OSCILOSopt User Guide

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OSCILOSopt is a variant of OSCILOS­lite [1] which allows the user to optimise a thermoacoustically unstable combustor by varying the combustor dimensions. Optimisation is completed using a genetic algorithm. OSCILOSopt lifts significant sections of code from OSCILOSlite­ and follows the same structure and thus will be updated in line with OSCILOSlite. For this reason, it is recommended that the OSCILOSlite User Guide [1] is read before this document, as this document only details the additional functions and inputs required in OSCILOSopt, relative to OSCILOS­lite. All mentions of OSCILOSlite refer to [1,2]. This open source code is available from <https://www.oscilos.com/> along with the other versions of OSCILOS [2,3].

Contents

[1 Getting Started 2](#_Toc72872531)

[1.1 Running OSCILOSopt 2](#_Toc72872532)

[1.2 Structure of OSCILOSopt 2](#_Toc72872533)

[2 Inputs 5](#_Toc72872534)

[2.1 Initialisation 5](#_Toc72872535)

[2.2 Optimisation 5](#_Toc72872536)

[2.3 Geometry Bounds 6](#_Toc72872537)

[2.4 Linear Constraints 7](#_Toc72872538)

[3 Genetic Algorithm Termination 8](#_Toc72872539)

[4 Outputs 9](#_Toc72872540)

[5 OSCILOSopt Example Cases 10](#_Toc72872541)

[5.1 Rijke Tube 10](#_Toc72872542)

[5.1.1 Inputs 10](#_Toc72872543)

[5.1.2 Outputs 12](#_Toc72872544)

[5.2 NoiseDyn Burner 16](#_Toc72872545)

[5.2.1 Inputs 16](#_Toc72872546)

[5.2.2 Outputs 18](#_Toc72872547)

[5.3 Palies Burner 22](#_Toc72872548)

[5.3.1 Inputs 22](#_Toc72872549)

[5.3.2 Outputs 24](#_Toc72872550)

[6 References 29](#_Toc72872551)

# Getting Started

## Running OSCILOSopt

OSCILOSopt is written in MATLAB, version R2021a, and requires the following MATLAB Toolboxes to be installed:

* Global Optimization Toolbox (Not required for other versions of OSCILOS)
* Optimization Toolbox

## Structure of OSCILOSopt

Each optimisation routine is started by running the ./OSCILOS\_opt.m main script in the root directory and a summary of the files and folders which make up OSCILOSopt can be found in Figure 1. ./OSCILOS\_opt.m calls the following seven subfunctions located in ./SubFunctions/.

1. Init\_subfc – as in OSCILOSlite.
2. Optimisation\_subfc – Optimises geometry using a genetic algorithm.
3. Geometry\_subfc – as in OSCILOSlite.
4. Mean\_flow\_subfc – as in OSCILOSlite.
5. Flame\_subfc – as in OSCILOSlite.
6. BC\_subfc – as in OSCILOSlite.
7. Solver\_subfc – as in OSCILOSlite.

The Optimisation\_subfc.m subfunction optimises the combustor geometry by calling the optimisation functions in ./SubFunctions/OptimFunctions/.

1. GA\_init\_subfc – Initialises the genetic algorithm used for optimisation.
2. Geometry\_bounds\_subfc – Sets upper and lower bounds on geometry to constrain optimisation.
3. Objective\_subfc – The function which is minimised during optimisation.
4. GA\_out\_subfc – Provides termination criteria for the genetic algorithm.
5. Plot\_results\_subfc – Plots the results of the optimisation procedure.

The OSCILOSopt inputs are located in text files which can be read and edited in the ./Inputs/ subfolder and are as follows.

* Initialisation (Init.txt) – Modified from OSCILOSlite, see Section 2.1.
* Geometry (Geometry.txt) – As in OSCILOSlite.
* Mean Flow (Mean\_flow.txt) – As in OSCILOSlite.
* Boundary Conditions (Inlet.txt & Outlet.txt) – As in OSCILOSlite.
* Flame Model (Flame.txt) – As in OSCILOSlite.
* Scan Range (Scan\_range.txt) – As in OSCILOSlite.
* Optimisation (Optimisation.txt) – See Section 2.2.
* Geometry Bounds (Geometry\_bounds.txt) – See Section 2.3.

Output files may be written to ./Outputs/ and include the following.

* Initialisation (./Outputs/Initialisation/)
  + A text file of the initial geometry (Initial\_geometry.txt).
  + Two images of the initial combustor (Geometry.\*, where \* is fig or pdf).
  + A text file of the initial combustor eigenvalues (Eigenvalues.txt).
  + Two images of the initial combustor eigenvalue map (Eigenvalue\_map.\*, where \* is fig or pdf).
* Results (./Outputs/Results/)
  + A text file of the optimised geometry (Final\_geometry.txt).
  + Two images of the optimised combustor (Geometry.\*, where \* is fig or pdf).
  + A text file of the optimised combustor eigenvalues (Eigenvalues.txt).
  + Two images of the optimised combustor eigenvalue map (Eigenvalue\_map.\*, where \* is fig or pdf).
  + Two images showing the progression of optimisation after each genetic algorithm generation (GA\_plot.\*, where \* is fig or pdf).

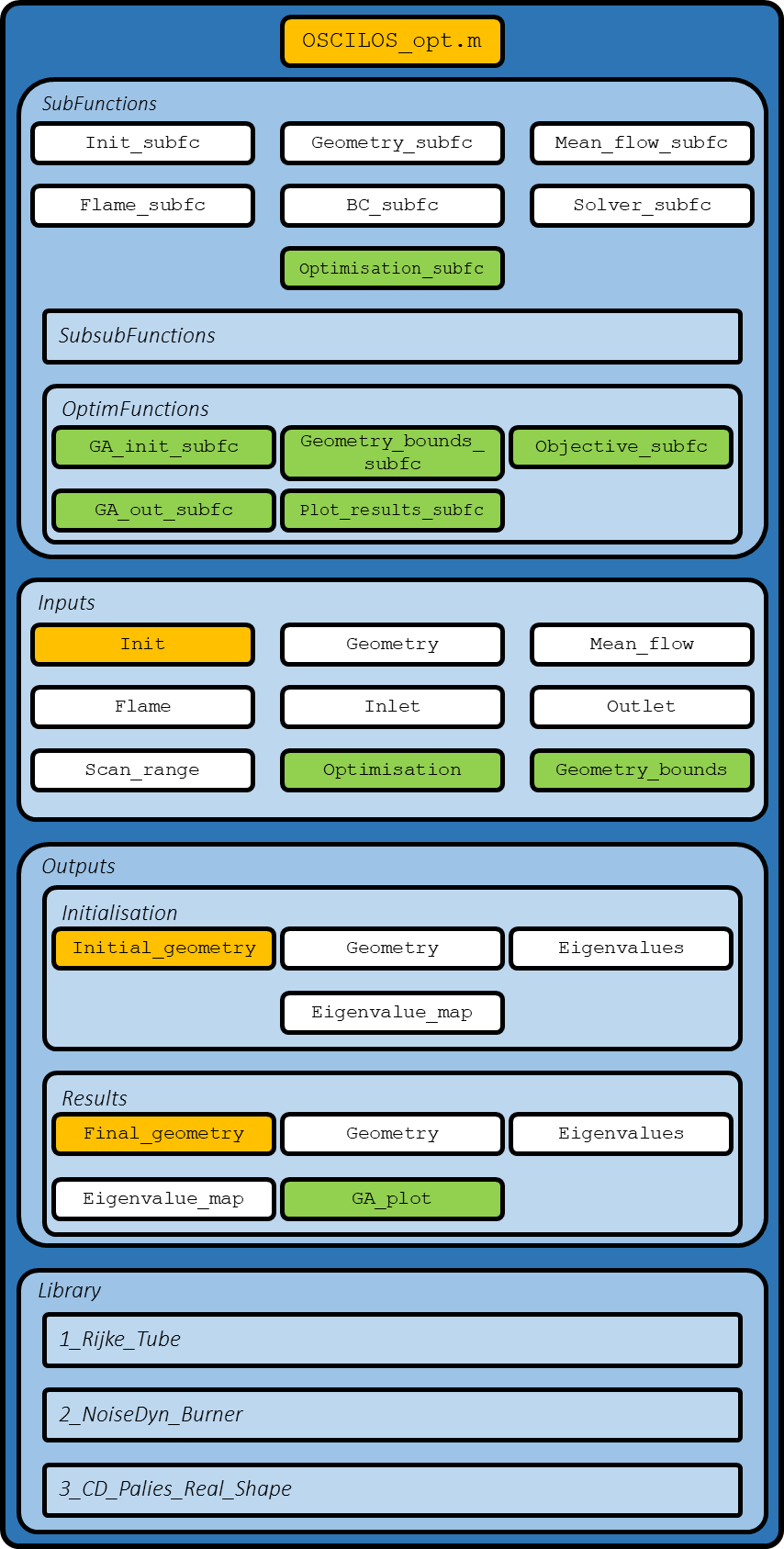


Figure : Folders, subfolders and files which make up OSCILOSopt. White files exist as in OSCILOSlite, orange files are slightly modified compared to OSCILOSlite and green files are new to OSCILOSopt.

# Inputs

OSCILOSopt input files located in the ./Inputs/ folder are as described in the OSCILOSlite User Guide, except for the following three files, which are either unique to OSCILOSopt or modified from OSCILOSlite.

## Initialisation

The initialisation parameters are read from the file ./Inputs/Initialisation.txt. The parameters are set and behave as in OSCILOSlite, with one additional parameter, Optimise, added to the file. The Init.txt file should take the form:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Disp\_figs | Small\_plots | Save\_pdfs | Save\_figs | Save\_eig | Plot\_modes | Optimise |
|  |  |  |  |  |  |  |

Optimise determines whether OSCILOSopt carries out the optimisation routine (Optimise = 1), or not (Optimise = 0).

The ability to plot the modes is generally not required when optimising the geometry and modes can be plotted by running the optimised geometry in OSCILOSlite. Therefore, the first *n* modes will not be plotted (Plot\_modes = n) as the required code has been suppressed as a comment in ./SubFunctions/Solver\_subfc.m, so the variable only remains to maintain consistency with OSCILOSlite during future updates. To plot the first *n* modes for the initial and optimised geometry, the suppression of the code in ./SubFunctions/Solver\_subfc.m can be removed.

## Optimisation

The optimisation parameters are read from the file ./Inputs/Optimisation.txt. These parameters determine how the genetic algorithm is conducted. The Optimisation.txt file should take the form:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Geom\_bounds | Population | MaxGenerations | EliteCount | Max\_GR |
|  |  |  |  |  |

Each parameter in the Optimisation.txt file is now described:

* Geom\_bounds: Sets the upper and lower bounds on each axial length and radius which makes up the combustor’s geometry. Either all axial lengths and radii described in ./Inputs/Geometry.txt vary by the same percentage, *x*% (0<x≤100), or the bounds on each dimension are individually specified as in Section 2.3 (x=0).
* Population: The population of each genetic algorithm generation.
* MaxGenerations: The maximum number of genetic algorithm generations before termination.
* EliteCount: The number of elite individuals carried forward to successive generations.
* Max\_GR: The value which all growth rates must fall below for early termination of the algorithm, measured in .

## Geometry Bounds

The geometry bounds parameters are read from the file ./Inputs/Geometry\_bounds.txt. These parameters set the maximum and minimum values of each dimension of the combustor and is only read when the parameter Geom\_bounds = 0 in ./Inputs/Optimisation.txt. The Geometry\_bounds.txt file should take the form:

|  |  |  |  |
| --- | --- | --- | --- |
| x[m]\_lower | x[m]\_upper | r[m]\_lower | r[m]\_upper |
|  |  |  |  |
| … | … | … | … |

Each parameter in the Geometry\_bounds.txt file is now described:

* x[m]\_lower: Lower bound for each axial length in Geometry\_bounds.txt.
* x[m]\_upper: Upper bound for each axial length in Geometry\_bounds.txt.
* r[m]\_lower: Lower bound for each radius in Geometry\_bounds.txt.
* r[m]\_upper: Upper bound for each radius in Geometry\_bounds.txt.

Axial lengths and radii are defined as in the example in Figure 2, with sets of radii bounds and sets of axial length bounds.

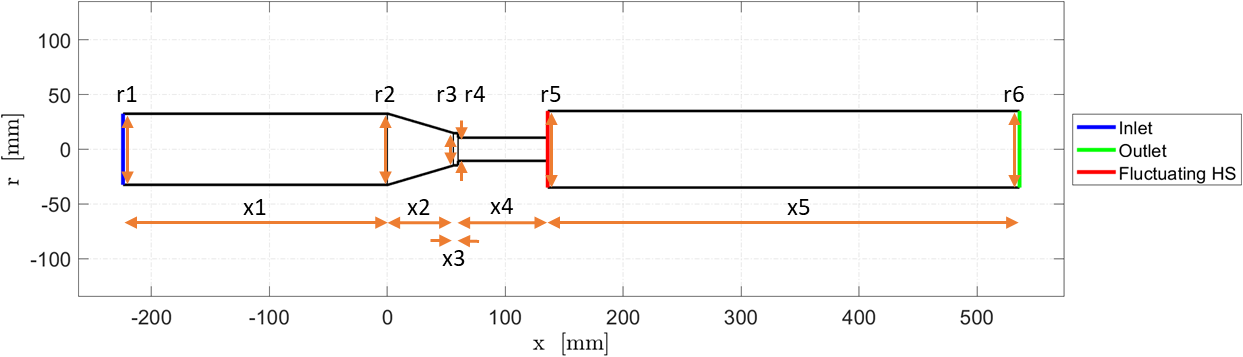
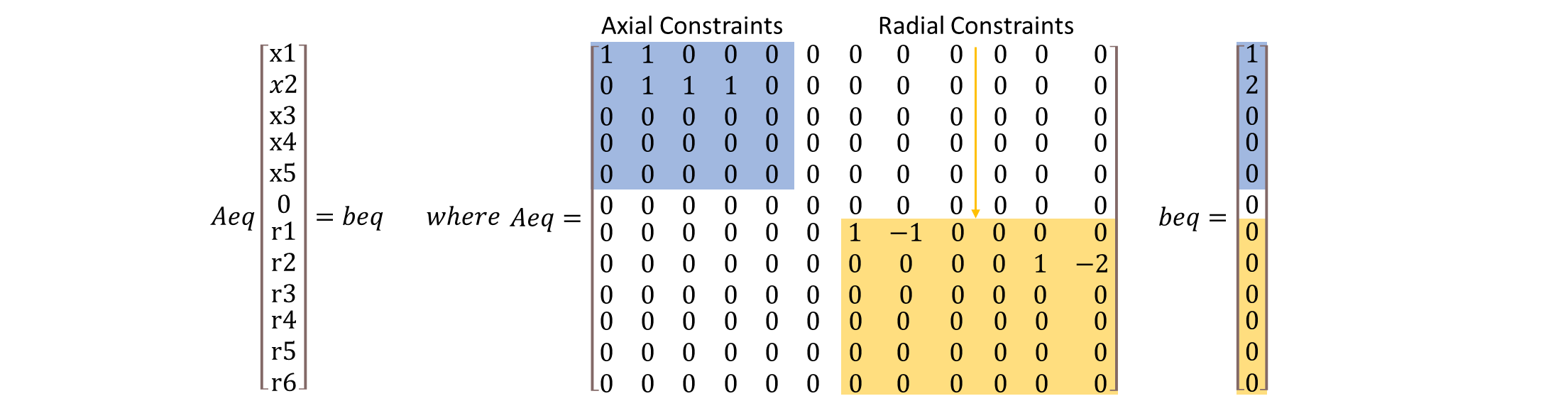


Figure : Example of how axial lengths and radii are defined in Geom\_bounds.txt

## Linear Constraints

OSCILOSopt also allows the user to set linear constraints on the combustor geometry. The main scenarios in which this may be applied would when keeping two radii equal, such as a constant radius at the entrance and exit of the plenum chamber in Figure 2 (), or keeping the total burner length constant ().

The user defines such constraints in the Geometry\_bounds\_subfc subfunction in the linear constraint section. The constraints are defined as variables in the two linear equality matrices, and , below. The cells highlighted in blue can impose axial constraints, whilst the yellow cells define constraints on the radii.



is a matrix, where is the number of radius (or axial position) values defined in the Geometry.txt input file. is a matrix.

Below, examples are given for using the linear equality constraints based on the notation in Figure 2.

The first rows, highlighted in blue, allow for axial length constraints to be applied to the geometry. The first two rows of and above provide example uses of the axial length constraints.

* The first line ensures
* The second line ensures

The final rows, highlighted in yellow, allow for constraints to be applied to the combustor radii. The first two rows in the section above provide example uses of the radial constraints.

* The first line ensures , such that
* The second line ensures , such that

# Genetic Algorithm Termination

Once the optimisation routine has begun, there are three scenarios in which it will terminate.

* The maximum number of generations set in ./Inputs/Optimisation.txt is exceeded by the genetic algorithm and the best performing geometry of the algorithm is taken as the optimised geometry.
* All growth rates relating to a given geometry are below the maximum growth rate value stated in ./Inputs/Optimisation.txt, and this geometry is taken as the optimised geometry.
* There is no change in best performing geometry over 10 successive generations. The algorithm terminates and the best performing geometry is taken as the optimised geometry. This value can be changed in ./SubFunctions/OptimFunctions/GA\_out\_subfc.m.

If the best performing geometry, after one of the criteria above have been met, is not thermoacoustically stable, a warning message will appear indicating a stable geometry has not been found for the given parameters. Similarly, a warning message will be displayed if the initial geometry is already stable. If this is so, the user can either proceed with the optimisation, to find a geometry with increasingly negative growth rates, by clicking “Continue” in MATLAB, or the program can be terminated.

# Outputs

The ./Outputs/ folder contains two subfolders. ./Outputs/Initialisation stores data regarding the initial geometry, whilst the final, optimised, data is stored in ./Outputs/Results.

A copy of the initial geometry text file is saved as ./Outputs/Initialisation/Initial\_geometry.txt in the form below. A comparable text file also saves the final combustor geometry in the same form as ./Outputs/Initialisation/Final\_geometry.txt.

|  |  |  |  |
| --- | --- | --- | --- |
| x[m] | r[m] | SectionIndex | TubeIndex |
|  |  |  |  |
| … | … | … | … |

The results of the eigenvalue calculations are saved for both the initial and optimised geometry in ./Outputs/Initialisation/Eigenvalues.txt and ./Outputs/Results/Eigenvalues.txt respectively in the form below, when Save\_eigs in ./Inputs/Initialisation.txt is set as 1.

|  |  |  |
| --- | --- | --- |
| Mode number | Frequency [Hz] | Growth rate [1/s] |
|  |  |  |
| … | … | … |

The Mode number numbers the modes in order of increasing frequency, whilst Frequency [Hz] and Growth rate [1/s] store the corresponding frequency and growth rate of each mode.

Provided Disp\_figs in ./Inputs/Initialisation.txt is set as 1, figures showing the combustor geometry and eigenvalue maps are displayed for both the initial and final geometry, as described in [1]. The figures are saved in ./Outputs/Initialisation/ and ./Outputs/Results/ as Geometry.fig and Eigenvalues\_map.fig when Save\_figs in ./Inputs/Initialisation.txt is set as 1, and as pdfs, Geometry.pdf and Eigenvalues\_map.pdf, when Save\_pdfs in ./Inputs/Initialisation.txt is set as 1.

GA\_plot.pdf and GA\_plot.fig are also saved in ./Outputs/Results/ when Save\_pdfs and Save\_figs in ./Inputs/Initialisation.txt are set as 1. GA\_plot is a plot of the mean and best genetic algorithm scores at each generation of the algorithm, visually representing the optimisation of the geometry from one generation to the next.

# OSCILOSopt Example Cases

This section provides three OSCILOSopt example cases with input and output files for reference when developing new cases. The three cases described are as follows and the input files are available in the folder ./Library/ in OSCILOSopt.

* Rijke Tube, see Section 5.1 – ./Library/1\_Rijke\_Tube.
* NoiseDyn Burner, see Section 5.2 – ./Library/2\_NoiseDyn\_Burner.
* Palies Burner, see Section 5.3 – ./Library/2\_CD\_Palies\_Real\_Shape.

## Rijke Tube

A Rijke tube is an extensively studied, simple, constant cross section duct with a heat source at ¼ of the tube length [4]. This section provides an example case of how the unstable geometry can be optimised to produce a stable duct.

### Inputs

The Init.txt file is constructed as follows such that all figures and outputs are displayed and saved, and the optimisation routine is initiated.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Disp\_figs | Small\_plots | Save\_pdfs | Save\_figs | Save\_eig | Plot\_modes | Optimise |
|  |  |  |  |  |  |  |

The Geometry.txt file specifies the shape of the Rijke Tube.

|  |  |  |  |
| --- | --- | --- | --- |
| x[m] | r[m] | SectionIndex | TubeIndex |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

The tube is a constant area duct with a fluctuating heat source (SectionIndex = 11) at ¼ of the duct length (x[m]=0.275).

The mean flow parameters at the inlet are then specified with the temperature increase across the heat source in Mean\_flow.txt.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| P1[Pa] | T1[K] | Choice\_M1\_u1 | M1\_u1 | Choice\_gamma | Delta\_T\_HS |
|  |  |  |  |  |  |

The tube has an open inlet (Type=1) specified in Inlet.txt.

|  |  |  |  |
| --- | --- | --- | --- |
| Type | Param\_1 | Param\_2 | Param\_3 |
|  |  |  |  |

The tube has an open outlet (Type=1) specified in Outlet.txt.

|  |  |  |  |
| --- | --- | --- | --- |
| Type | Param\_1 | Param\_2 | Param\_3 |
|  |  |  |  |

The flame is represented by an (Type=1) model, with unity gain (Param\_1=1) and a time delay of 3 ms (Param\_2=3), in Flame.txt.

|  |  |  |
| --- | --- | --- |
| Type | Param\_1 | Param\_2 |
|  |  |  |

OSCILOSopt will search for modes in the Rijke Tube in the frequency range and growth rate range as specified in Scan\_range.txt.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| min\_freq | max\_freq | number\_freq | min\_GR | max\_GR | number\_GR |
|  |  |  |  |  |  |

The parameters describing the optimisation routine are in Optimisation.txt. The upper and lower geometry bounds are specified by Geometry\_bounds.txt (Geom\_bounds=0). The genetic algorithm’s population, maximum number of generations before termination and elite count are stated (Population=5, MaxGenerations=20, EliteCount=1) and if all growth rates fall below , the algorithm will terminate (Max\_GR=-25).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Geom\_bounds | Population | MaxGenerations | EliteCount | Max\_GR |
|  |  |  |  |  |

As Geom\_bounds=0 in Optimisation.txt, the upper and lower bounds for each axial position and radius is set in Geometry\_bounds.txt. The duct has a constant radius, , and the tube length is fixed at with a linear equality constraint, Section 2.4. In this example case, only the location of the heat source is able to vary (between and ). The length of the first tube section can vary from to long and the second tube section can vary from to long.

|  |  |  |  |
| --- | --- | --- | --- |
| x[m]\_lower | x[m]\_upper | r[m]\_lower | r[m]\_upper |
|  |  |  |  |
|  |  |  |  |
|  |  | 0 |  |

### Outputs

The optimisation is conducted by running the OSCILOS\_opt.m script in the main directory.

The initial combustor geometry is saved as an output text file as Initial\_geometry.txt, Table 1, and as a figure (in .fig and .pdf formats), Figure 3.

Table : Initial geometry of Rijke Tube with fluctuating heat source at 1/4 length

|  |  |  |  |
| --- | --- | --- | --- |
| x[m] | r[m] | SectionIndex | TubeIndex |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

Chart, scatter chart

Description automatically generated

Figure : Initial Rijke Tube geometry

OSCILOSopt­ determines and saves the six modes appearing in this Rijke Tube as Eigenvalues.txt, including both frequency and growth rate in Table 2. It can be seen that three frequencies have positive corresponding growth rates, modes 1, 3 and 5, and thus the Rijke Tube is thermoacoustically unstable, as expected. The modes are plotted and saved as Eigenvalues\_map.fig and Eigenvalues\_map.pdf, Figure 4.

Table : Eigenvalues of Rijke Tube identified by OSCILOSopt

|  |  |  |
| --- | --- | --- |
| Mode number | Frequency [Hz] | Growth rate [1/s] |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

Chart

Description automatically generated

Figure : Contour map of Rijke Tube eigenvalues with modes at white stars

After plotting and saving the initial geometry, the optimisation routine commences. A visualisation of the progression of the genetic algorithm is given by the output figure GA\_plot.\*, Figure 5. The figure is displayed and is updated during optimisation after each generation with the corresponding best and mean fitness values of the generation.

Chart, scatter chart

Description automatically generated

Figure : Plot of best and mean scores at each genetic algorithm generation for Rijke Tube

The simple tube can be seen to optimise quickly as only the axial position of the fluctuating heat source is able to vary.

After the completion of the optimisation routine, the best performing geometry is saved as a text file, .fig and .pdf as in Table 3 and Figure 6. The heat source has translated from an unstable position at ¼ of the tube length towards the midpoint of the tube.

Table : Final geometry of tube after optimisation

|  |  |  |  |
| --- | --- | --- | --- |
| x[m] | r[m] | SectionIndex | TubeIndex |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

Chart

Description automatically generated

Figure : Optimised Rijke Tube geometry

The eigenvalues of the relevant modes are then saved in a text file as well as eigenvalue maps. After optimisation, it can be seen, in Table 4 and Figure 6, that all growth rates are negative, and the routine has therefore found a stable geometry within the bounds set in ./Inputs/Geometry\_bounds.txt.

Table : Eigenvalues of optimised Rijke Tube identified by OSCILOSopt

|  |  |  |
| --- | --- | --- |
| Mode number | Frequency [Hz] | Growth rate [1/s] |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

Chart, bar chart

Description automatically generated with medium confidence

Figure : Contour map of optimised Rijke Tube eigenvalues with modes at white stars

## NoiseDyn Burner

The NoiseDyn burner is a perfectly premixed confined turbulent combustor located at EM2C laboratory [5–7].

### Inputs

The Init.txt file is constructed as follows such that all figures and outputs are displayed and saved, and the optimisation routine is initiated.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Disp\_figs | Small\_plots | Save\_pdfs | Save\_figs | Save\_eig | Plot\_modes | Optimise |
|  |  |  |  |  |  |  |

The Geometry.txt file specifies the shape of the NoiseDyn burner.

|  |  |  |  |
| --- | --- | --- | --- |
| x[m] | r[m] | SectionIndex | TubeIndex |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

The burner contains a fluctuating heat source (SectionIndex = 11) at the entry to the combustion chamber (x[m]=0.409).

The mean flow parameters at the inlet are then specified with the temperature increase across the flame in Mean\_flow.txt.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| P1[Pa] | T1[K] | Choice\_M1\_u1 | M1\_u1 | Choice\_gamma | Delta\_T\_HS |
|  |  |  |  |  |  |

The burner has a closed inlet (Type=2) specified in Inlet.txt.

|  |  |  |  |
| --- | --- | --- | --- |
| Type | Param\_1 | Param\_2 | Param\_3 |
|  |  |  |  |

The burner has an open end at the outlet, described using an unflanged Levine-Schwinger condition [2,3] (Type=11) specified in Outlet.txt.

|  |  |  |  |
| --- | --- | --- | --- |
| Type | Param\_1 | Param\_2 | Param\_3 |
|  |  |  |  |

The flame is represented by an (Type=1) model with unity gain (Param\_1=1) and a time delay of (Param\_2=3) in Flame.txt.

|  |  |  |
| --- | --- | --- |
| Type | Param\_1 | Param\_2 |
|  |  |  |

OSCILOSopt will search for modes in the NoiseDyn burner in the frequency range and growth rate range as specified in Scan\_range.txt.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| min\_freq | max\_freq | number\_freq | min\_GR | max\_GR | number\_GR |
|  |  |  |  |  |  |

The parameters describing the optimisation routine are in Optimisation.txt. Each axial position and burner radius are able to vary by (Geom\_bounds=15) during optimisation. The genetic algorithm’s population, maximum number of generations before termination and elite count are stated (Population=100, MaxGenerations=30, EliteCount=10) and if all growth rates fall below , the algorithm will terminate (Max\_GR=-50).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Geom\_bounds | Population | MaxGenerations | EliteCount | Max\_GR |
|  |  |  |  |  |

As Geom\_bounds=15 in Optimisation.txt, the Geometry\_bounds.txt file is redundant and therefore not filled.

|  |  |  |  |
| --- | --- | --- | --- |
| x[m]\_lower | x[m]\_upper | r[m]\_lower | r[m]\_upper |
|  |  |  |  |

### Outputs

The optimisation is conducted by running the OSCILOS\_opt.m script in the main directory.

The initial combustor geometry is saved as an output text file as Initial\_geometry.txt, Table 5, and as a figure (in .fig and .pdf formats), Figure 8.

Table : Initial geometry of NoiseDyn burner

|  |  |  |  |
| --- | --- | --- | --- |
| x[m] | r[m] | SectionIndex | TubeIndex |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

Chart, box and whisker chart

Description automatically generated

Figure : Initial NoiseDyn burner geometry

OSCILOSopt­ determines and saves the three modes appearing in this burner as Eigenvalues.txt, including both frequency and growth rate in Table 6. It can be seen that one mode has a positive growth rate, mode 1, and thus the burner is thermoacoustically unstable, as expected. The modes are plotted and saved as Eigenvalues\_map.fig and Eigenvalues\_map.pdf, Figure 9.

Table : Eigenvalues of NoiseDyn burner identified by OSCILOSopt

|  |  |  |
| --- | --- | --- |
| Mode number | Frequency [Hz] | Growth rate [1/s] |
|  |  |  |
|  |  |  |
|  |  |  |

Chart, bar chart

Description automatically generated

Figure : Contour map of NoiseDyn burner eigenvalues with modes at white stars

After plotting and saving the initial geometry, the optimisation routine commences. A visualisation of the progression of the genetic algorithm is given by the output figure GA\_plot.\*, Figure 10. The figure is displayed and is updated during optimisation after each generation with the corresponding best and mean fitness values of the generation.

Chart, scatter chart

Description automatically generated

Figure : Plot of best and mean scores at each genetic algorithm generation for NoiseDyn burner

After the completion of the optimisation routine, the best performing geometry is saved as a text file, .fig and .pdf as in Table 7 and Figure 11.

Table : Final geometry of burner after optimisation

|  |  |  |  |
| --- | --- | --- | --- |
| x[m] | r[m] | SectionIndex | TubeIndex |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

Chart

Description automatically generated with medium confidence

Figure : Optimised NoiseDyn burner geometry

The eigenvalues of the relevant modes are then saved in a text file as well as eigenvalue maps. After optimisation, it can be seen, in Table 8 and Figure 12, that all growth rates are negative, and the routine has therefore found a stable geometry within the bounds set in ./Inputs/Geometry\_bounds.txt.

Table : Eigenvalues of optimised NoiseDyn burner identified by OSCILOSopt

|  |  |  |
| --- | --- | --- |
| Mode number | Frequency [Hz] | Growth rate [1/s] |
|  |  |  |
|  |  |  |
|  |  |  |

Chart, bar chart

Description automatically generated

Figure : Contour map of optimised NoiseDyn burner eigenvalues with modes at white stars

## Palies Burner

The widely researched Palies burner [8] is a thermoacoustically unstable premixed turbulent combustor.

### Inputs

The Init.txt file is constructed as follows such that all figures and outputs are displayed and saved, and the optimisation routine is initiated.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Disp\_figs | Small\_plots | Save\_pdfs | Save\_figs | Save\_eig | Plot\_modes | Optimise |
|  |  |  |  |  |  |  |

The Geometry.txt file specifies the shape of the Palies burner.

|  |  |  |  |
| --- | --- | --- | --- |
| x[m] | r[m] | SectionIndex | TubeIndex |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

The burner contains a fluctuating heat source (SectionIndex = 11) at the entry to the combustion chamber (x[m]=0.136) and the radius varies linearly between x[m]=0.000m and x[m]=0.056m (TubeIndex=1).

The mean flow parameters at the inlet are then specified with the temperature increase across the flame in Mean\_flow.txt.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| P1[Pa] | T1[K] | Choice\_M1\_u1 | M1\_u1 | Choice\_gamma | Delta\_T\_HS |
|  |  |  |  |  |  |

The burner has a time lag condition (Type=4), with an amplitude of (Param\_1=0.96) and time lag of (Param\_2=0), specified in Inlet.txt.

|  |  |  |  |
| --- | --- | --- | --- |
| Type | Param\_1 | Param\_2 | Param\_3 |
|  |  |  |  |

The burner has an open outlet (Type=1) specified in Outlet.txt.

|  |  |  |  |
| --- | --- | --- | --- |
| Type | Param\_1 | Param\_2 | Param\_3 |
|  |  |  |  |

The flame is represented by an (Type=1) model with unity gain (Param\_1=1) and a time delay of (Param\_2=3) in Flame.txt.

|  |  |  |
| --- | --- | --- |
| Type | Param\_1 | Param\_2 |
|  |  |  |

OSCILOSopt will search for modes in the Palies burner in the frequency range and growth rate range as specified in Scan\_range.txt.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| min\_freq | max\_freq | number\_freq | min\_GR | max\_GR | number\_GR |
|  |  |  |  |  |  |

The parameters describing the optimisation routine are in Optimisation.txt. Each axial position and burner radius is able to vary by (Geom\_bounds=10) during optimisation. The genetic algorithm’s population, maximum number of generations before termination and elite count are stated (Population=50, MaxGenerations=40, EliteCount=5) and if all growth rates fall below , the algorithm will terminate (Max\_GR=-50).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Geom\_bounds | Population | MaxGenerations | EliteCount | Max\_GR |
|  |  |  |  |  |

As Geom\_bounds=10 in Optimisation.txt, the Geometry\_bounds.txt file is redundant and therefore not filled. The plenum entry and exit have a constant area, as set by a linear equality constraint, Section 2.4.

|  |  |  |  |
| --- | --- | --- | --- |
| x[m]\_lower | x[m]\_upper | r[m]\_lower | r[m]\_upper |
|  |  |  |  |

### Outputs

The optimisation is conducted by running the OSCILOS\_opt.m script in the main directory.

The initial combustor geometry is saved as an output text file as Initial\_geometry.txt, Table 9, and as a figure (in .fig and .pdf formats), Figure 13.

Table : Initial geometry of Palies burner

|  |  |  |  |
| --- | --- | --- | --- |
| x[m] | r[m] | SectionIndex | TubeIndex |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

Chart, line chart, box and whisker chart

Description automatically generated

Figure : Initial Palies burner geometry

OSCILOSopt­ determines and saves the three modes appearing in this burner as Eigenvalues.txt, including both frequency and growth rate in Table 10. It can be seen that two modes have positive growth rates, modes 2 and 3, and thus the burner is thermoacoustically unstable, as expected. The modes are plotted and saved as Eigenvalues\_map.fig and Eigenvalues\_map.pdf, Figure 14.

Table : Eigenvalues of Palies burner identified by OSCILOSopt

|  |  |  |
| --- | --- | --- |
| Mode number | Frequency [Hz] | Growth rate [1/s] |
|  |  |  |
|  |  |  |
|  |  |  |

Chart, bar chart

Description automatically generated

Figure : Contour map of Palies burner eigenvalues with modes at white stars

After plotting and saving the initial geometry, the optimisation routine commences. A visualisation of the progression of the genetic algorithm is given by the output figure GA\_plot.\*, Figure 15. The figure is displayed and is updated during optimisation after each generation with the corresponding best and mean fitness values of the generation.

Chart, scatter chart

Description automatically generated

Figure : Plot of best and mean scores at each genetic algorithm generation for Palies burner

After the completion of the optimisation routine, the best performing geometry is saved as a text file, .fig and .pdf as in Table 11 and Figure 16.

Table : Final geometry of burner after optimisation

|  |  |  |  |
| --- | --- | --- | --- |
| x[m] | r[m] | SectionIndex | TubeIndex |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

Chart, box and whisker chart

Description automatically generated

Figure : Optimised Palies burner geometry

The eigenvalues of the relevant modes are then saved in a text file as well as eigenvalue maps. After optimisation, it can be seen, in Table 12 and Figure 17, that all growth rates are negative, and the routine has therefore found a stable geometry within the bounds set in ./Inputs/Geometry\_bounds.txt.

Table : Eigenvalues of optimised Palies burner identified by OSCILOSopt

|  |  |  |
| --- | --- | --- |
| Mode number | Frequency [Hz] | Growth rate [1/s] |
|  |  |  |
|  |  |  |
|  |  |  |

Chart, bar chart

Description automatically generated

Figure : Contour map of optimised Palies burner eigenvalues with modes at white stars

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