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Open Source Combustion Instability Low Order Simulator for Longitudinal Modes (OSCILOS_long)

User guide

Developed by Dr. Jingxuan Li and Dr. Aimee S. Morgans

Programmed with MATLAB 2012b

First released on April 23, 2014

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What is OSCILOS?

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- ✓ OSCILOS is an open source code for simulating combustion instability. It is written in Matlab® / Simulink® and is very straightforward to run and edit.
- ✓ It can simulate both longitudinal and annular combustor geometries. It represents a combustor as a network of connected modules.
- ✓ The acoustic waves are modeled as either 1-D plane waves (longitudinal combustors) or 2-D plane/circumferential waves (annular combustors).
- ✓ A variety of inlet and exit acoustic boundary conditions are possible, including open, closed, choked and user defined boundary conditions.
- ✓ The response of the flame to acoustic waves is captured via a flame model; flame models ranging from linear n-tau models to non-linear flame describing functions can be prescribed.
- ✓ The mean flow is calculated simply by assuming 1-D flow conditions, with changes only across module interfaces or flames.
- ✓ This current version is for longitudinal modes. This assumes either a longitudinal/cannular/can combustor geometry, or an annular geometry but where only plane acoustic waves are known to be of interest.

Who is developing OSCILOS?

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- ✓ OSCILOS is being developed by Dr Aimee Morgans, Dr. Jingxuan Li and co-workers in the Department of Aeronautics, Imperial College London, UK.
- ✓ More details about the development team are available on the website: http://www.oscilos.com/.
- ✓ Current team members:

  Dr. Aimee S. Morgans

  Dr. Jingxuan Li

  Dong Yang

  Dr. Xingsi Han

  Charles Luzzato

Required Matlab toolboxes

- ✓ Control System Toolbox
- ✓ Matlab
- ✓ Optimization Toolbox
- ✓ Robust Control Toolbox
- ✓ Signal Processing Toolbox
- ✓ Simulink
- ✓ Symbolic Math Toolbox

Main console

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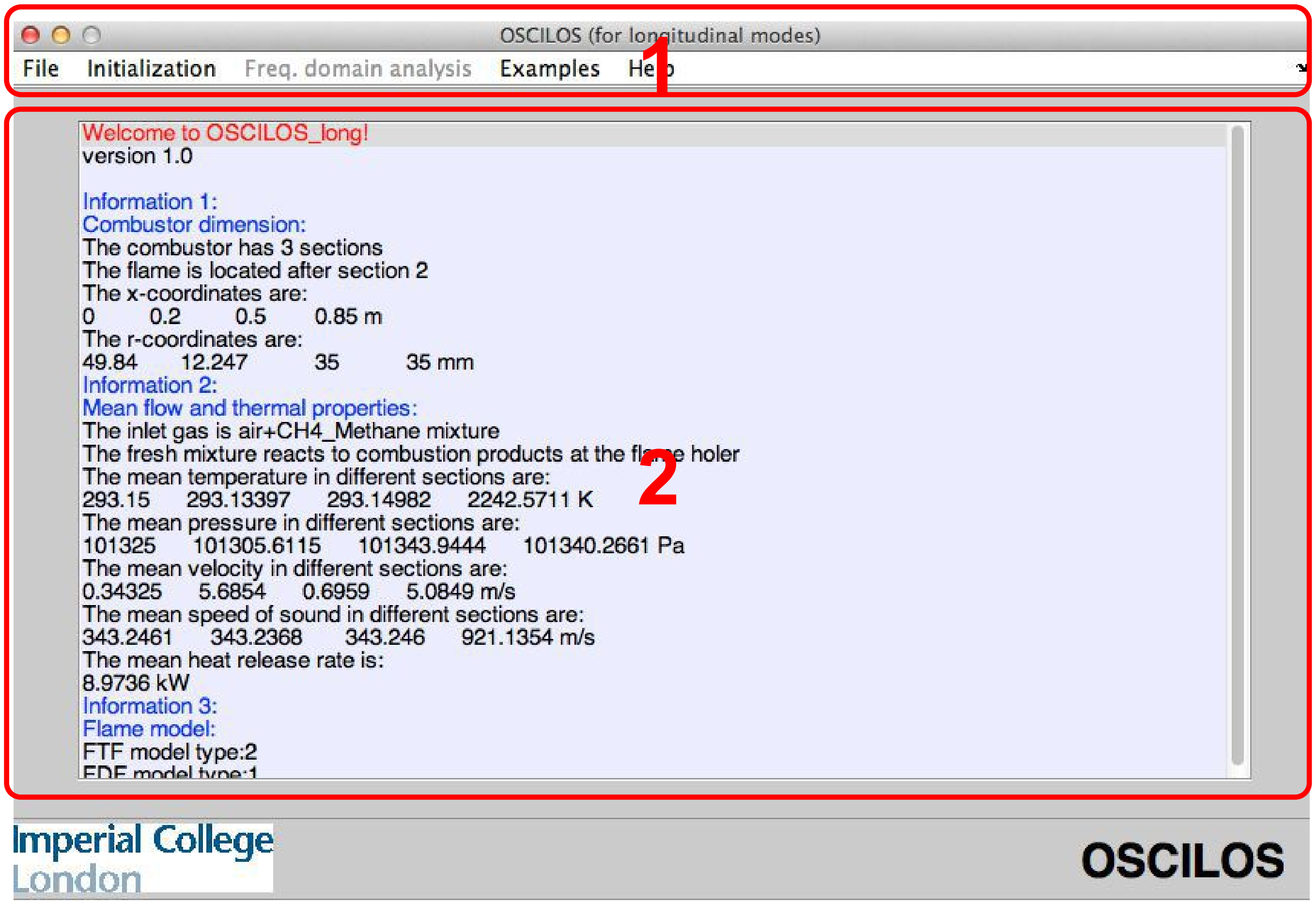

1. Menu Bar

The menu bar organizes the GUI menu hierarchy using a set of pull-down menus. A pull-down menu contains items that perform commonly executed actions.

2. Information window

Key information from the program run is printed in the information window.

Menu Bar

- ✓ File
  - ✓ New case
  - ✓ Load…
  - ✓ Save…
- ✓ Initialization
  - ✓ Chamber dimensions
  - ✓ Thermal properties
  - ✓ Flame model
  - ✓ Boundary conditions
- ✓ Frequency domain analysis
  - ✓ Pre-processing
  - ✓ Eigenmode calculation
- ✓ Help
  - ✓ About
  - ✓ User guide

File / New case

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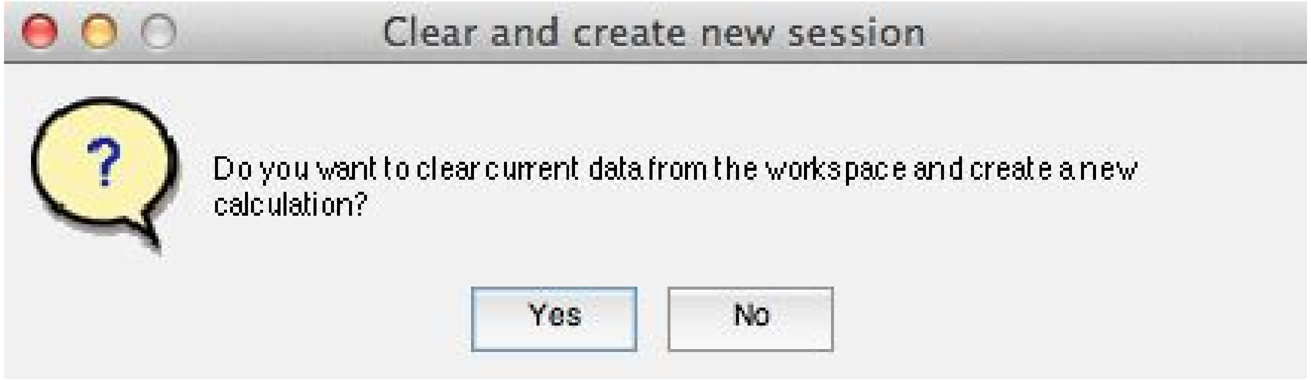
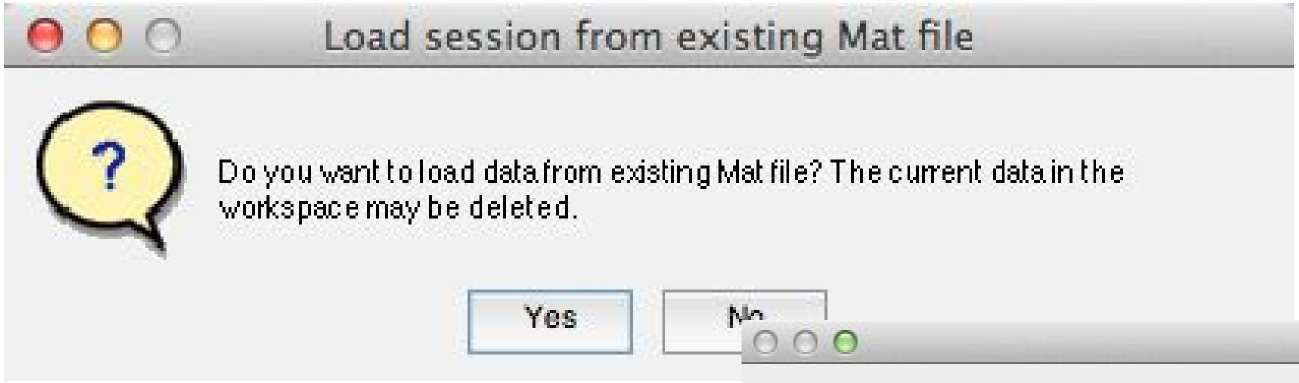
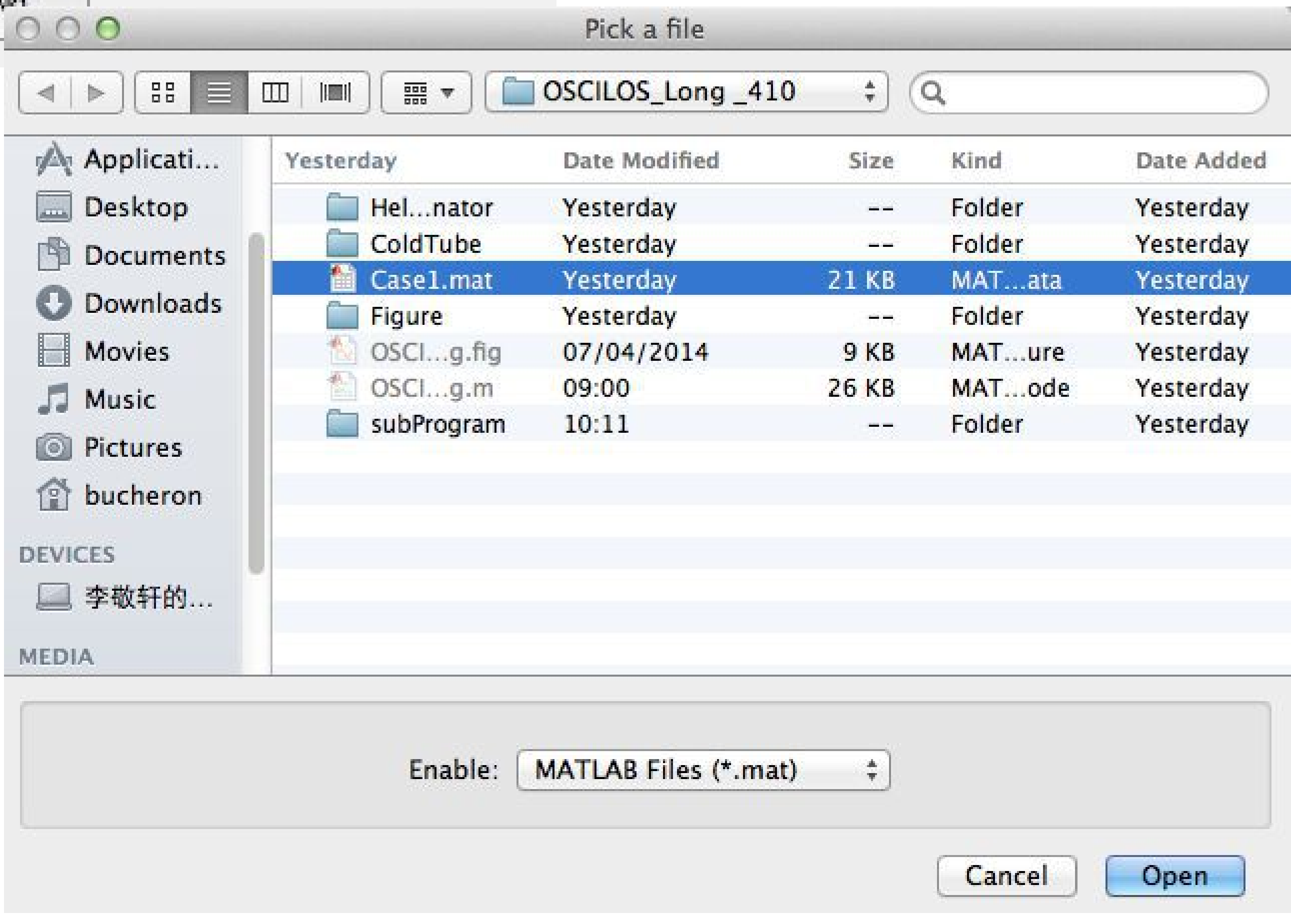
This menu option is used to clear current calculation results and create a new calculation.



File / Load…





This menu option is used to load data from existing Mat file. The current calculation results will be deleted once the user clicks “Yes”.

File / Save…

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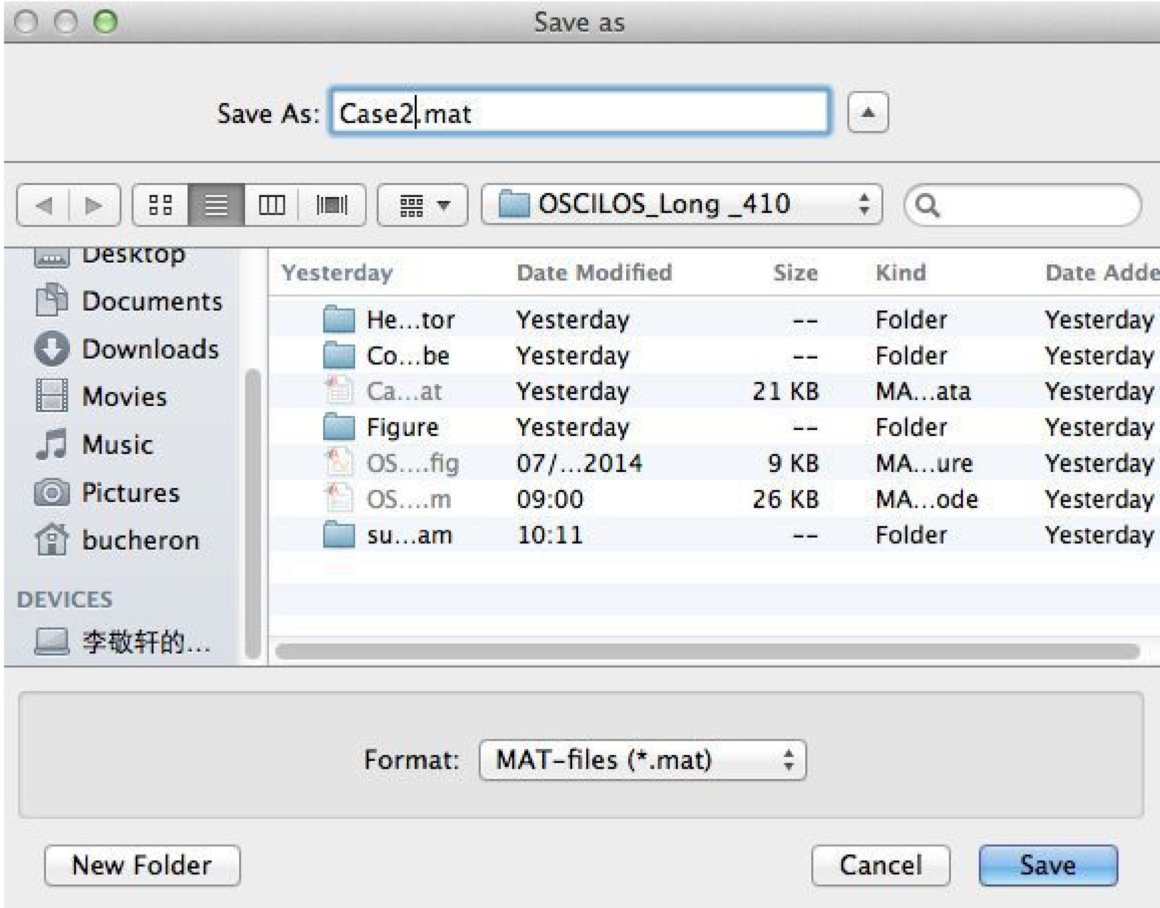
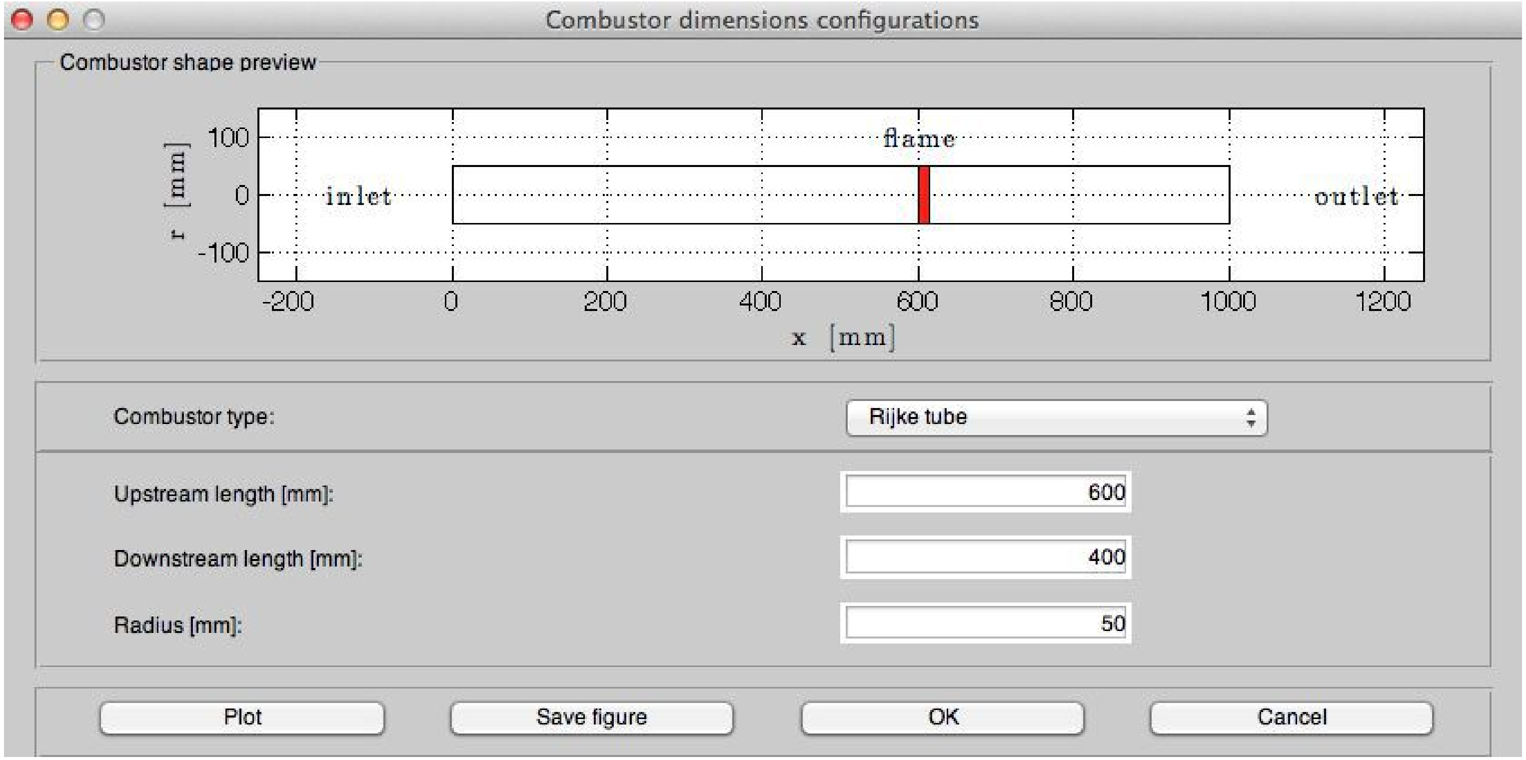
This menu option is used to save the current calculation results as a Mat file.



Initialization / Chamber dimensions

This menu option is used to set the geometric dimensions of the combustor.

The length and radius of the tube can be quickly configured for the case of a Rijke tube, as shown in the following figure.



Initialization / Chamber dimensions

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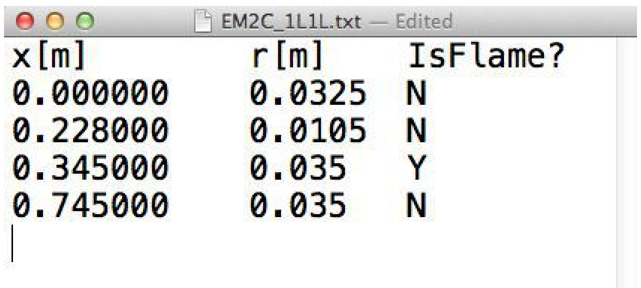
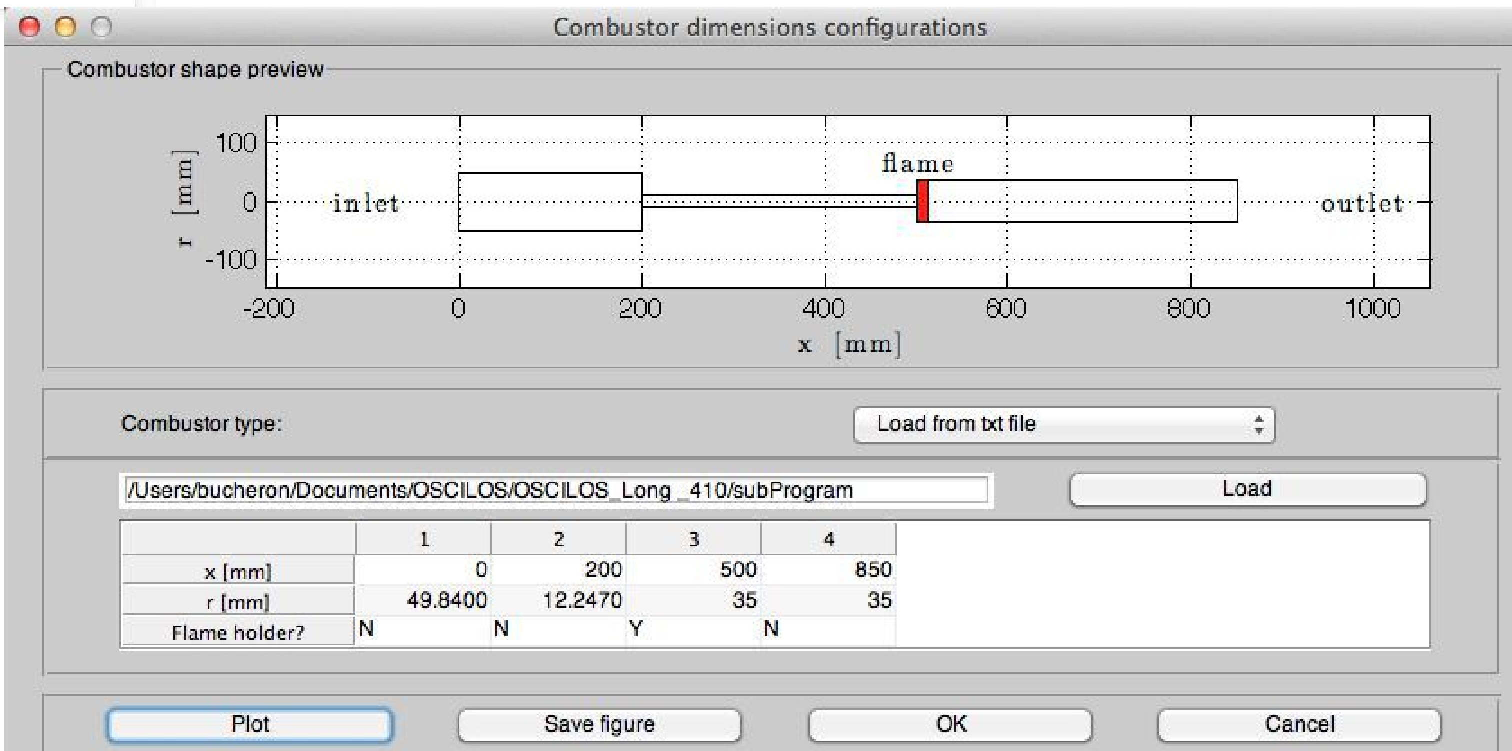
For complicated combustor geometries, users can load the information from an external txt file by clicking “load”.


EM2C_1L1L.txt — Edited

x[m]	r[m]	IsFlame?
0.000000	0.0325	N
0.228000	0.0105	N
0.345000	0.035	Y
0.745000	0.035	N



	1	2	3	4
x [mm]	0	200	500	850
r [mm]	49.8400	12.2470	35	35
Flame holder?	N	N	Y	N

Initialization / Chamber dimensions

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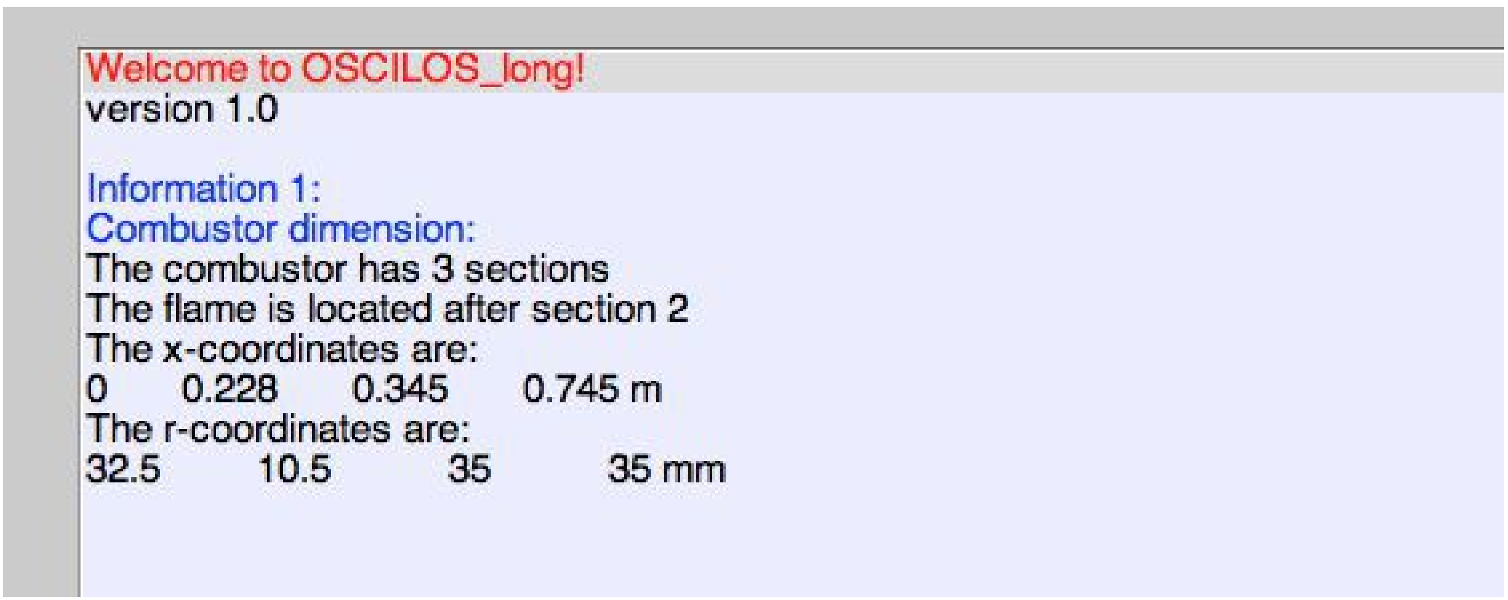
- ✓ A schematic of the combustor can be previewed by clicking "Plot".
- ✓ The figure can be saved by clicking "save figure".
- ✓ The current configuration is saved by clicking "OK". The key information will be printed in the information window.



Initialization / Thermal properties

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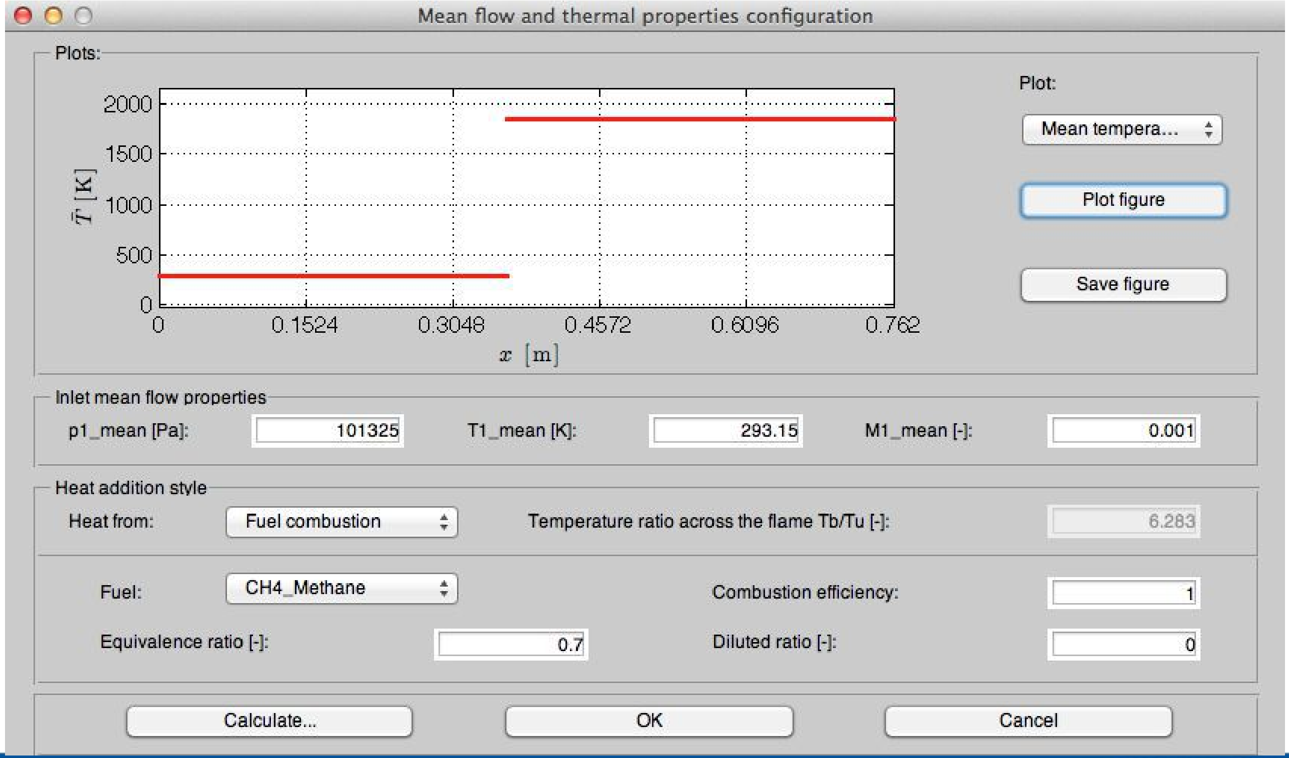
- ✓ This menu is used to set the inlet mean flow properties and the mean heat addition.
- ✓ The mean flow and thermal properties within each combustor section are considered uniform.
- ✓ The mean properties in different sections can be calculated by clicking “Calculate…” once all the inputs have been completed.



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Initialization / Thermal properties

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✓ Users can choose a model for the (mean) heat addition from the popup menu.

1. Heat from a heating grid (Tb/Tu is given), where Tu represents the temperature before the heating grid, and Tb indicates that after the grid. This is often used for the case of a Rijke tube.
2. Heat from fuel combustion.
   - ✓ User can choose the fuel from the popup menu, including CH_4, C_2H_4, C_2H_6, C_3H_8, C_4H_8, C_4H_{10} (n-butane), C_4H_{10} (isobutane) and $C_{12}H_{23}$ (Jet-A).
   - ✓ User can also set:
     - ✓ Equivalence ratio
     - ✓ Combustion efficiency
     - ✓ Dilution ratio

Initialization / Thermal properties

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- ✓ The distribution of mean temperature and mean flow velocity can be previewed by clicking “Plot figure”.
- ✓ The figures can be saved by clicking “Save figure”.
- ✓ The current configuration is saved by clicking “OK”. The key information will be printed in the information window.

```
Information 2:
Mean flow and thermal properties:
The inlet gas is air+CH4_Methane mixture
The fresh mixture reacts to combustion products at the flame holer
The mean temperature in different sections are:
293.15      293.1287      293.15006      1772.5353 K
The mean pressure in different sections are:
101325      101299.2341      101350.9068      101348.9626 Pa
The mean velocity in different sections are:
0.68649      6.5781      0.59177      3.3197 m/s
The mean speed of sound in different sections are:
343.2461      343.2337      343.2462      817.5776 m/s
The mean heat release rate is:
5.3059 kW
```

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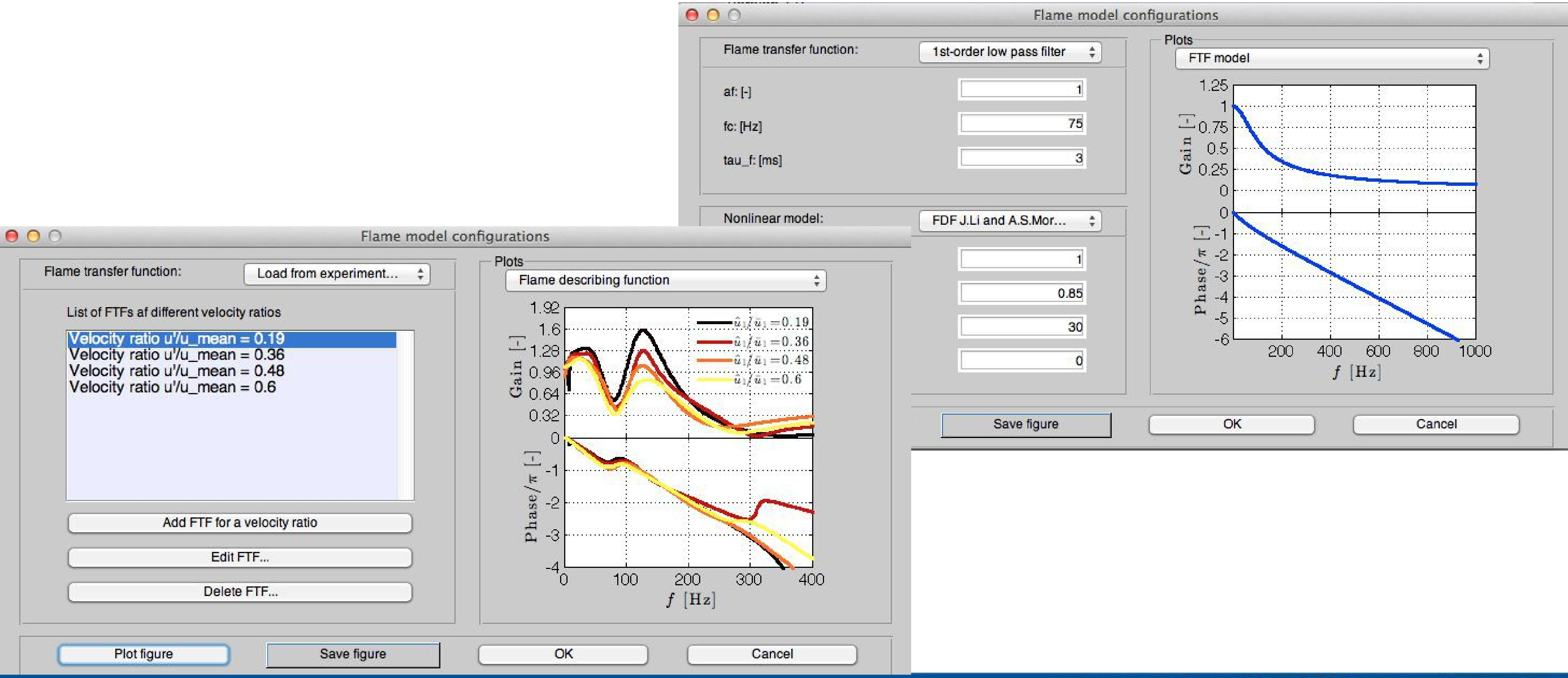
Initialization / Flame model

- ✓ This menu option is used to set the flame model, which describes how the (normalized) unsteady heat release rate of the flame responds to (normalized) velocity fluctuations .
- ✓ The user can choose between prescribing a flame transfer function model (with non-linearity options) or loading and fitting experimental data.



Flame transfer function

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Three kinds of flame transfer function (FTF) models can be prescribed.

1. n-tau model

$$\mathrm{FTF}(s) = a_f e^{-\tau_f s}$$

2. First order low pass filter

$$\mathrm{FTF}(s) = \frac{\omega_c}{s+\omega_c} a_f e^{-\tau_f s}$$

3. Second order low pass filter

$$\mathrm{FTF}(s) = \frac{\omega_c^2}{s^2 + 2\xi\omega_c s + \omega_c^2} a_f e^{-\tau_f s}$$

Where,

s : the Laplace variable

a_f : gain

τ_f : time delay

f_c : cut-off frequency

ξ : damping ratio

Non-linear model

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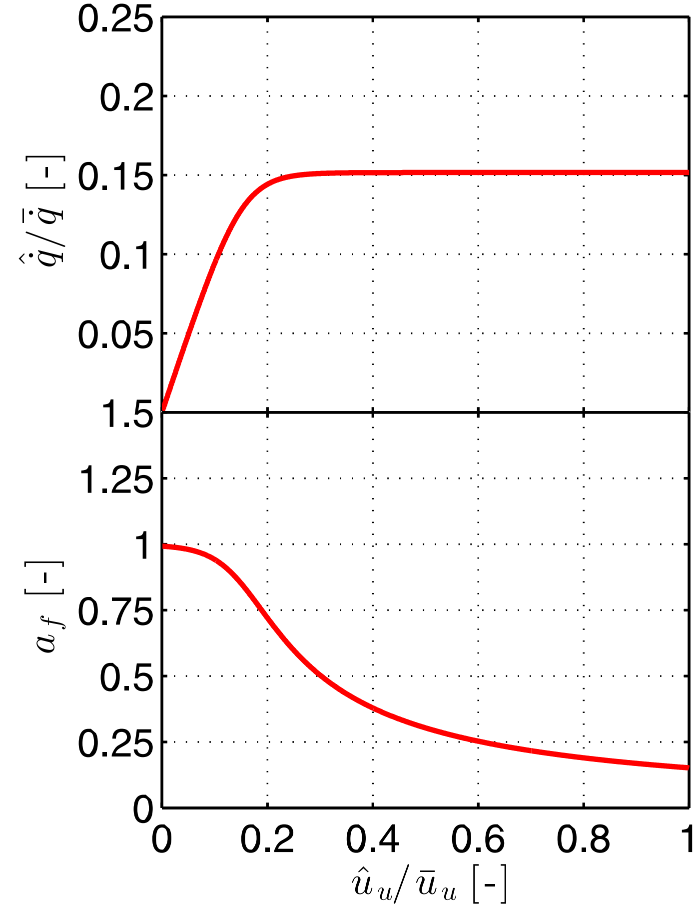
For the n-tau flame model, a non-linear option can be used to describe the gain saturation with increasing velocity disturbance ratio. The same model can also be applied to the first and second order low pass filters

$$\frac{\hat{\dot{q}}}{\bar{\dot{q}}} = \int_0^{\frac{\hat{u}}{\bar{u}}} \frac{1}{a_1 + (x + a_2)^b} dx$$

$$a_f = \frac{\hat{\dot{q}}}{\bar{\dot{q}}} \Big/ \frac{\hat{u}}{\bar{u}}$$



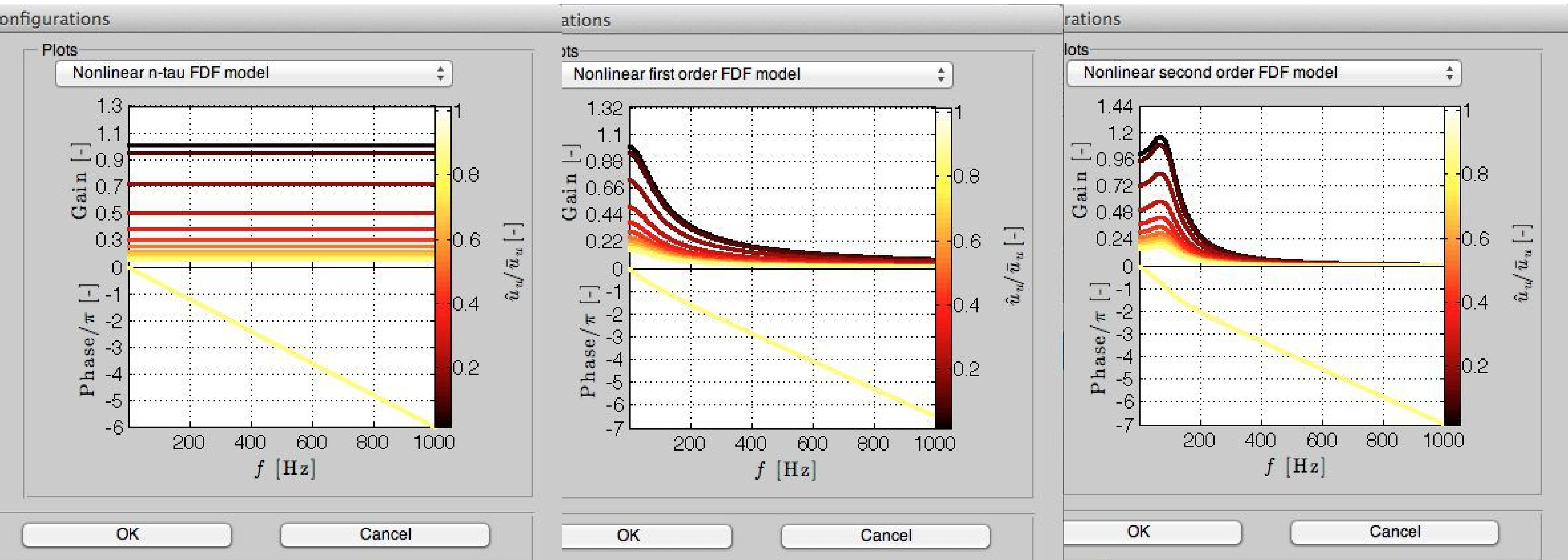
The figure opposite shows an example of the the evolution of the normalized heat release rate amplitude and the gain (a_f) with the velocity disturbance ratio. The gain decreases as the velocity ratio increases, saturating at around a forcing level of 0.2.

Here, $a_1 = 1,\ a_2 = 0.85,\ b = 30$

Flame describing function

If the response of the flame is assumed to be "weakly non-linear", a flame transfer function model and non-linearity model can be combined to give a "flame describing function" (FDF).

- ✓ The flame describing function can be previewed by choosing "Nonlinear FDF model" in the right popup menu and clicking "Plot figure".
- ✓ The figures can be saved by clicking "Save figure".



Load experimental FDF

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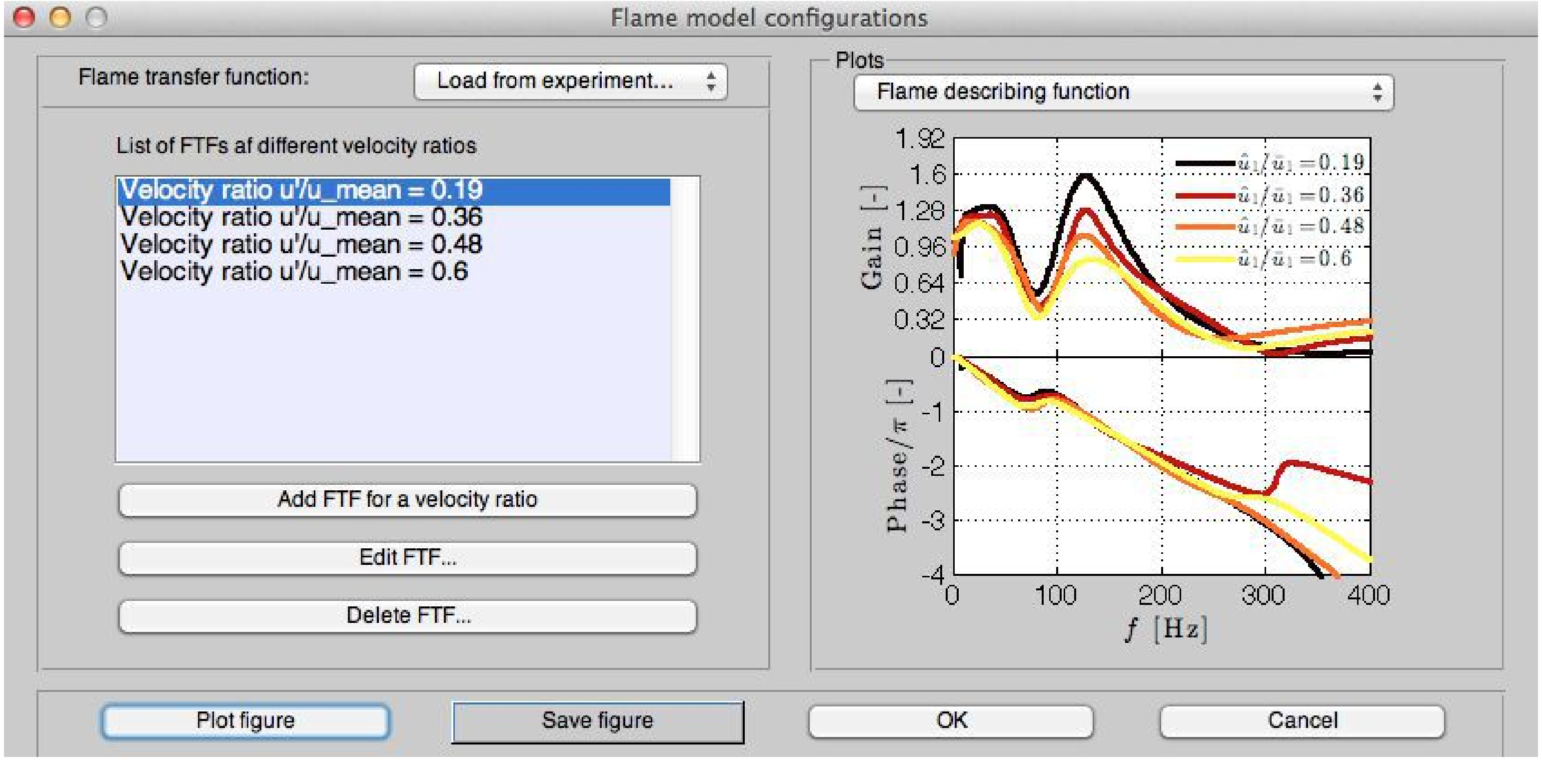
The flame describing function can be loaded from experimental frequency response data.

The user can add a set of flame transfer functions measured at different velocity ratios, by clicking "Add FTF for a velocity ratio".



Load experimental FTF and fitting

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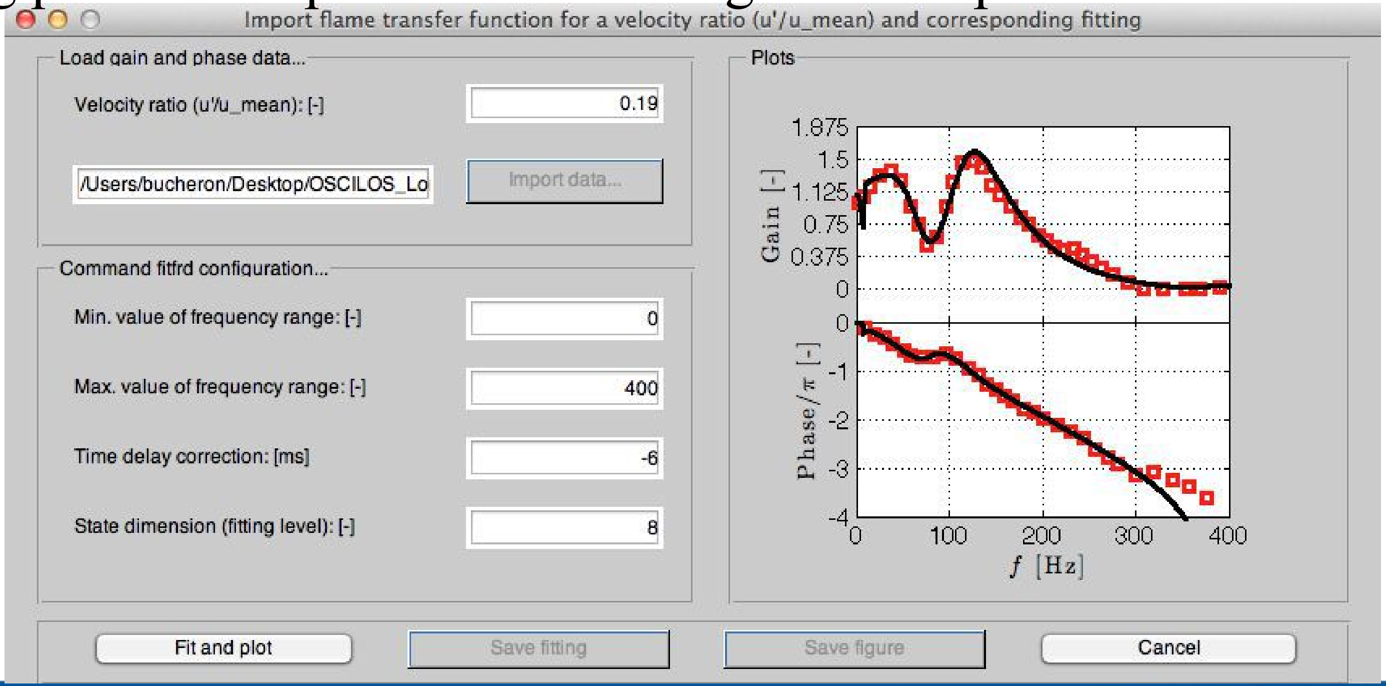
Once the button "Add FTF for a velocity ratio" is clicked, a window for displaying the experimental FTF and fitting will appear.

The user can set the velocity ratio and then import experimental FTF from an external Mat file. (It is better to save the data in a Mat file prior to running OSCILOS).

The user needs to set the fitting frequency range, time delay correction and fitting order, which are used for fitting.

The fitting process is operated on clicking "Fit and plot".



Initialization / Boundary condition

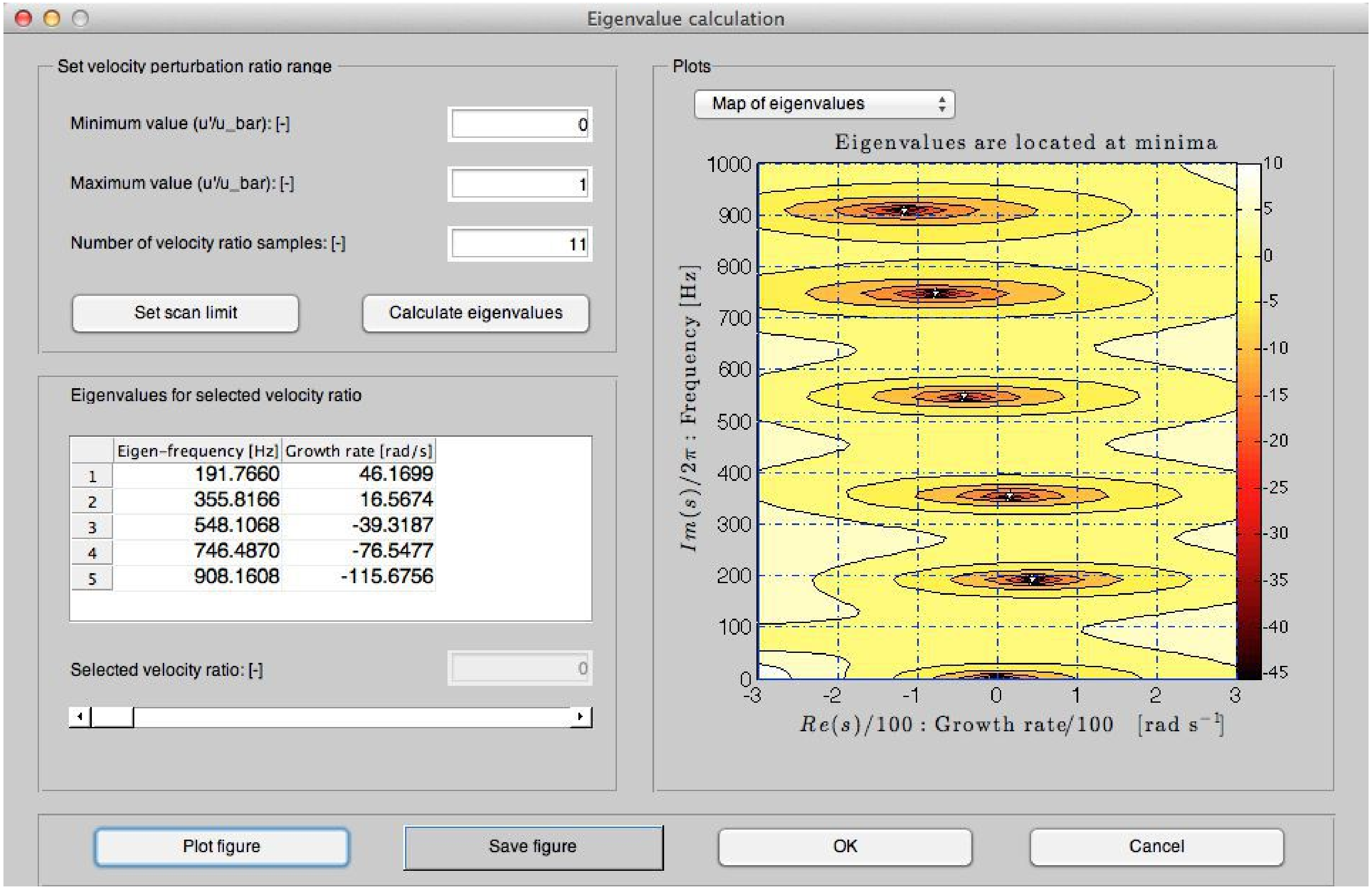
This menu option is used to set the boundary conditions at the inlet and outlet of the combustor. A pressure reflection coefficient (R) is used to describe the link between the incident and reflected acoustic waves.

Five kinds of boundary conditions are provided:

1. Open end without radiation (R = -1).
2. Closed end (R = 1).
3. Open end with radiation.
4. Choked end.
5. User defined (Amplitude and time delay)…
6. User defined (Amplitude and phase)…

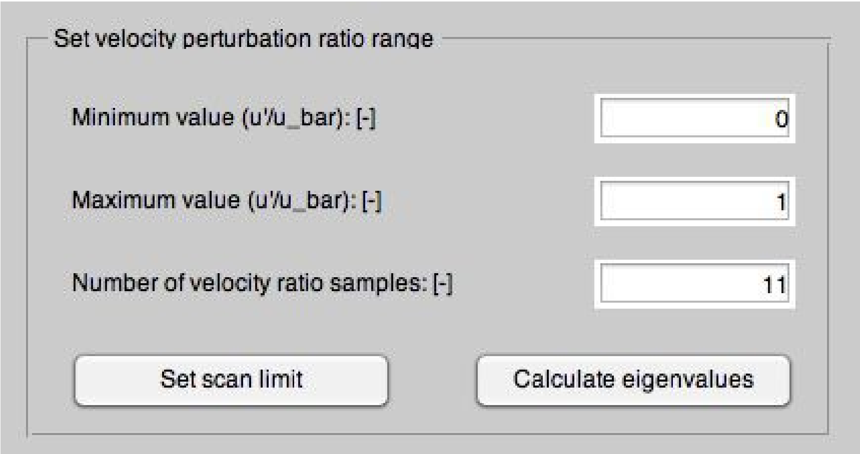
Freq. domain analysis / Eigenmode calculation

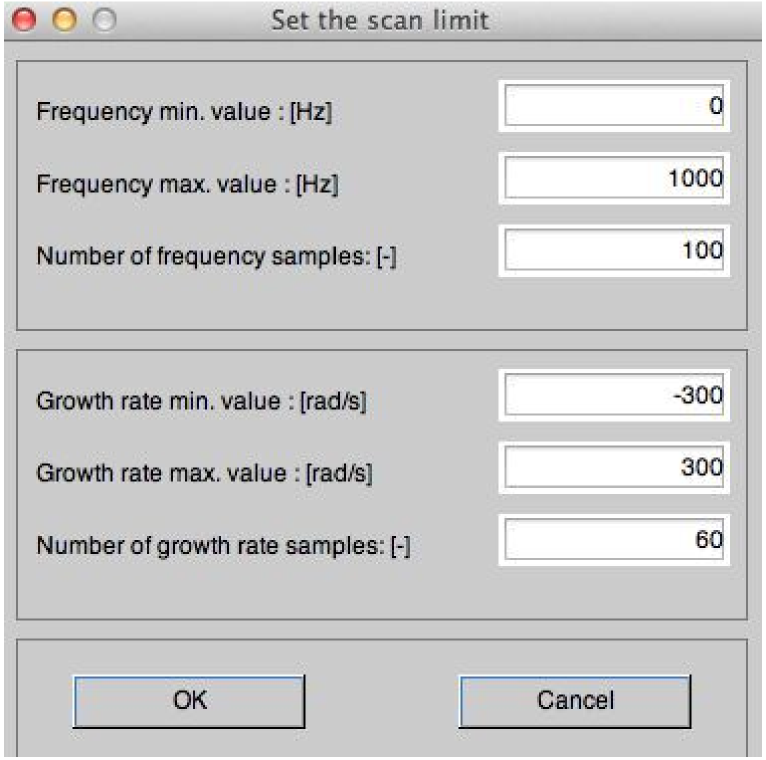
Once all initializations are complete, the user needs to click "Preprocessing" to allow the program to perform the necessary preprocessing. The user can then progress to the "Eigenmode calculation" panel.



Freq. domain analysis / Eigenmode calculation

If the user previously chose the flame describing function model in the "Flame model" panel, the minimum and maximum velocity ratios (uRatio_min and uRatio_max) now need to be set. The number of velocity ratio samples is also needed to equally space the velocity ratio range.





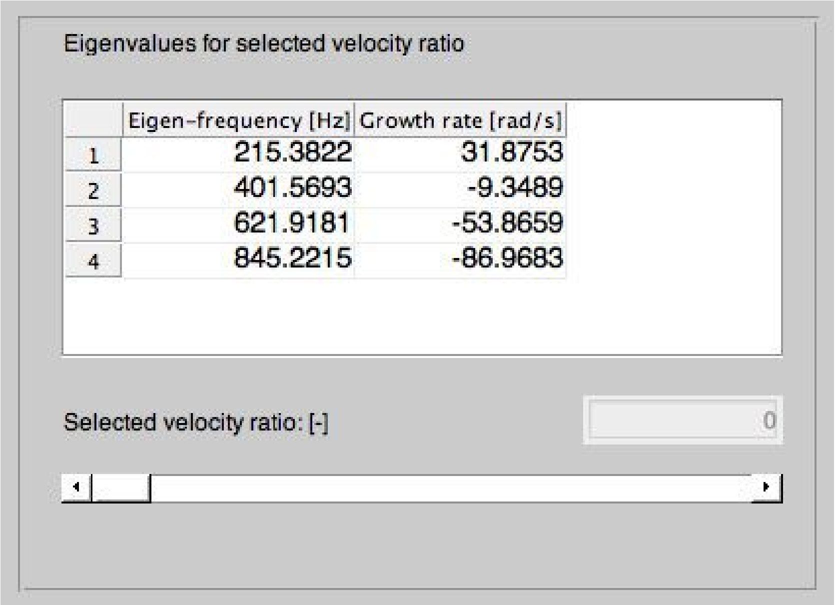
The user needs to define a scan range (including frequency and growth rate) to search for eigenvalues within this range. This can be done by clicking “Set scan limit”.

When all the sets have been done, the user can calculate the eigenvalues for a set of velocity ratios.

Freq. domain analysis / Eigenmode calculation

The eigenvalues for a selected velocity ratio appears in the table (as shown in the bottom figure).

The user can change the slider to switch the velocity ratio. The values in the table will automatically change with the velocity ratio.



	Eigen-frequency [Hz]	Growth rate [rad/s]
1	215.3822	31.8753
2	401.5693	-9.3489
3	621.9181	-53.8659
4	845.2215	-86.9683

Freq. domain analysis / Eigenmode calculation

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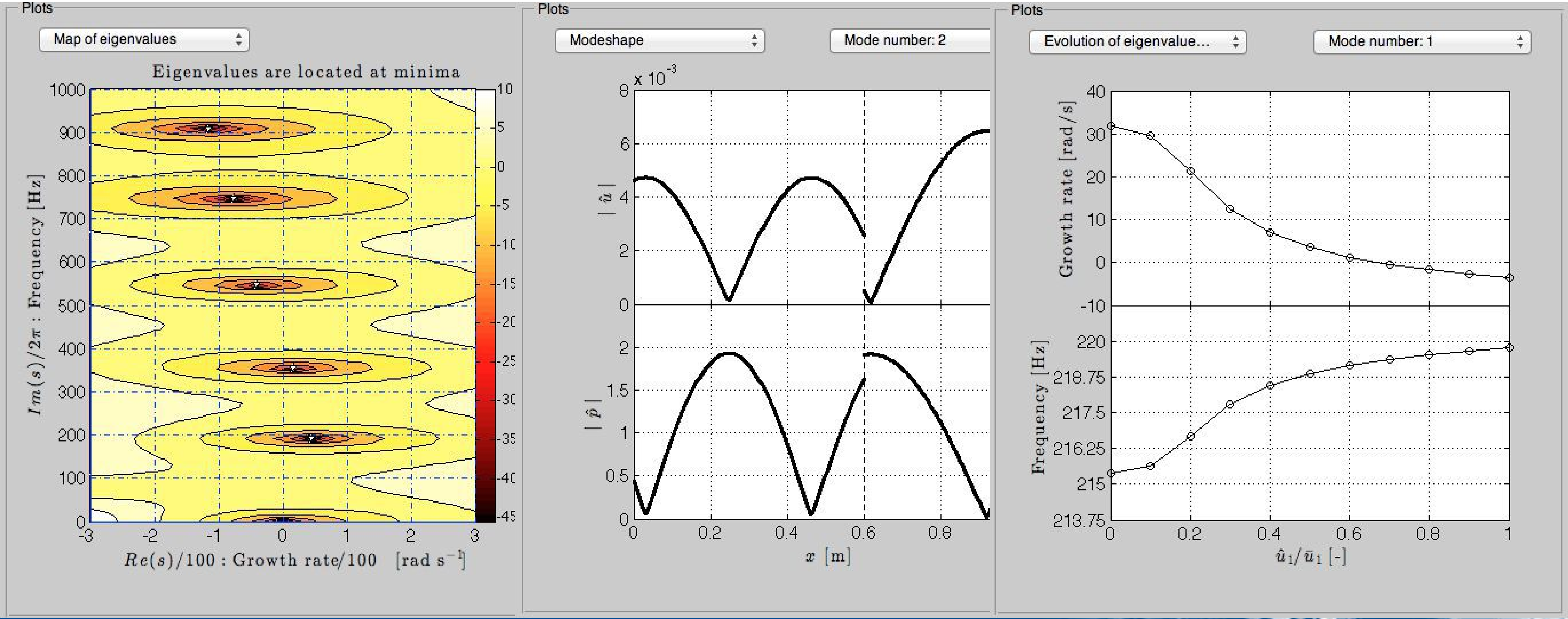
The user can plot three kinds of figures from the choices of the popup menu:

- ✓ A contour map showing the eigenvalue locations (growth rate and frequency)
- ✓ The mode shape
- ✓ The evolution of eigenvalues with increasing velocity ratio



Time domain simulation

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The code for the time domain simulation will be released soon, including:

- ✓ Time domain simulations for a simple geometry are illustrated in example of a Rijke tube , including the nonlinearities and the effect of active control.
- ✓ Time domain simulations for general combustor geometries (longitudinal modes).