface model

```
SGofpdemodel(model); B=ans
```

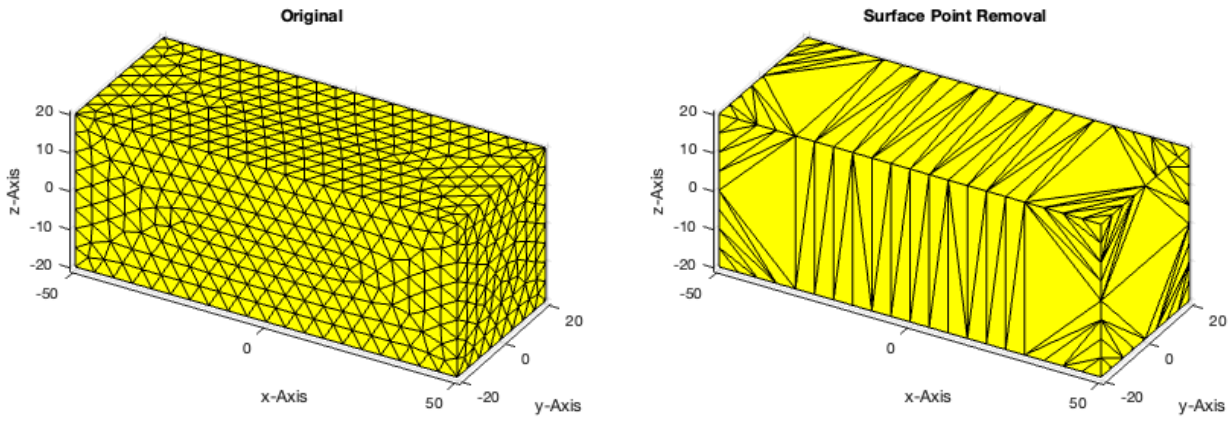
```
ans =
  Figure (1: AOI Matlab Solid Modeler app_2012_11_09) with properties:

      Number: 1
        Name: 'AOI Matlab Solid Modeler app_2012_11_09'
       Color: [1 1 0.9000]
    Position: [31 803 960 540]
       Units: 'pixels'

  Use GET to show all properties
B =
  struct with fields:

    VL: [924×3 double]
    FL: [1844×3 double]
    FC: [1844×3 double]
```



1.5 Remove surface points of the surface model but protect the edge points

```
SGremsurfpoints(B); C=ans
```

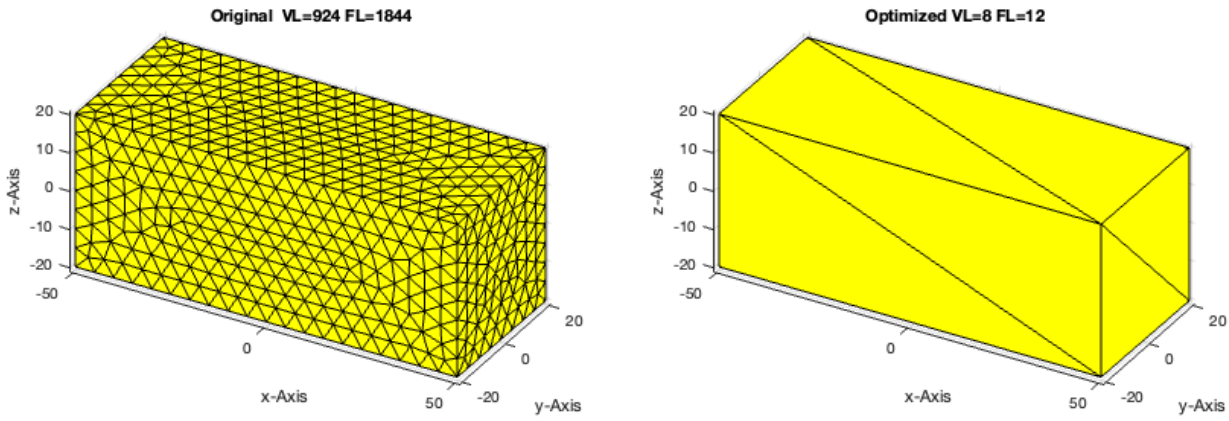
```
C =
  struct with fields:

    VL: [140×3 double]
    FL: [276×3 double]
    FC: [276×3 double]
```



1.6 Remove unused edge points and surface points of the surface model

```
SGremsurfedgepoints(B); C=ans
```

```
C =
  struct with fields:

       VL: [8×3 double]
       FL: [12×3 double]
       FC: [12×3 double]
    Tname: {}
        T: {}
     TFiL: {}
```

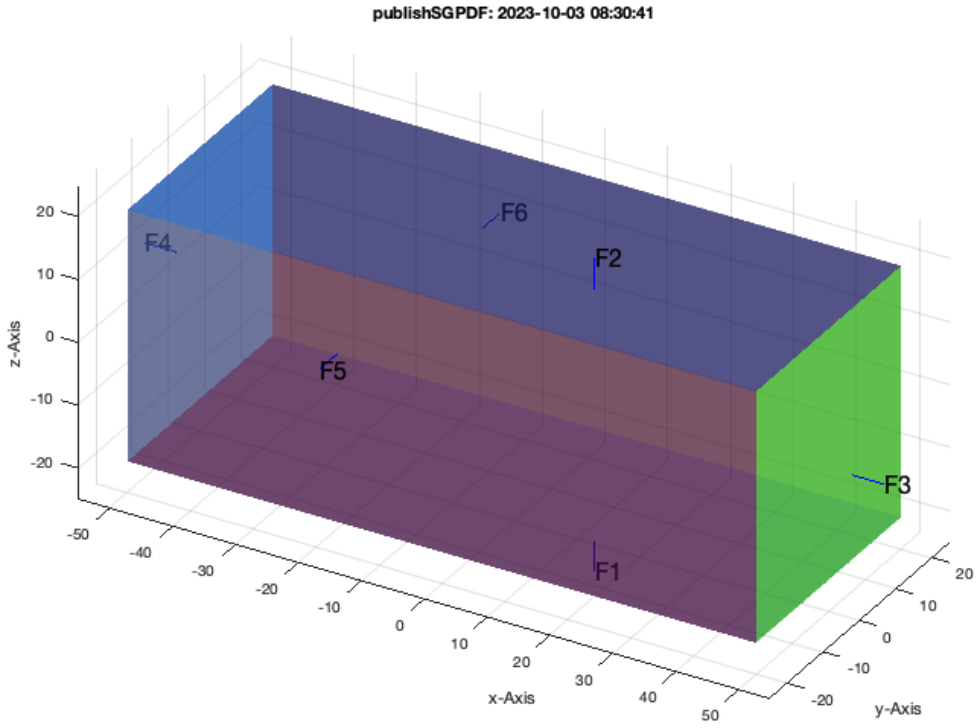


2. Selection of Feature Surfaces for load specification

2.1 Feature surface plot on surface model lebel

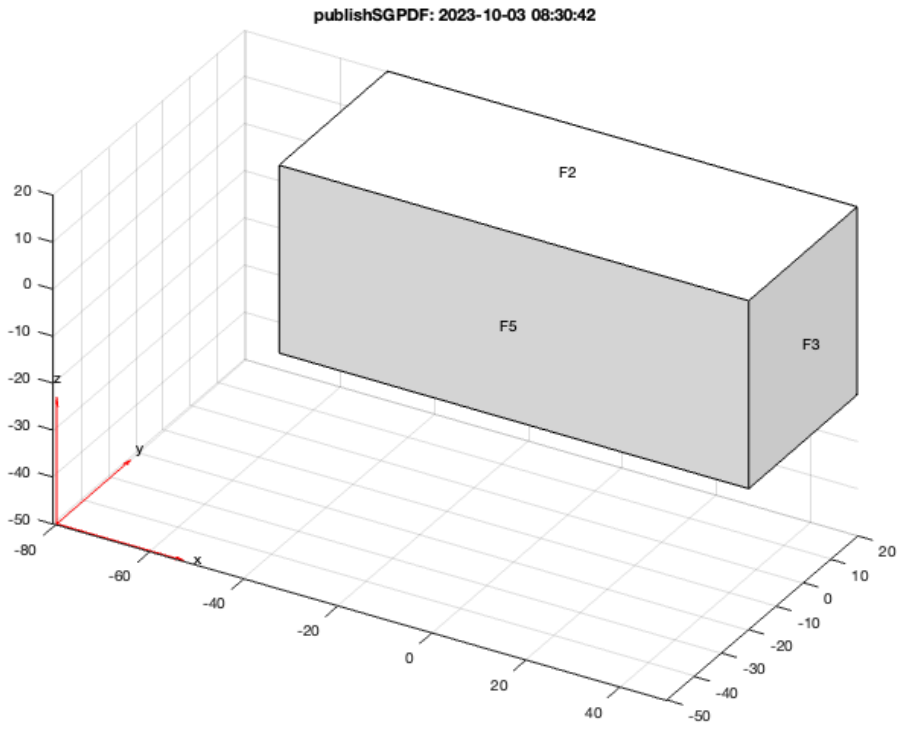
```
SGfigure; view(30,30);
FSplot(A);
```

```
6 Feature Surfaces found! Only the largest 99.90% (4.000 .. 4000.0mm^2), i.e. 6 of 6 are shown.
```



2.2 Feature surface plot on pde model lebel

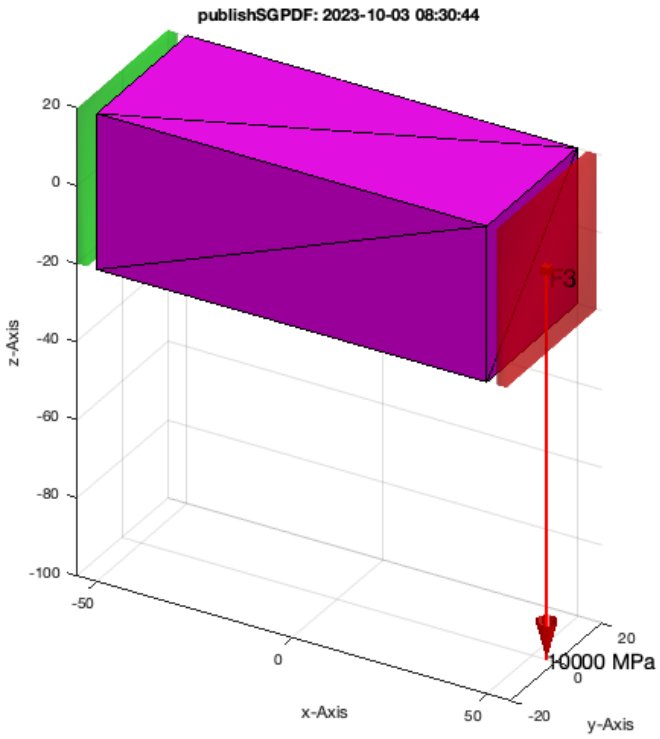
```
SGfigure; view(30,30)
pdeplotfaces(model);
```



3. Calculating surface load dependend displacement and von-Miss stress situation

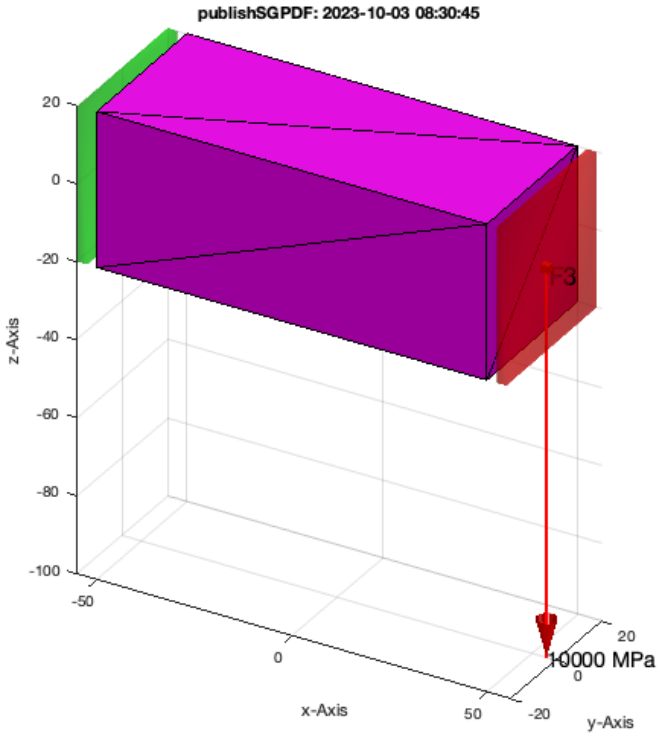
3.1 Display a loading condition Fixed facet is 4, loaded surface is 3, load vector in z using Propertynames

```
SGfigure; SGplot(A,'m'); view(30,30);
SGplotsurfaceload (A,'FixedFaceIndices',4,'LoadFaceIndices',3,'Load',[0 0 -1e4]);
```



3.2 Display a loading condition Fixed facet is 4, loaded surface is 3, load vector in z using varargin

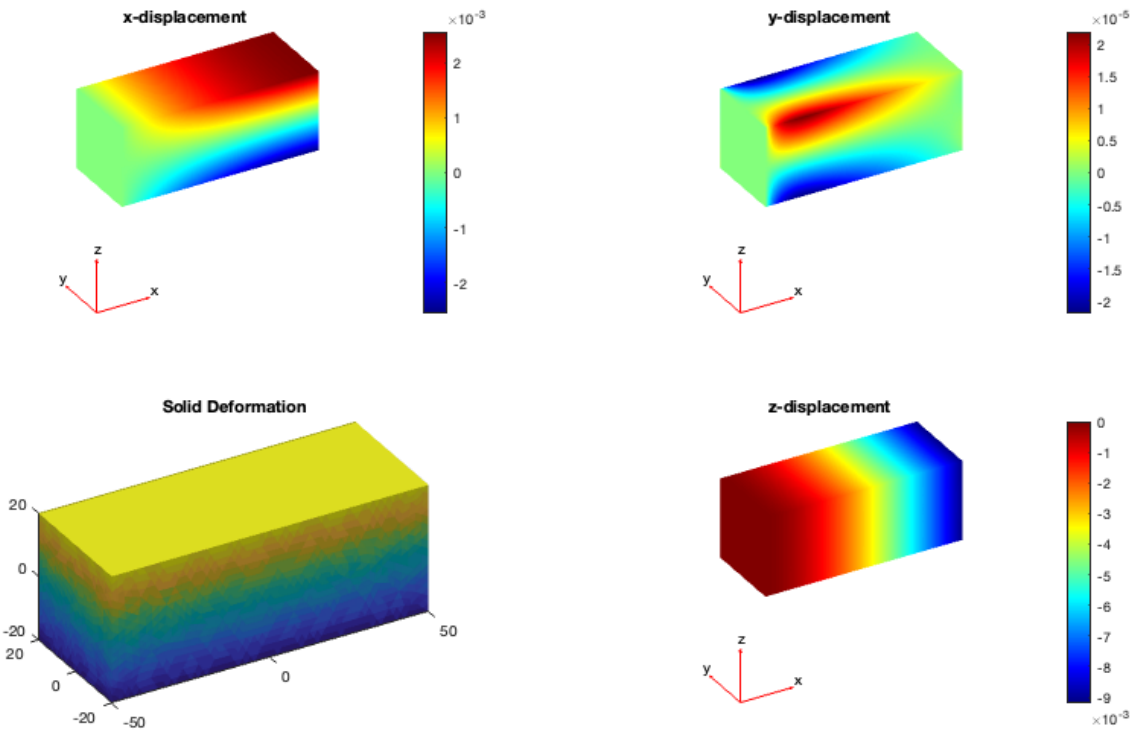
```
SGfigure; SGplot(A,'m'); view(30,30);
SGplotsurfaceload (A,4,3,[0 0 -1e4]);
```



3.3 Fixed facet is 4, loaded surface is 3, load vector in z using varargin

```
pdesolvesurfaceload(model,4,3,[0 0 -1e4]);
```

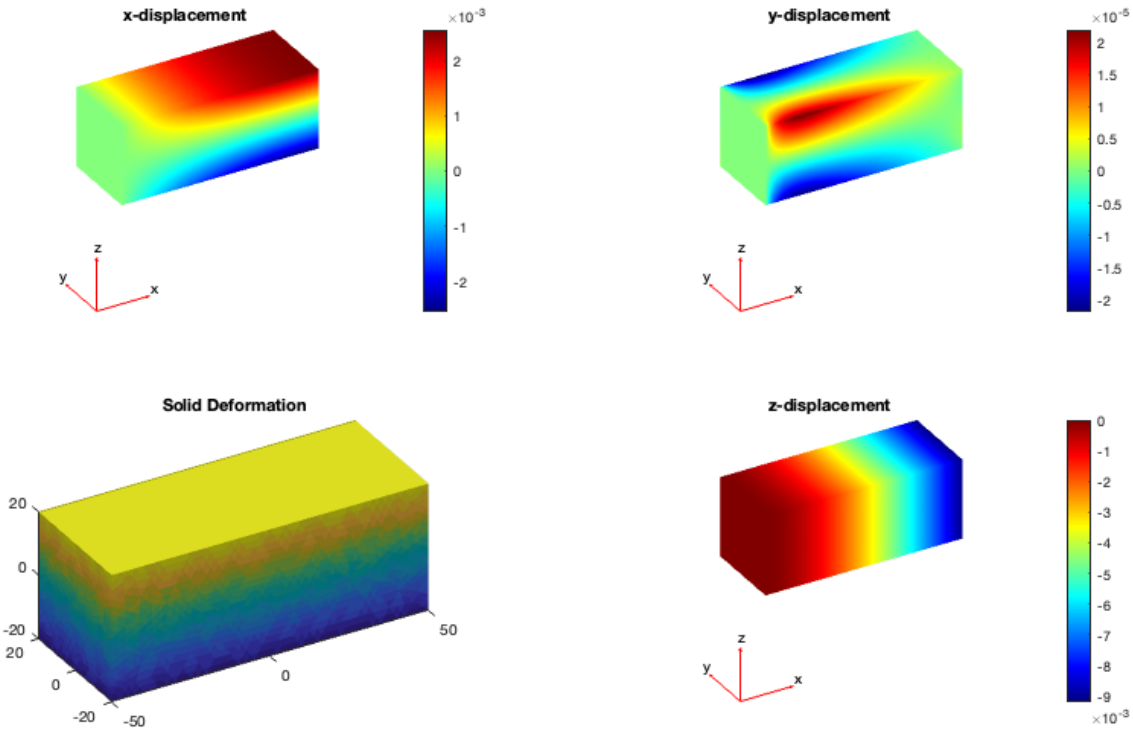
```
ATTENTION: The already existing pde BoundaryConditions are deleted first
```



3.4 Fixed facet is 4, loaded surface is 3, load vector in z using Propertynames

```
pdesolvesurfaceload(model,'FixedFaceIndices',4,'LoadFaceIndices',3,'Load',[0 0 -1e4]);
```

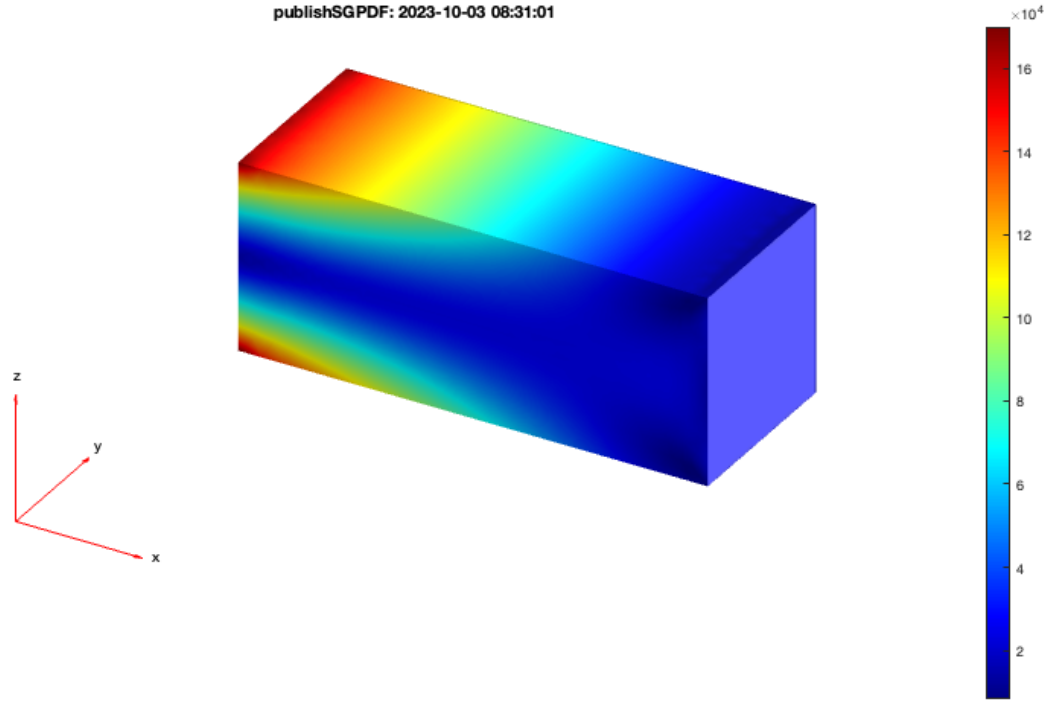
```
ATTENTION: The already existing pde BoundaryConditions are deleted first
```



3.5 Show von-mises-Stress for load condition

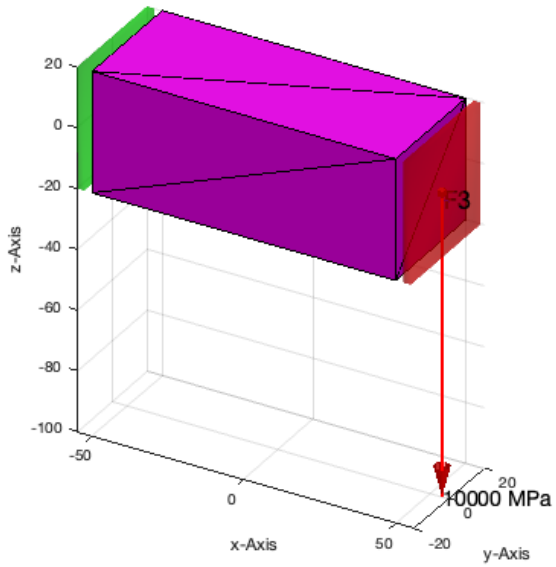
```
[result,model]=pdesolvesurfaceload(model,'FixedFaceIndices',4,'LoadFaceIndices',3,'Load',[0 0 -1e4]);
pdestressstatic(model,result);
```

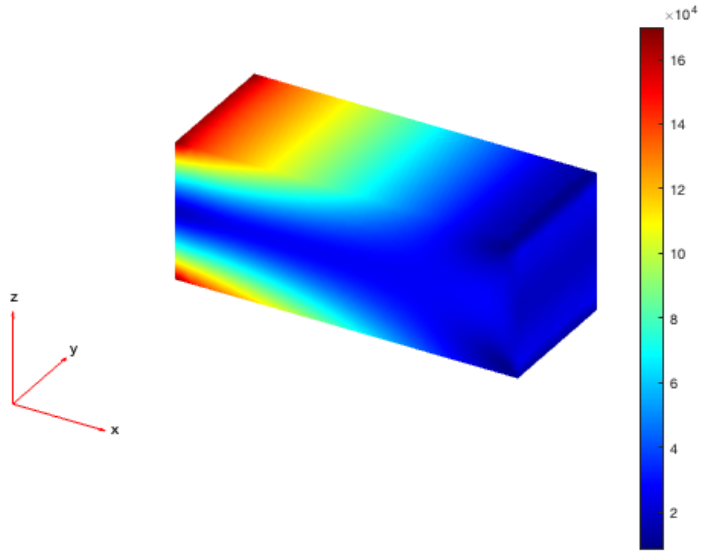
```
ATTENTION: The already existing pde BoundaryConditions are deleted first
```



3.6 Show von-mises-Stress and load condition

```
close all; figure(1);  view(30,30); SGplot(A,'m');
SGplotsurfaceload (A,'FixedFaceIndices',4,'LoadFaceIndices',3,'Load',[0 0 -1e4]);
figure(2); view(30,30);
[~,stress]=pdestressstatic(model,result);
pdeplot3D(model,'colormapdata',stress);
```





3.7 Do the same for the matlab standard fem solid: BracketWithHole

```
A=SGreadSTL(which('BracketWithHole.stl'),1000);
model=pdemodelofSG(A);
[result,model]=pdesolvesurfaceload(model,'FixedFaceIndices',3,'LoadFaceIndices',9,'Load',[0 0 -1e4]);
close all; figure(1);  view(30,30); FSplot(A);
SGplotsurfaceload (A,'FixedFaceIndices',3,'LoadFaceIndices',9,'Load',[0 0 -1e4]);
figure(2); view(30,30);
[~,stress]=pdestressstatic(model,result);
pdeplot3D(model,'colormapdata',stress);
```

```
LOADING ASCII STL-File: /Applications/MATLAB_R2023a.app/toolbox/pde/pdedata/BracketWithHole.stl scaling factor: 1000
Processing 2102 lines:
Finishing solid bracket_with_hole_meters
ATTENTION: The already existing pde BoundaryConditions are deleted first
9 Feature Surfaces found! Only the largest 99.90% (39.433 .. 39433.2mm^2), i.e. 9 of 9 are shown.
```

4 Structural Optimization

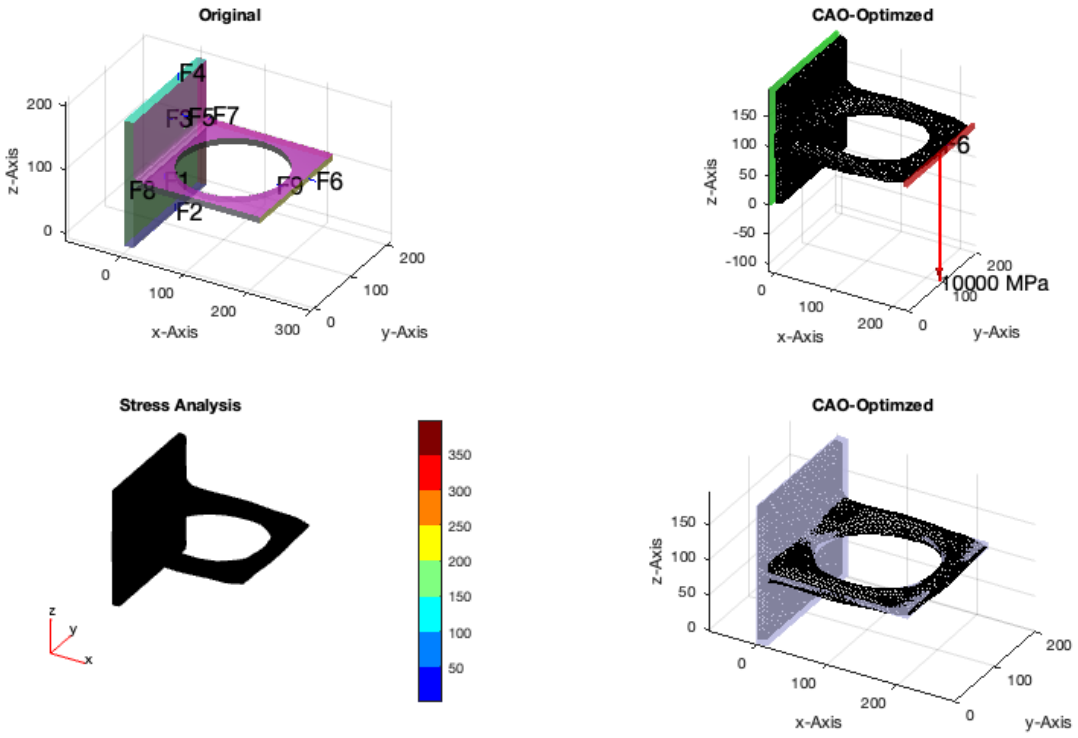
4.1 CAO Optimization using load face 9

```
SGshapeOptiCAO(A,'FixedFaceIndices',3,'LoadFaceIndices',9,'Load',[0 0 -1e4]);
```

4.2 CAO Optimization using load face 6

```
SGshapeOptiCAO(A,'FixedFaceIndices',3,'LoadFaceIndices',6,'Load',[0 0 -1e4]);
```

```
Iteration   0: Volume of SG is 801084.6513
Iteration   1: Volume of SG is 789935.0822
Iteration   2: Volume of SG is 779164.6696
Iteration   3: Volume of SG is 770958.1838
Iteration   4: Volume of SG is 764234.1656
Iteration   5: CAO end: CAO process stops because meshing size does not fit.

******************** CAO result **********************
Original volume: 801084.6513 mm^3
Optimized volume: 764234.1656 mm^3
Original maximal von Mises stress: 1679.0178 N/mm^2
Optimized maximal von Mises stress: 397.9235 N/mm^2
9 Feature Surfaces found! Only the largest 99.90% (39.433 .. 39433.2mm^2), i.e. 9 of 9 are shown.
```



4.3 CAO Optimization using load face 5

SGshapeOptiCAO(A,'FixedFaceIndices',3,'LoadFaceIndices',5,'Load',[0 0 -1e4]);

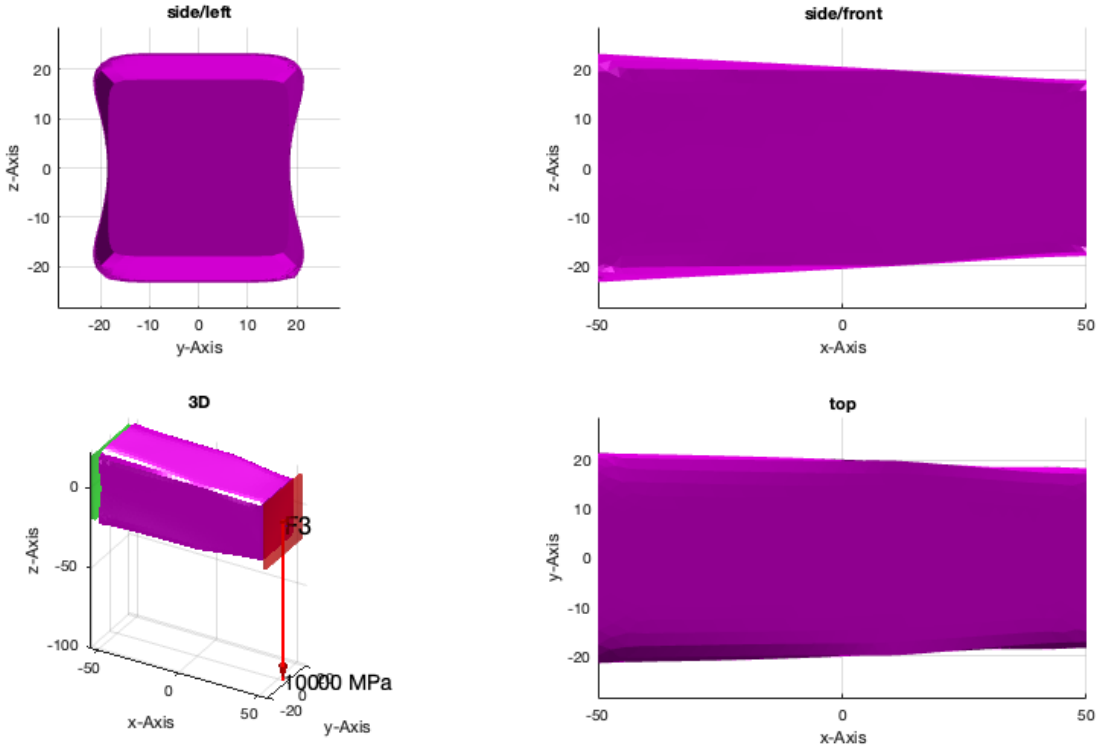
4.4 CAO Optimization using load face 1

SGshapeOptiCAO(A,'FixedFaceIndices',3,'LoadFaceIndices',1,'Load',[0 0 -1e4]);

4.5 CAO Optimization of a simple bar

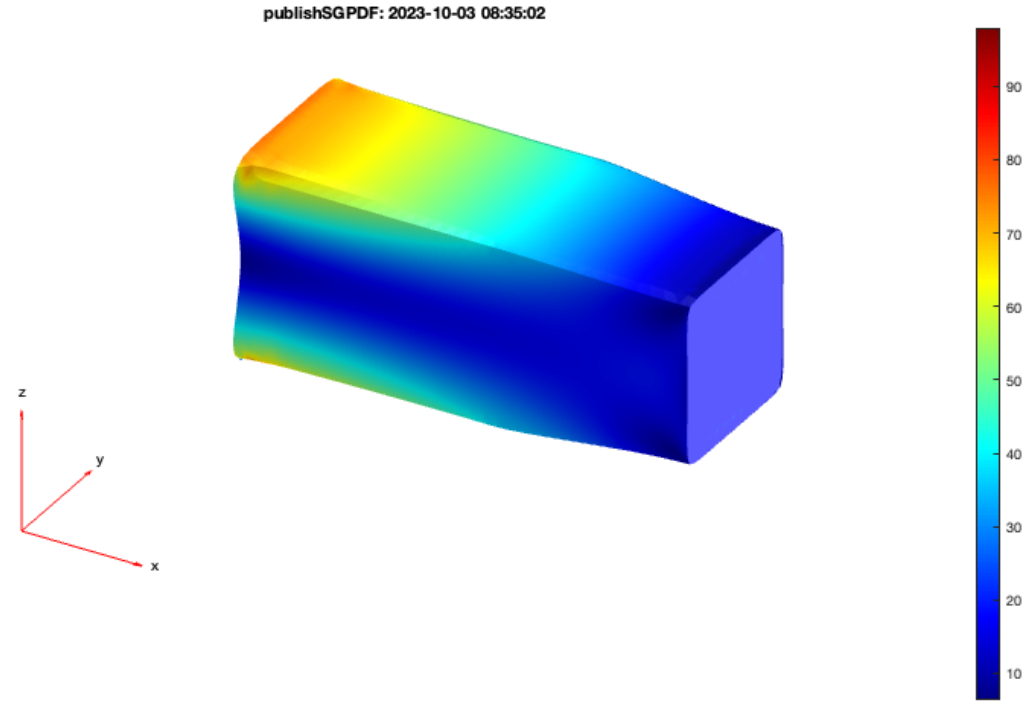
```
A=SGbox([100,40,40])
[B,result,model]=SGshapeOptiCAO(A,'FixedFaceIndices',4,'LoadFaceIndices',3,'Load',[0 0 -1e4]);
SGplot4(B,'m');
subplot(2,2,3); SGplotsurfaceload(A,'FixedFaceIndices',4,'LoadFaceIndices',3,'Load',[0 0 -1e4]);
```

```
A =
  struct with fields:

       VL: [8×3 double]
       FL: [12×3 double]
    Tname: {'B'  'F'  'X+'  'X-'  'Y+'  'Y-'}
        T: {1×6 cell}
     TFiL: {[]  []  []  []  []  []}
Iteration   0: Volume of SG is 160000
Iteration   1: Volume of SG is 159744.8536
Iteration   2: Volume of SG is 159463.2535
Iteration   3: Volume of SG is 159127.165
Iteration   4: Volume of SG is 158756.2911
Iteration   5: Volume of SG is 158383.9463
Iteration   6: Volume of SG is 158029.9453
Iteration   7: CAO end: CAO process stops because meshing size does not fit.

******************* CAO result *********************
Original volume: 160000 mm^3
Optimized volume: 158029.9453 mm^3
Original maximal von Mises stress: 110.8547 N/mm^2
Optimized maximal von Mises stress: 86.9479 N/mm^2
```



4.6 Show the stress distribution in the CAO optimized shape

```
SGfigure; pdestressstatic(model,result);
view(30,30);
```



Final Remarks

```
close all
```

```
VLFLlicense
```

```
Error using matlab.ui.Figure/addprop
Invalid or deleted object.
Error in internal.matlab.publish.PublishFigures/leavingCell (line 108)
                    addprop(f, obj.publishGeneratedFigure);
Error in snapnow>leavingCell (line 212)
            newFiles = data.plugins(iPlugins).instance.leavingCell(iCell);
Error in snapnow (line 144)
                        data = leavingCell(iCell(k), data, doCapture(k));
Error in VLFL_EXP42 (line 144)
SGshapeOptiCAO(A,'FixedFaceIndices',3,'LoadFaceIndices',9,'Load',[0 0 -1e4]);
Error in evalmxdom>instrumentAndRun (line 116)
text = evalc(evalstr);
Error in evalmxdom (line 21)
[data,text,laste] = instrumentAndRun(file,cellBoundaries,imageDir,imagePrefix,options);
Error in publish

Error in publishSGPDF (line 15)
    publish(vname,form);
Iteration   0: Volume of SG is 801143.4667
Iteration   1: CAO end: CAO process stops because meshing size does not fit.

******************** CAO result **********************
Original volume: 801143.4667 mm^3
Optimized volume: 801143.4667 mm^3
Original maximal von Mises stress: 549.3953 N/mm^2
Optimized maximal von Mises stress: 549.3953 N/mm^2
9 Feature Surfaces found! Only the largest 99.90% (39.433 .. 39433.2mm^2), i.e. 9 of 9 are shown.



This VLFL-Lib, Rel.  (2023-Oct-03), is for limited non commercial educational use only!
Licensee: Tim Lueth (Development Version)!
Please contact Tim Lueth, Professor at TU Munich, Germany!
WARNING: This VLFL-Lib (Rel. ) license will exceed at 06-Jul-2078 08:35:03!
Executed 03-Oct-2023 08:35:05 by 'timlueth' on a MACI64 using Mac OSX 13.6 | R2023a Update 5 | SG-Lib 5.4
======================================== Used Matlab products: ========================================
database_toolbox
distrib_computing_toolbox
fixed_point_toolbox
image_toolbox
map_toolbox
matlab
pde_toolbox
simmechanics
simscape
simulink
=======================================================================================================
```

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