OSCILOS$_{opt}$ User Guide

Henry Jones, Renaud Gaudron & Aimee S. Morgans

Department of Mechanical Engineering, Imperial College London, UK

Version 1.0, 25/05/2021

OSCILOS$_{opt}$ is a variant of OSCILOS$_{lite}$ [1] which allows the user to optimise a thermoacoustically unstable combustor by varying the combustor dimensions. Optimisation is completed using a genetic algorithm. OSCILOS$_{opt}$ lifts significant sections of code from OSCILOS$_{lite}$ and follows the same structure and thus will be updated in line with OSCILOS$_{lite}$. For this reason, it is recommended that the OSCILOS$_{lite}$ User Guide [1] is read before this document, as this document only details the additional functions and inputs required in OSCILOS$_{opt}$, relative to OSCILOS$_{lite}$. All mentions of OSCILOS$_{lite}$ 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

1.1 Running OSCILOS$_{opt}$

OSCILOS$_{opt}$ 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

1.2 Structure of OSCILOS$_{opt}$

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 OSCILOS$_{opt}$ can be found in Figure 1. `./OSCILOS_opt.m` calls the following seven subfunctions located in `./SubFunctions/`.

1. `Init_subfc` – as in OSCILOS$_{lite}$.
2. `Optimisation_subfc` – Optimises geometry using a genetic algorithm.
3. `Geometry_subfc` – as in OSCILOS$_{lite}$.
4. `Mean_flow_subfc` – as in OSCILOS$_{lite}$.
5. `Flame_subfc` – as in OSCILOS$_{lite}$.
6. `BC_subfc` – as in OSCILOS$_{lite}$.
7. `Solver_subfc` – as in OSCILOS$_{lite}$.

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 OSCILOS$_{opt}$ 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 OSCILOS$_{lite}$, see Section 2.1.

- Geometry (Geometry.txt) – As in OSCILOS$_{lite}$.
- Mean Flow (Mean_flow.txt) – As in OSCILOS$_{lite}$.
- Boundary Conditions (Inlet.txt & Outlet.txt) – As in OSCILOS$_{lite}$.
- Flame Model (Flame.txt) – As in OSCILOS$_{lite}$.
- Scan Range (Scan_range.txt) – As in OSCILOS$_{lite}$.
- 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).

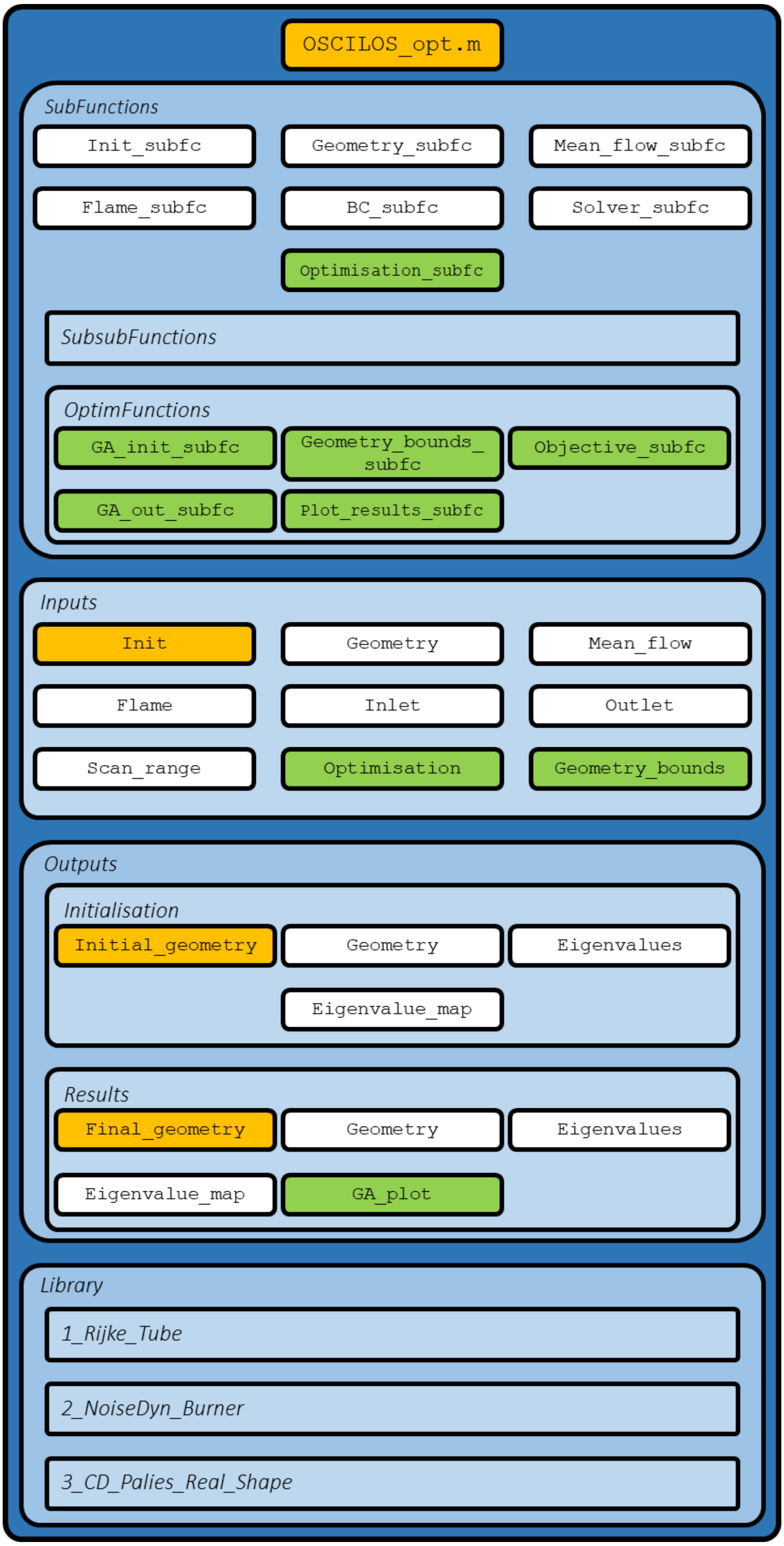

Figure 1: Folders, subfolders and files which make up OSCILOS$_{opt}$. White files exist as in OSCILOS$_{lite}$, orange files are slightly modified compared to OSCILOS$_{lite}$ and green files are new to OSCILOS$_{opt}$.

2 Inputs

OSCILOS$_{opt}$ input files located in the `./Inputs/` folder are as described in the OSCILOS$_{lite}$ User Guide, except for the following three files, which are either unique to OSCILOS$_{opt}$ or modified from OSCILOS$_{lite}$.

2.1 Initialisation

The initialisation parameters are read from the file `./Inputs/Initialisation.txt`. The parameters are set and behave as in OSCILOS$_{lite}$, 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
$\{0;1\}$	$\{0;1\}$	$\{0;1\}$	$\{0;1\}$	$\{0;1\}$	$\mathbb{N}^+$	$\{0;1\}$

`Optimise` determines whether OSCILOS$_{opt}$ 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 OSCILOS$_{lite}$. 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 OSCILOS$_{lite}$ 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.

2.2 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
$\{x = 0\}$ $\{x \in \mathbb{R} \mid 0 < x \leq 100\}$	$\mathbb{N}^+$	$\mathbb{N}^+$	$\mathbb{N}^+$	$\mathbb{R}$

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 s^{-1}.

2.3 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
$\mathbb{R}^+$	$\mathbb{R}^+$	$\mathbb{R}^+$	$\mathbb{R}^+$
…	…	…	…

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 N sets of radii bounds and $N-1$ sets of axial length bounds.

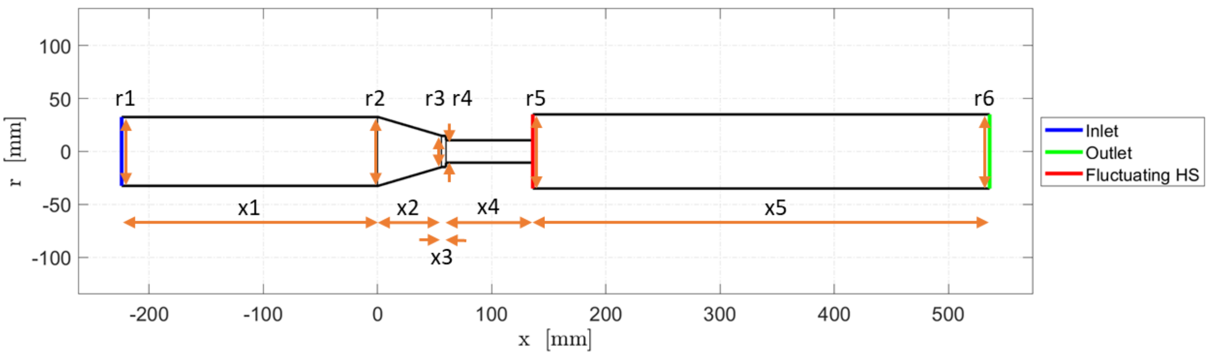

Figure 2: Example of how axial lengths and radii are defined in Geom_bounds.txt

2.4 Linear Constraints

OSCILOS$_{\text{opt}}$ 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 ($r1 - r2 = 0$), or keeping the total burner length constant ($x1 + x2 + x3 + x4 + x5 = 0.760$).

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, Aeq and beq, below. The cells highlighted in blue can impose axial constraints, whilst the yellow cells define constraints on the radii.

Axial Constraints — Radial Constraints

$$Aeq\begin{bmatrix} x1 \\ x2 \\ x3 \\ x4 \\ x5 \\ 0 \\ r1 \\ r2 \\ r3 \\ r4 \\ r5 \\ r6 \end{bmatrix} = beq \quad where\ Aeq = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad beq = \begin{bmatrix} 1 \\ 2 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Aeq is a $2N \times 2N$ matrix, where N is the number of radius (or axial position) values defined in the `Geometry.txt` input file. beq is a $2N \times 1$ matrix.

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

The first $N - 1$ rows, highlighted in blue, allow for $N - 1$ axial length constraints to be applied to the geometry. The first two rows of Aeq and beq above provide example uses of the axial length constraints.

- The first line ensures $x1 + x2 = 1$
- The second line ensures $x2 + x3 + x4 = 2$

The final N rows, highlighted in yellow, allow for N 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 $r1 - r2 = 0$, such that $r1 = r2$
- The second line ensures $r5 - 2 \times r6 = 0$, such that $r5 = 2r6$

3 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.

4 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
$\mathbb{R}^+$	$\mathbb{R}^+$	$\{0; 10; 11\}$	$\{0; 1\}$
…	…	…	…

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]
$\mathbb{N}^+$	$\mathbb{R}^+$	$\mathbb{R}^+$
…	…	…

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.

5 OSCILOS$_{opt}$ Example Cases

This section provides three OSCILOS$_{opt}$ 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 OSCILOS$_{opt}$.

- 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.

5.1 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.

5.1.1 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
1	1	1	1	1	0	1

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

x[m]	r[m]	SectionIndex	TubeIndex
0.000	0.0800	0	0
0.275	0.0800	11	0
1.100	0.0800	0	0

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
101325.0	293	2	10	1	1.2

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

Type	Param_1	Param_2	Param_3
1	–	–	–

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

Type	Param_1	Param_2	Param_3
1	–	–	–

The flame is represented by an $n - \tau$ (`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
1	1	3

OSCILOS$_{opt}$ will search for modes in the Rijke Tube in the frequency range $0 - 1000\ Hz$ and growth rate range $\pm 200\ s^{-1}$ as specified in `Scan_range.txt`.

min_freq	max_freq	number_freq	min_GR	max_GR	number_GR
0	1000	50	−200	200	50

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 $-25\ s^{-1}$, the algorithm will terminate (Max_GR=-25).

Geom_bounds	Population	MaxGenerations	EliteCount	Max_GR
0	5	20	1	−25

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, $0.080\ m$, and the tube length is fixed at $1.100\ m$ with a linear equality constraint, Section 2.4. In this example case, only the location of the heat source is able to vary (between $0.250\ m$ and $0.800\ m$). The length of the first tube section can vary from $0.250m$ to $0.800m$ long and the second tube section can vary from $0.300m$ to $0.850m$ long.

x[m]_lower	x[m]_upper	r[m]_lower	r[m]_upper
0.250	0.800	0.080	0.080
0.300	0.850	0.080	0.080
0.000	0.000	0.080	0.080

5.1.2 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 1: Initial geometry of Rijke Tube with fluctuating heat source at 1/4 length

x[m]	r[m]	SectionIndex	TubeIndex
0.000	0.0800	0	0
0.275	0.0800	11	0
1.100	0.0800	0	0

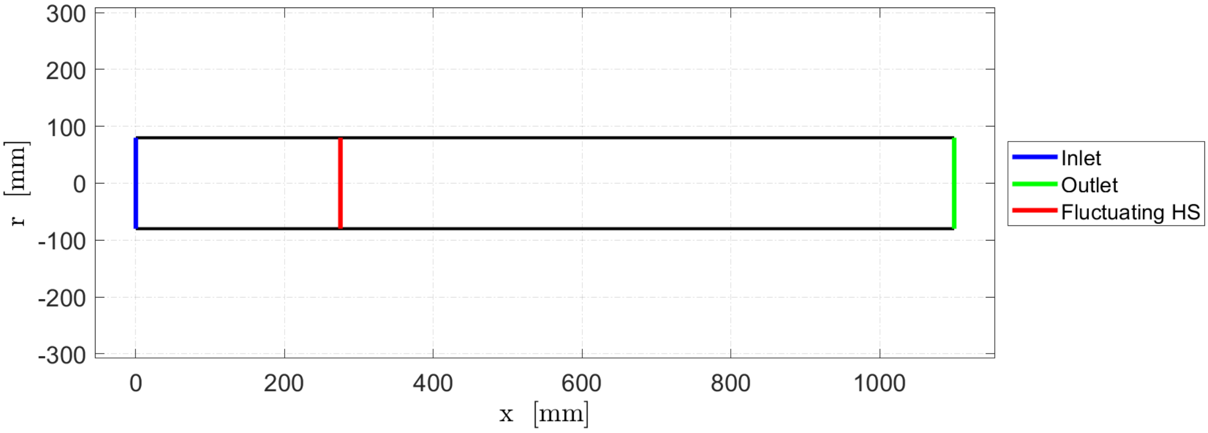

Figure 3: Initial Rijke Tube geometry

OSCILOS$_{opt}$ 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 2: Eigenvalues of Rijke Tube identified by OSCILOS$_{opt}$

Mode number	Frequency [Hz]	Growth rate [1/s]
1	159	4.17
2	333	−2.39
3	508	4.83
4	668	−3.33
5	827	1.74
6	999	−2.16

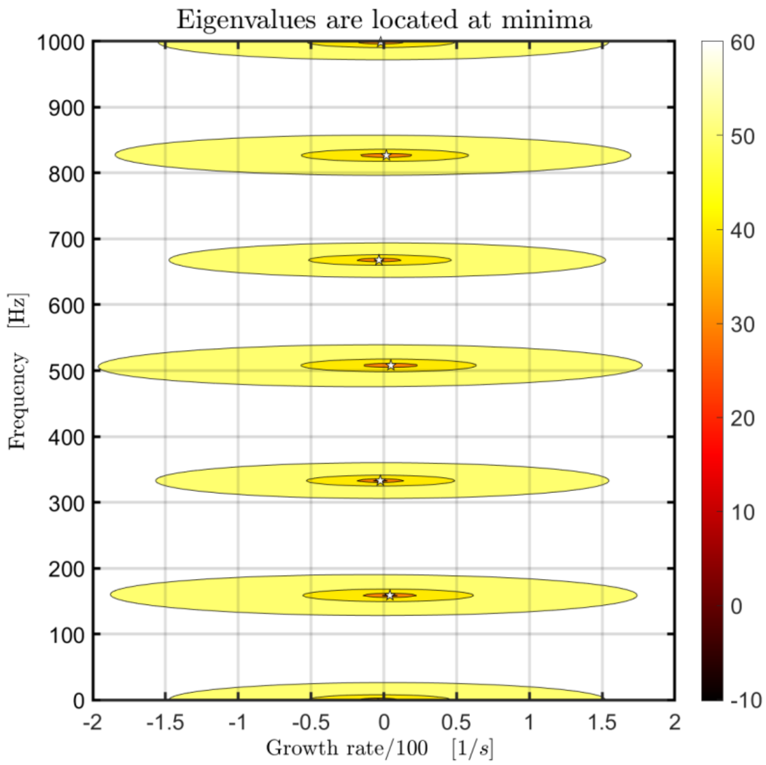

Figure 4: Contour map of Rijke Tube eigenvalues with modes at white stars

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.

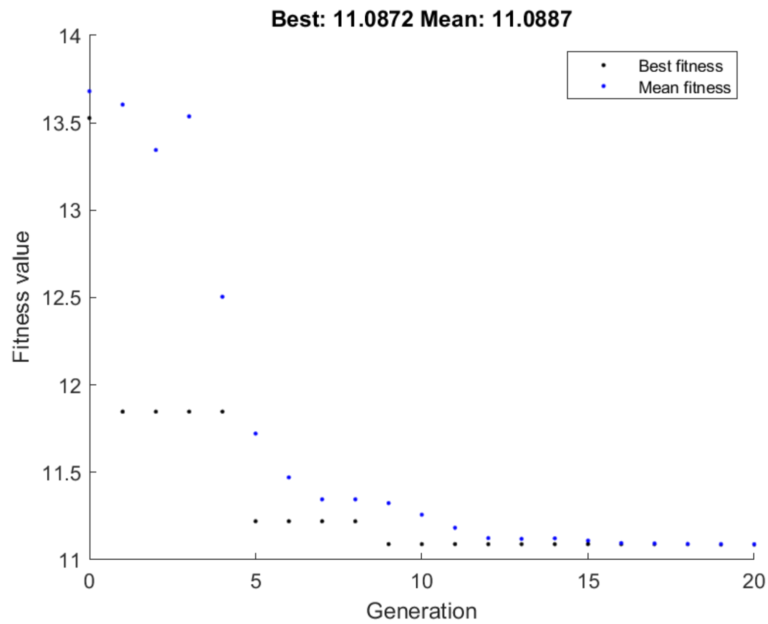

Figure 5: Plot of best and mean scores at each genetic algorithm generation for Rijke Tube

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 3: Final geometry of tube after optimisation

x[m]	r[m]	SectionIndex	TubeIndex
0.000	0.0800	0	0
0.593	0.0800	11	0
1.100	0.0800	0	0

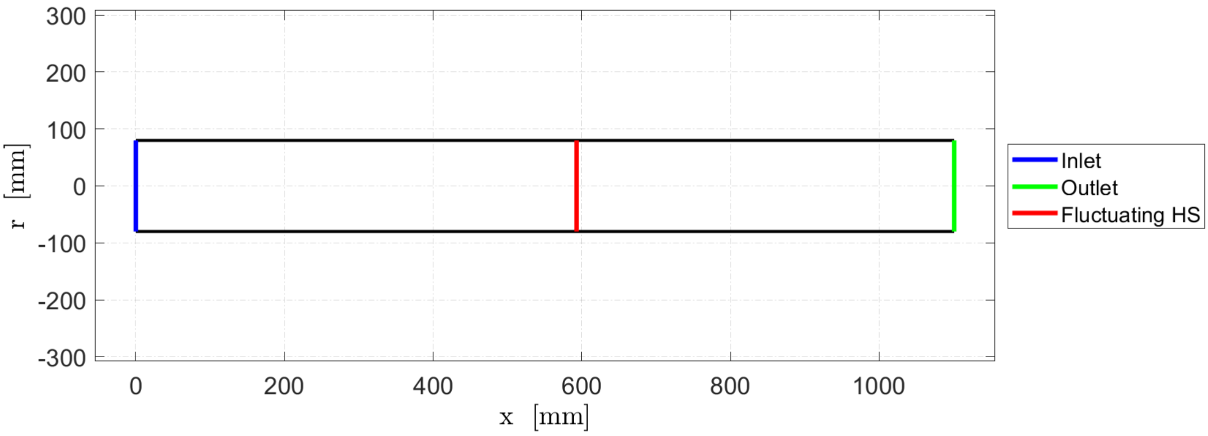

Figure 6: Optimised Rijke Tube geometry

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 4: Eigenvalues of optimised Rijke Tube identified by OSCILOS$_{opt}$

Mode number	Frequency [Hz]	Growth rate [1/s]
1	165	−3.15
2	326	−6.08
3	494	−6.14
4	651	−11.04
5	819	−11.44

6	975	−12.10

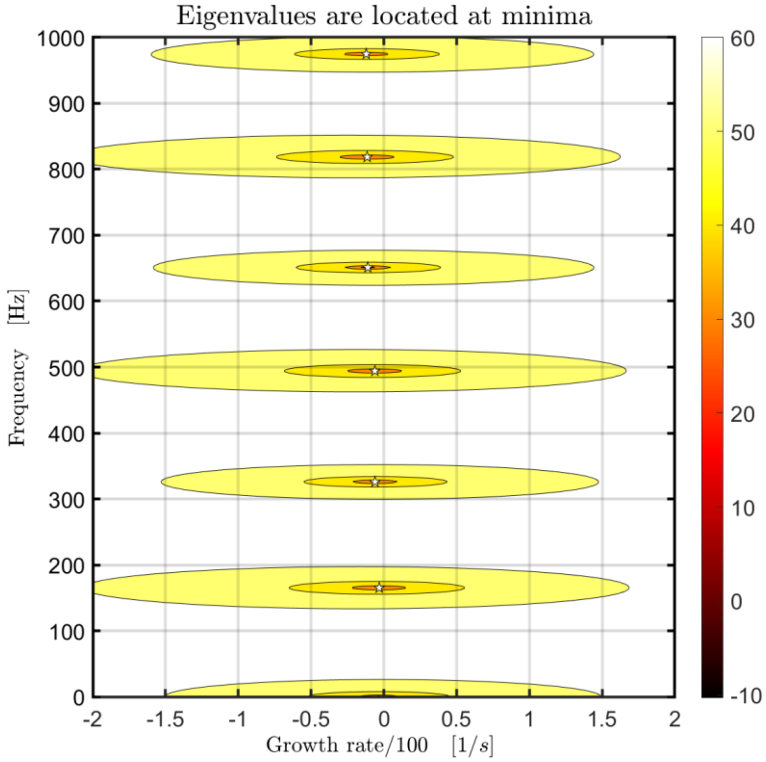

Figure 7: Contour map of optimised Rijke Tube eigenvalues with modes at white stars

5.2 NoiseDyn Burner

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

5.2.1 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
1	1	1	1	1	0	1

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

x[m]	r[m]	SectionIndex	TubeIndex
0.000	0.0325	0	0
0.295	0.0110	0	0
0.315	0.0200	0	0

0.345	0.007348	0	0
0.353	0.0100	0	0
0.409	0.046263	11	0
0.663	0.0325	0	0
1.323	0.0325	0	0

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
101325.0	293	2	3	1	6

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

Type	Param_1	Param_2	Param_3
2	–	–	–

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
11	–	–	–

The flame is represented by an $n - \tau$ (`Type=1`) model with unity gain (`Param_1=1`) and a time delay of $3ms$ (`Param_2=3`) in `Flame.txt`.

Type	Param_1	Param_2
1	1	3

OSCILOS$_{\text{opt}}$ will search for modes in the NoiseDyn burner in the frequency range $0 - 1000\ Hz$ and growth rate range $\pm 200\ s^{-1}$ as specified in `Scan_range.txt`.

min_freq	max_freq	number_freq	min_GR	max_GR	number_GR
0	1000	50	-200	200	50

The parameters describing the optimisation routine are in `Optimisation.txt`. Each axial position and burner radius are able to vary by $\pm 15\%$ (`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 $-50\ s^{-1}$, the algorithm will terminate (`Max_GR=-50`).

Geom_bounds	Population	MaxGenerations	EliteCount	Max_GR
15	100	30	10	-50

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
–	–	–	–

5.2.2 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 5: Initial geometry of NoiseDyn burner

x[m]	r[m]	SectionIndex	TubeIndex
0.000	0.0325	0	0
0.295	0.0110	0	0
0.315	0.0200	0	0
0.345	0.007348	0	0
0.353	0.0100	0	0
0.409	0.046263	11	0
0.663	0.0325	0	0
1.323	0.0325	0	0

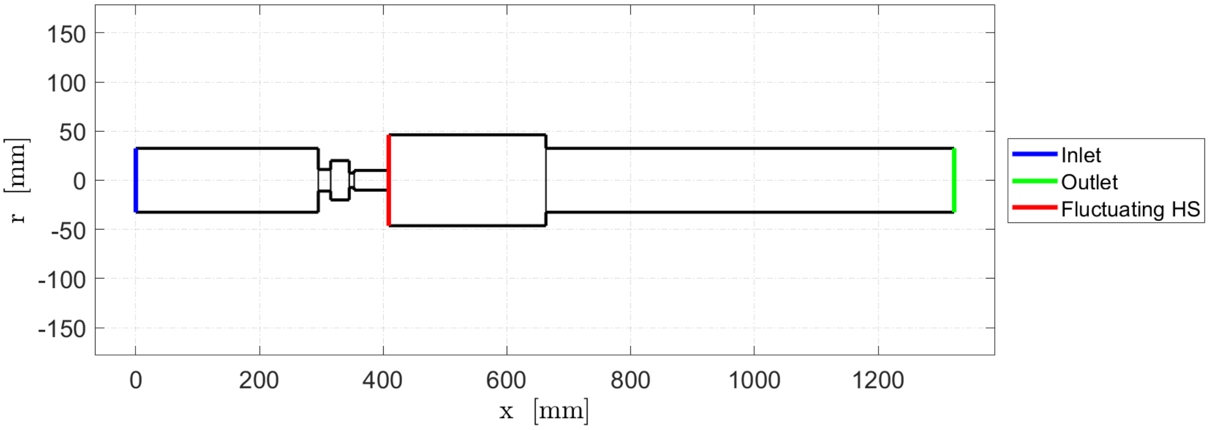

Figure 8: Initial NoiseDyn burner geometry

OSCILOS$_{opt}$ 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 6: Eigenvalues of NoiseDyn burner identified by OSCILOS$_{opt}$

Mode number	Frequency [Hz]	Growth rate [1/s]
1	165	114.22
2	574	−3.77
3	658	−53.01

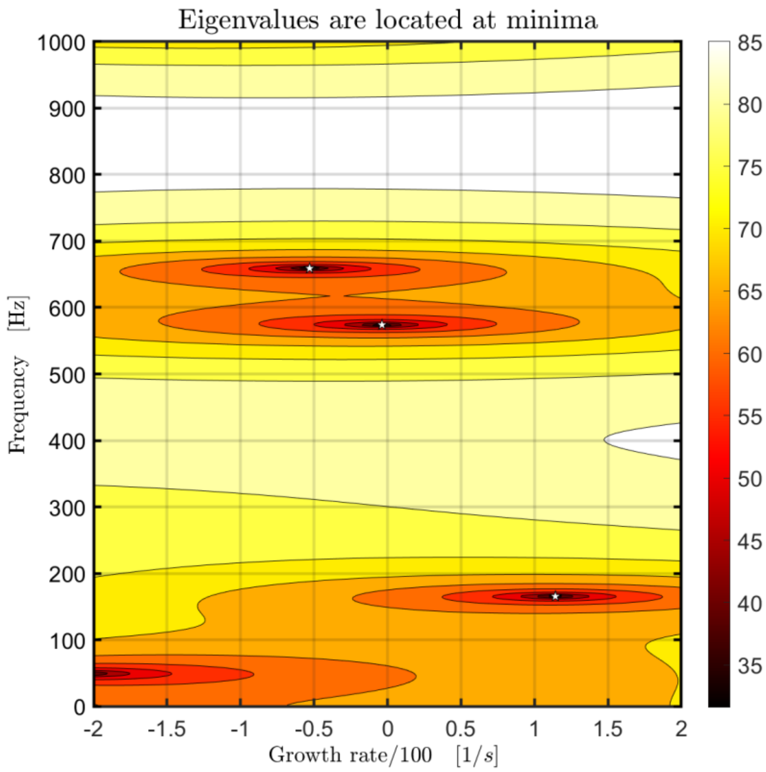

Figure 9: Contour map of NoiseDyn burner eigenvalues with modes at white stars

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.

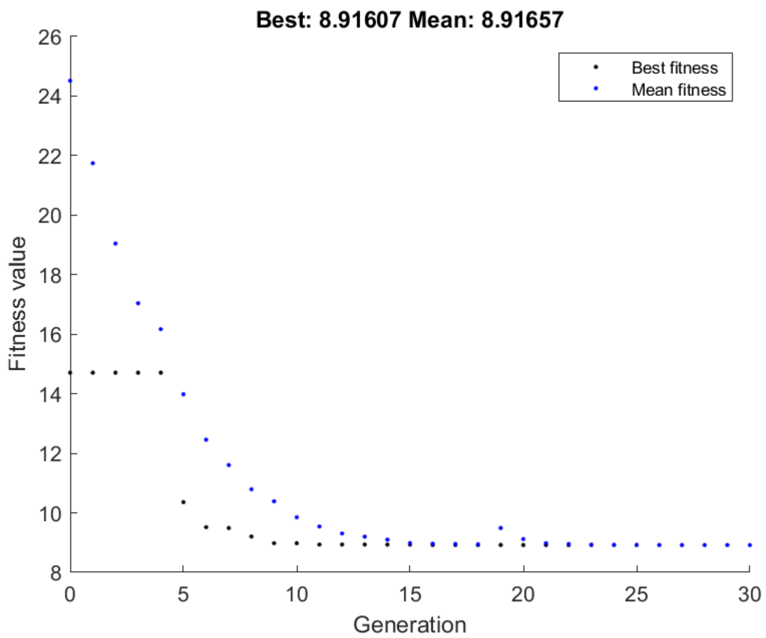

Figure 10: Plot of best and mean scores at each genetic algorithm generation for NoiseDyn burner

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 7: Final geometry of burner after optimisation

x[m]	r[m]	SectionIndex	TubeIndex
0.0000	0.0322	0	0
0.2564	0.0097	0	0
0.2747	0.0180	0	0
0.3007	0.0064	0	0
0.3077	0.0094	0	0
0.3713	0.0400	11	0
0.5888	0.0373	0	0
1.1584	0.0373	0	0

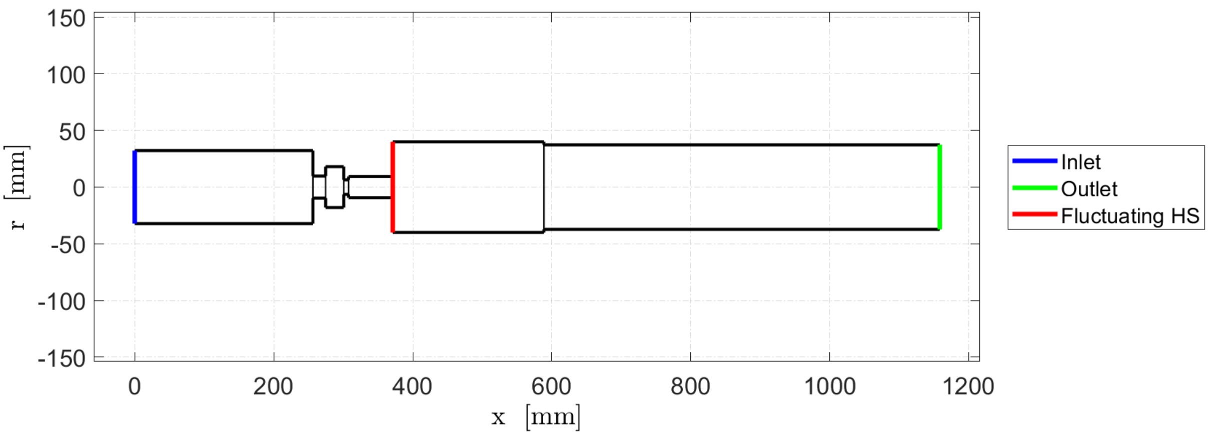

Figure 11: Optimised NoiseDyn burner geometry

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 8: Eigenvalues of optimised NoiseDyn burner identified by OSCILOS$_{opt}$

Mode number	Frequency [Hz]	Growth rate [1/s]
1	205	−54.87
2	654	−12.12
3	775	−3.83

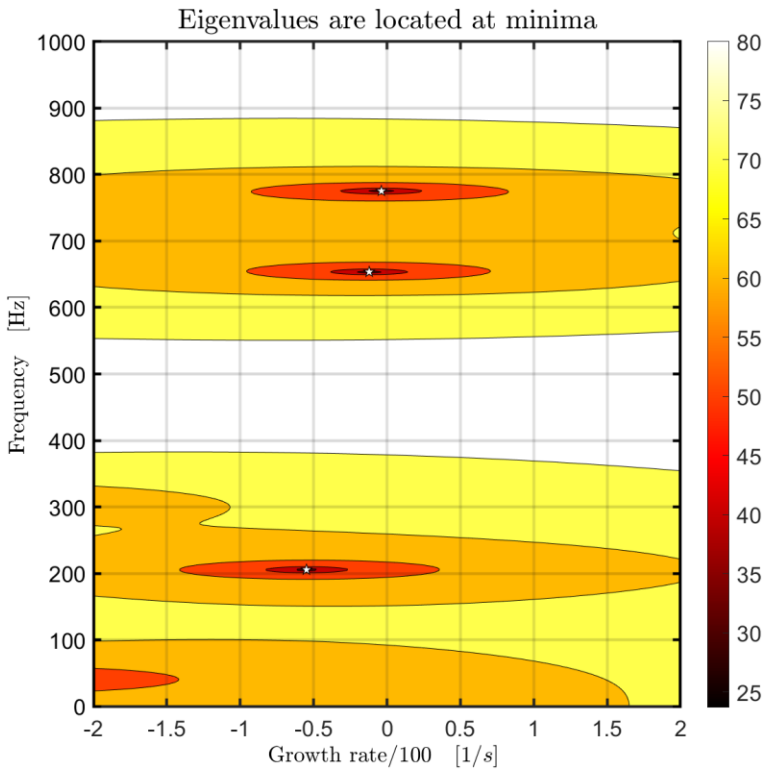

Figure 12: Contour map of optimised NoiseDyn burner eigenvalues with modes at white stars

5.3 Palies Burner

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

5.3.1 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
1	1	1	1	1	0	1

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

x[m]	r[m]	SectionIndex	TubeIndex
−0.224	0.0325	0	0
0.000	0.0325	0	1
0.056	0.0147	0	0
0.060	0.0106	0	0
0.136	0.0350	11	0

0.536	0.0350	0	0

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
101325.0	300	2	0.43825	1	5.3395

The burner has a time lag condition (`Type=4`), with an amplitude of 0.96 (`Param_1=0.96`) and time lag of $0ms$ (`Param_2=0`), specified in `Inlet.txt`.

Type	Param_1	Param_2	Param_3
4	0.96	0	–

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

Type	Param_1	Param_2	Param_3
1	–	–	–

The flame is represented by an $n - \tau$ (`Type=1`) model with unity gain (`Param_1=1`) and a time delay of $3ms$ (`Param_2=3`) in `Flame.txt`.

Type	Param_1	Param_2
1	1	3

OSCILOS$_{\mathrm{opt}}$ will search for modes in the Palies burner in the frequency range $0 - 1000\ Hz$ and growth rate range $\pm 200\ s^{-1}$ as specified in `Scan_range.txt`.

min_freq	max_freq	number_freq	min_GR	max_GR	number_GR
0	1000	50	−200	200	50

The parameters describing the optimisation routine are in `Optimisation.txt`. Each axial position and burner radius is able to vary by $\pm 10\%$ (`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 $-50s^{-1}$, the algorithm will terminate (`Max_GR=-50`).

Geom_bounds	Population	MaxGenerations	EliteCount	Max_GR
10	50	40	5	-50

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
–	–	–	–

5.3.2 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 9: Initial geometry of Palies burner

x[m]	r[m]	SectionIndex	TubeIndex
-0.224	0.0325	0	0
0.000	0.0325	0	1
0.056	0.0147	0	0
0.060	0.0106	0	0
0.136	0.0350	11	0
0.536	0.0350	0	0

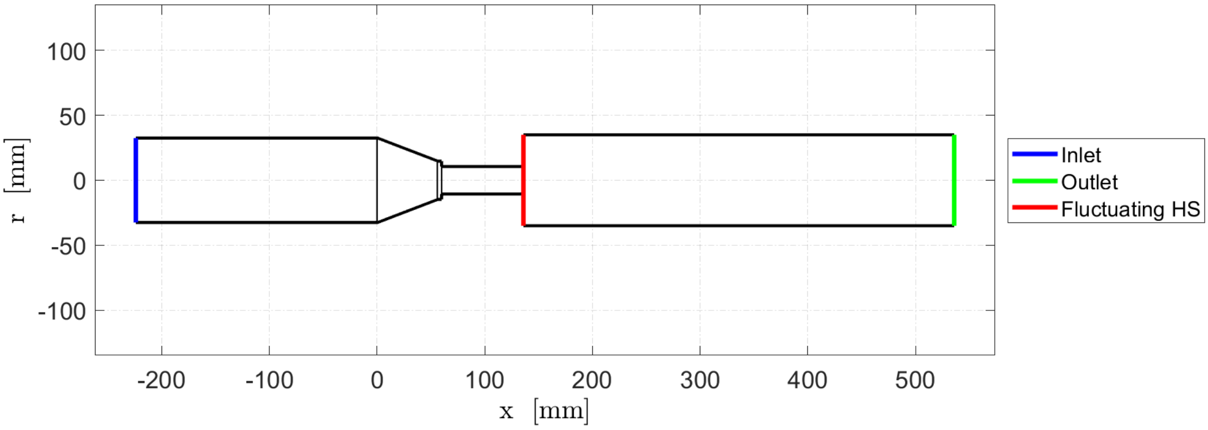

Figure 13: Initial Palies burner geometry

OSCILOS$_{opt}$ 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 10: Eigenvalues of Palies burner identified by OSCILOS$_{opt}$

Mode number	Frequency [Hz]	Growth rate [1/s]
1	154	−190.53
2	480	92.97
3	701	7.46

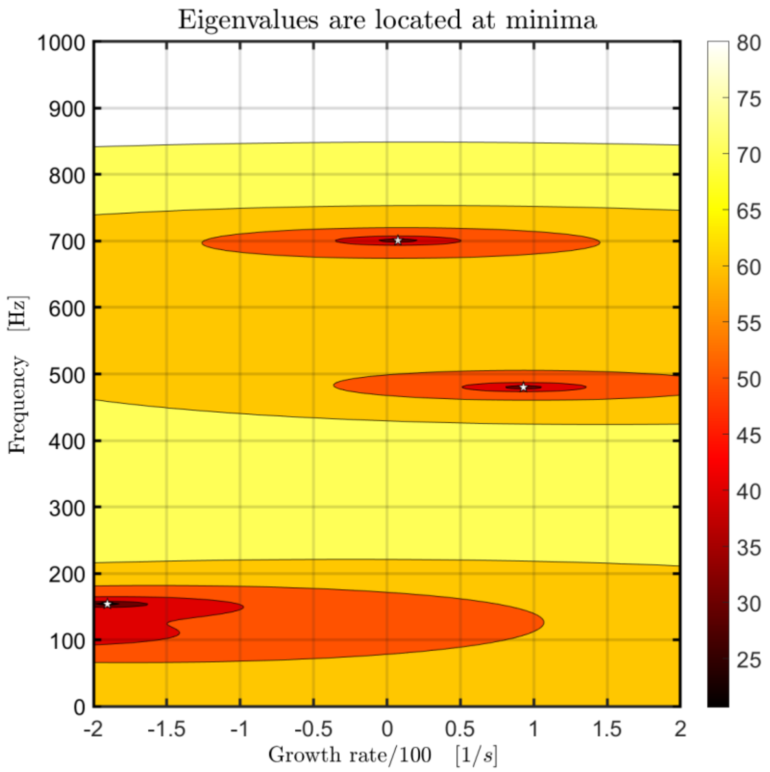

Figure 14: Contour map of Palies burner eigenvalues with modes at white stars

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.

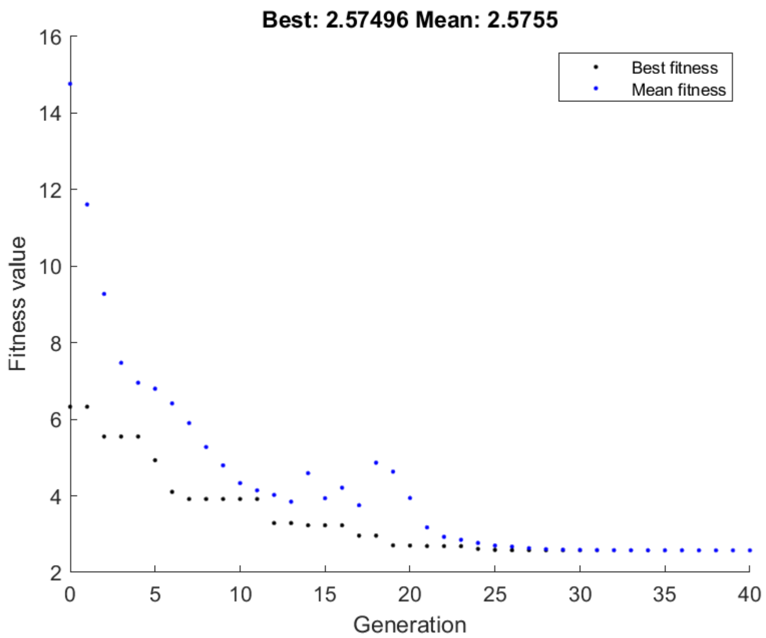

Figure 15: Plot of best and mean scores at each genetic algorithm generation for Palies burner

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 11: Final geometry of burner after optimisation

x[m]	r[m]	SectionIndex	TubeIndex
0.000	0.0307	0	0
0.241	0.0307	0	1
0.296	0.0151	0	0
0.300	0.0098	0	0
0.380	0.0357	11	0
0.749	0.0357	0	0

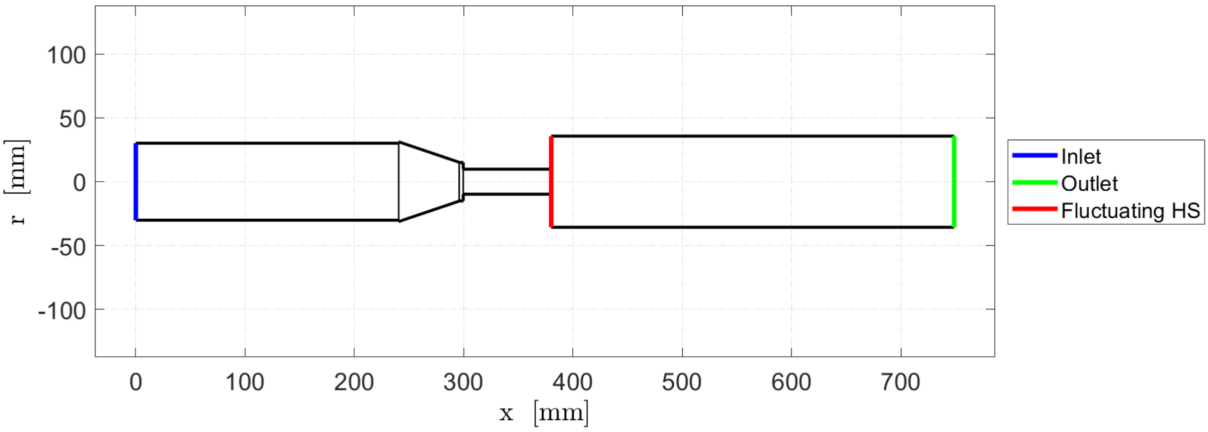

Figure 16: Optimised Palies burner geometry

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 12: Eigenvalues of optimised Palies burner identified by $OSCILOS_{opt}$

Mode number	Frequency [Hz]	Growth rate [1/s]
1	108	−159.33
2	514	−78.32
3	665	−25.66

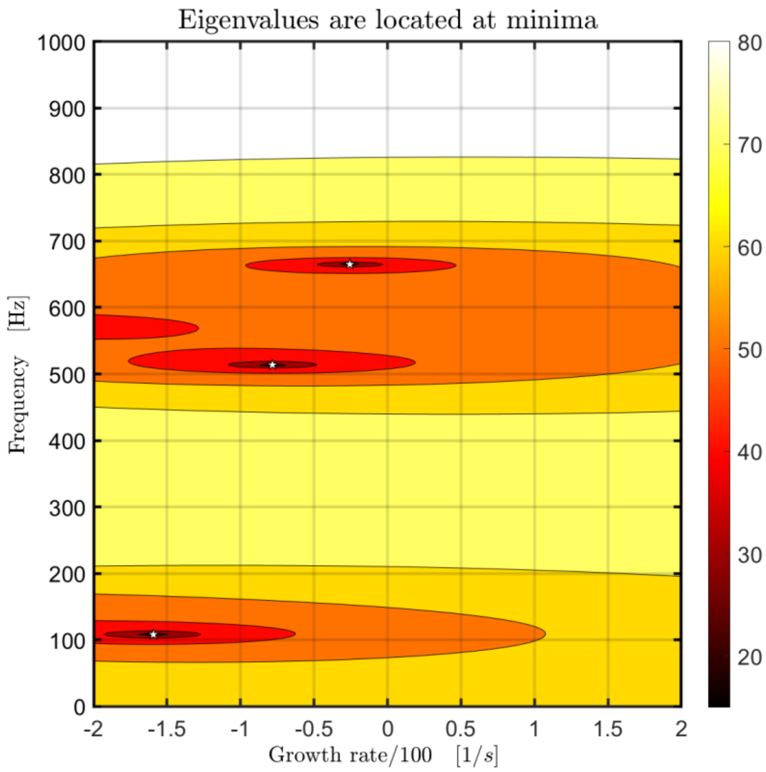

Figure 17: Contour map of optimised Palies burner eigenvalues with modes at white stars

6 References

[1] Gaudron R, Maclaren A, Morgans AS. *OSCILOS_lite User Guide.* [Online]. London: Department of Mechanical Engineering, Imperial College London. 2021. Available from: https://www.oscilos.com/documentation.html

[2] Li J, Yang D, Luzzato C, Morgans AS. *OSCILOS Report*. [Online]. London: Department of Mechanical Engineering, Imperial College London. 2017. Available from: https://www.oscilos.com/documentation.html

[3] Li J, Morgans AS. *Open Source Combustion Instability Low Order Simulator for Longitudinal Modes (OSCILOS long) User guide for version 1 . 5. Department of Mechanical Engineering, Imperial College London*. 2014

[4] Raun RL, Becks MW, Finlinson JC, Brooks KP. *A Review of Rijke Tubes, Rijke Burners and Related Devices*. Prog Energy Combust Sci. 19(4):313–64. 1993;

[5] Gaudron R. *Acoustic Response of Premixed Flames Submitted to Harmonic Sound Waves*. PhD thesis. Université Paris-Saclay; 2018.

[6] Gaudron R, Gatti M, Mirat C, Schuller T. *Flame Describing Functions of a Confined Premixed Swirled Combustor With Upstream and Downstream Forcing*. J Eng Gas Turbines Power. 141(5):1–9. 2019;

[7] Gaudron R, Gatti M, Mirat C, Schuller T. *Impact of the Acoustic Forcing Level on the Transfer Matrix of a Turbulent Swirling Combustor with and Without Flame*. Flow, Turbul Combust. 103(3):751–71. 2019;

[8] Palies P, Schuller T, Durox D, Gicquel LYM, Candel S. *Acoustically Perturbed Turbulent Premixed Swirling Flames*. Phys Fluids. 23(3):037101 (9 pages). 2011;