# Calculation of HF Eigenmodes in Liquid Rocket Combustion Chambers

COMSOL Application

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AIRBUS SAFRAN LAUNCHERS

1 Thermo-Acoustic Combustion Instability in Rocket Engines

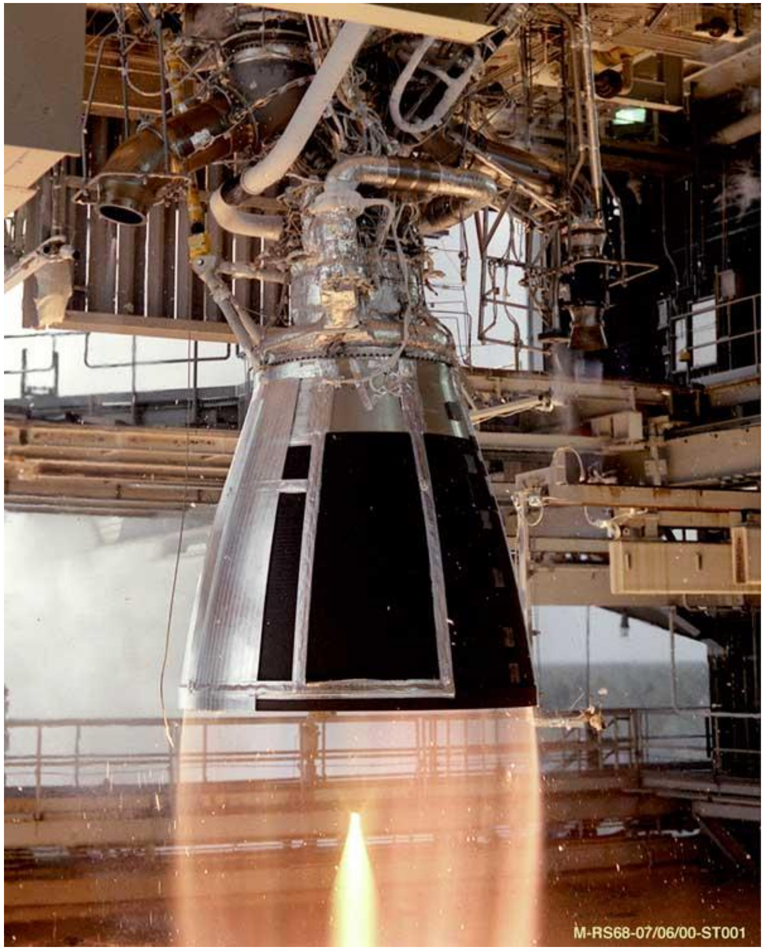
2 Comsol Calulation

3 Summary

# 1 Thermo-Acoustic Combustion Instability in Rocket Engines

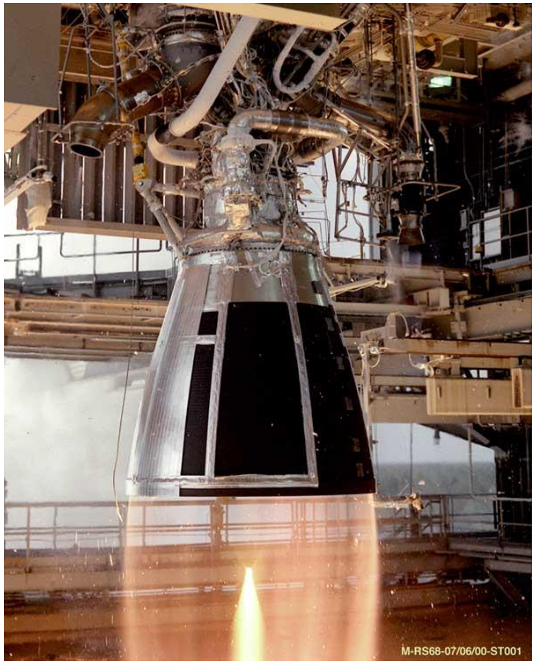
# Rocket Engines

## How does it work?




http://www.nasa.gov/images/content/148709main_d4_testing_08.jpg, (accessed on 07.09.2016)

# Rocket Engines

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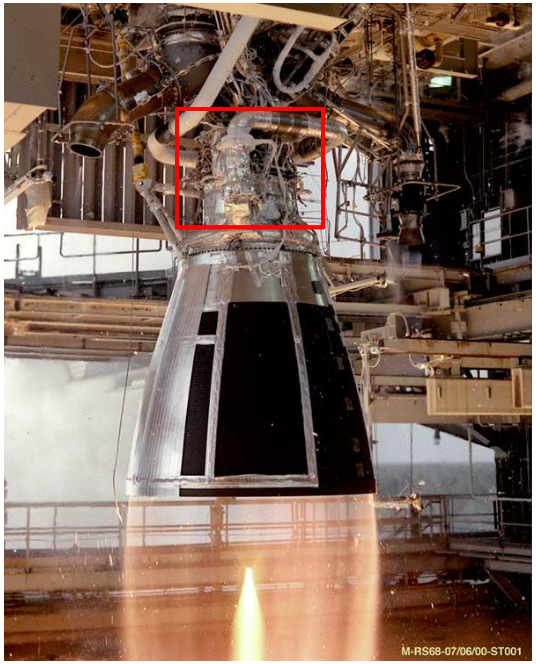


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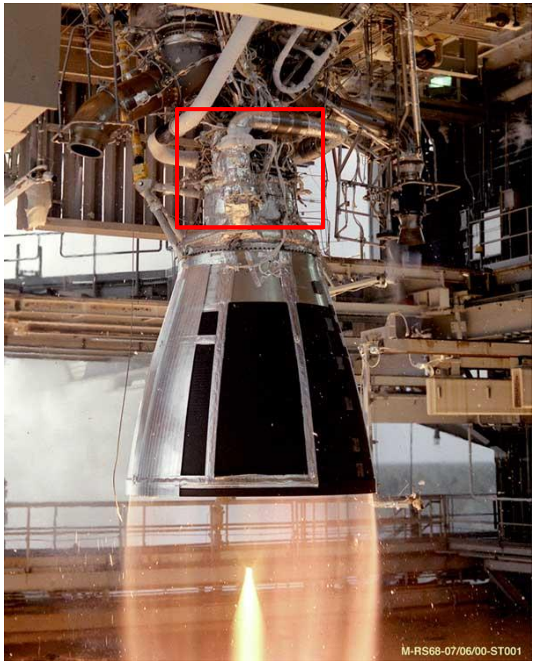


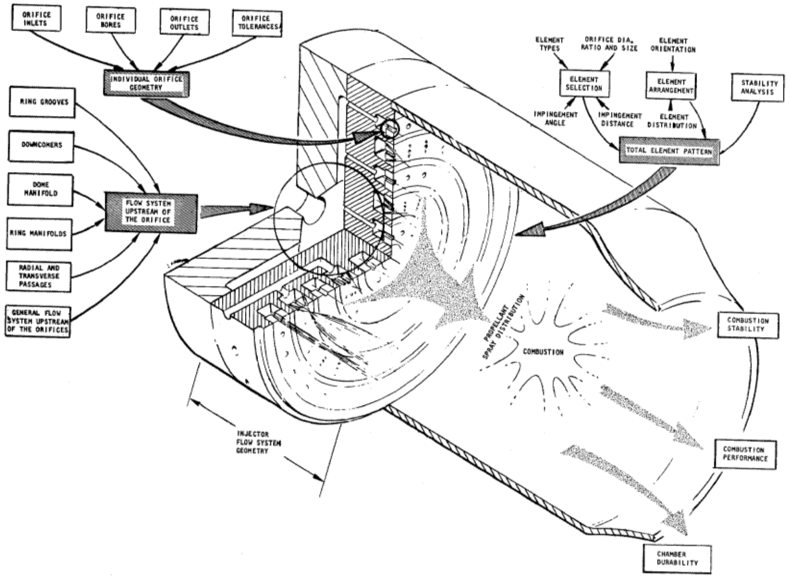


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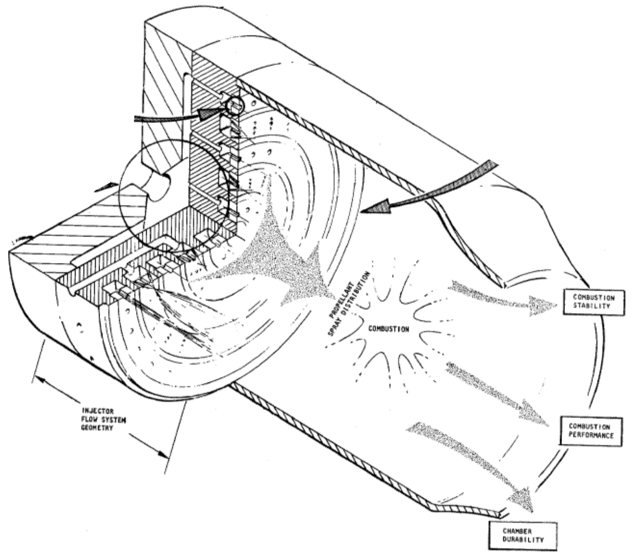


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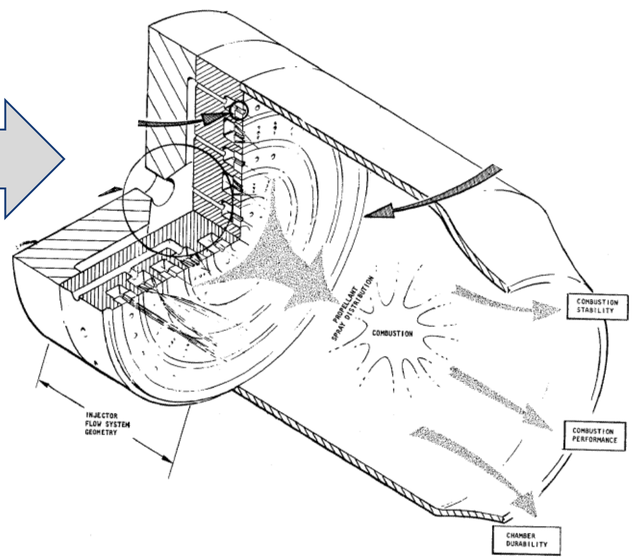
## Flowrates and Pressure Levels

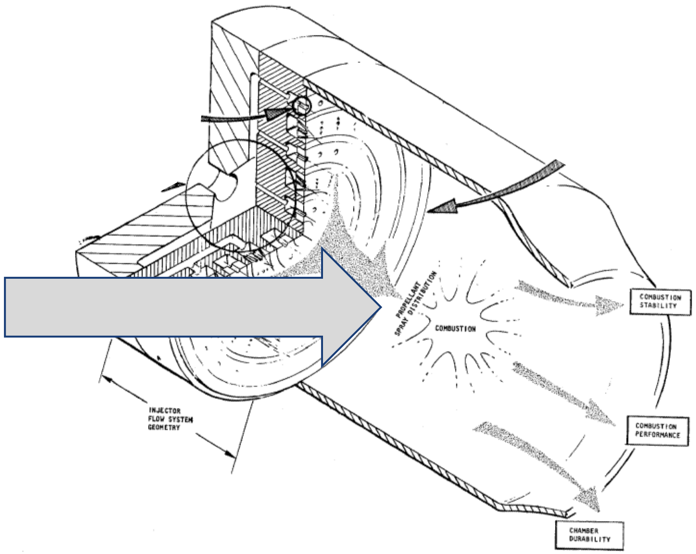

Image: Michel Bobillier




Jet d'eau, Geneve: 500l/s, 16bar, 140m

# Rocket Engines

## Thermal Power

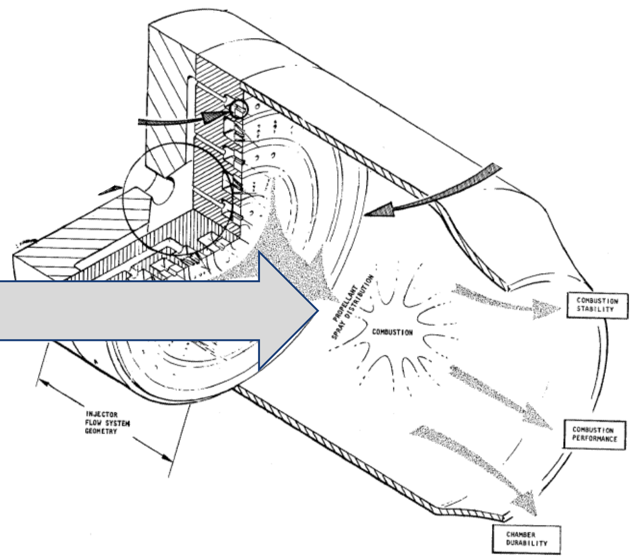




Neckarwestheim: 1400 MW

# Rocket Engines

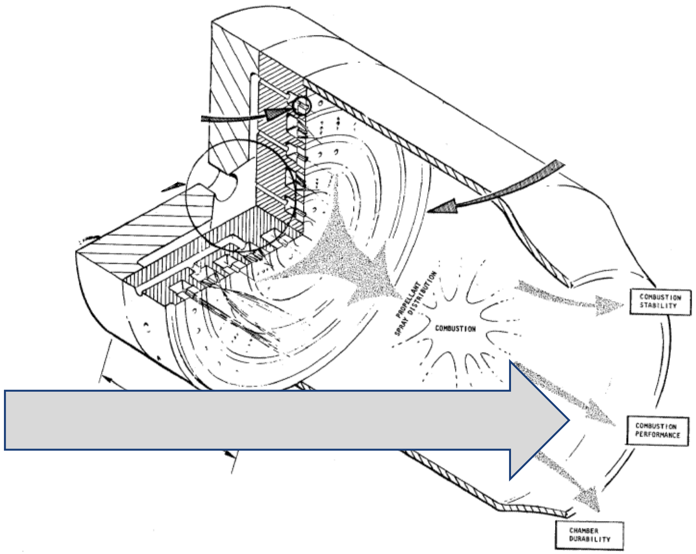
## Temperatures





2 x Melting Point of Steel

## Velocities

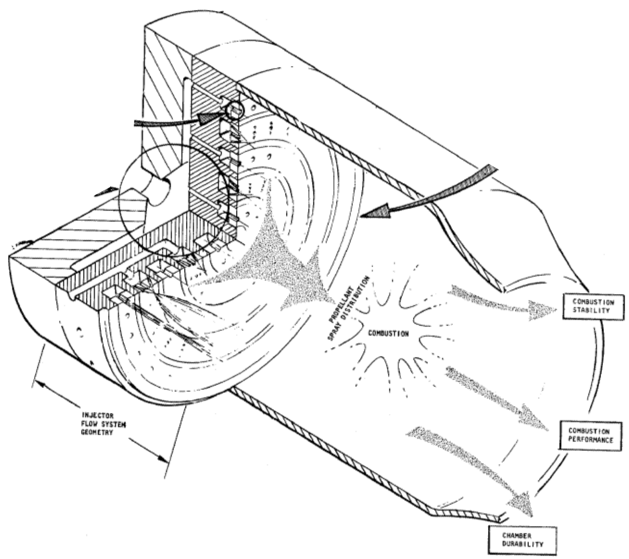




Approx. 4000m/s → 4 x A12 maximum speed

# Rocket Engines

- Application at the physical limits
- Large quantities of energy present
- Limited margins against failures
- Small deviations can have catastrophic effects

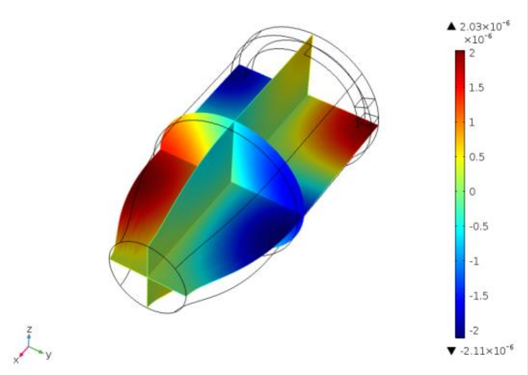




➔ Need for a safe, smooth, robust mode of operation

# 1 / High Frequency Combustion Instability

Combustion chamber acoustics conserve pressure and velocity fluctuations



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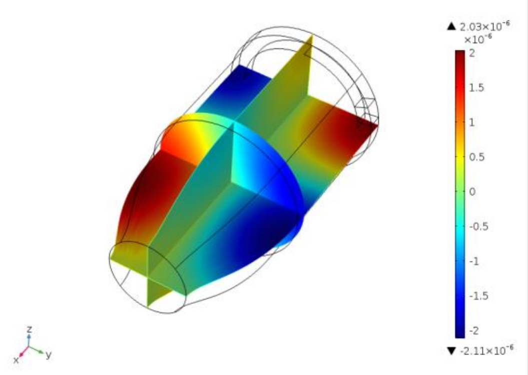
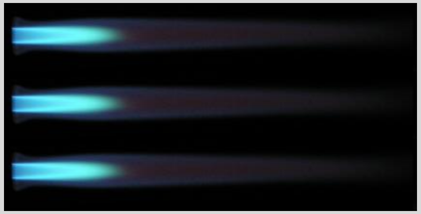
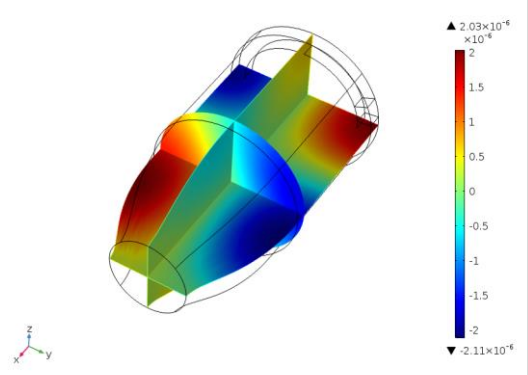
Combustion chamber acoustics conserve pressure and velocity fluctuations




Combustion process is sensitive to pressure and velocity fluctuations



Combustion chamber acoustics conserve pressure and velocity fluctuations

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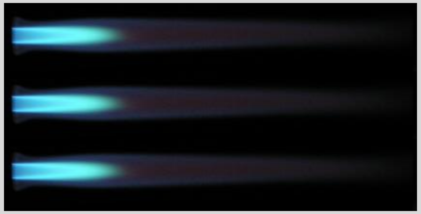
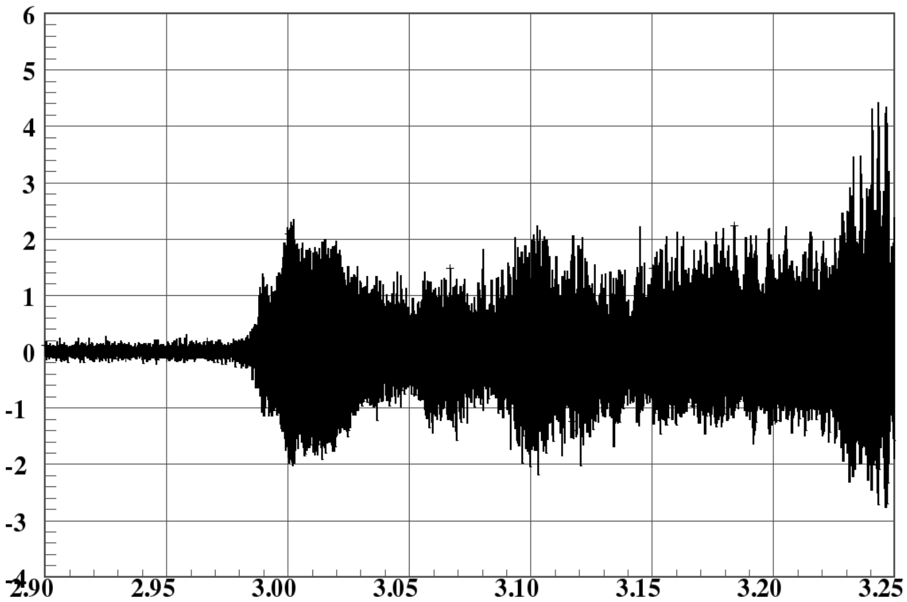
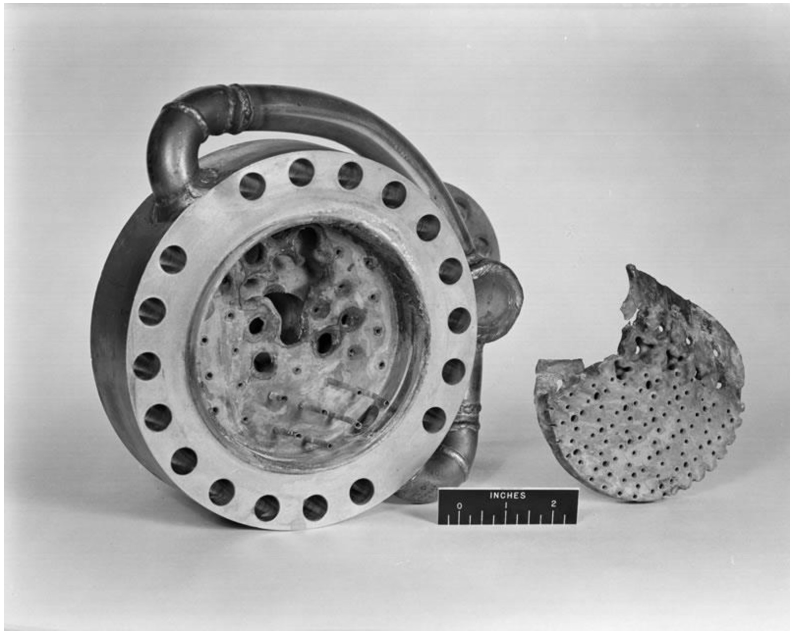


Fluctuating combustion induces heat release fluctuations and pressure fluctuations

# 1 / High Frequency Combustion Instability



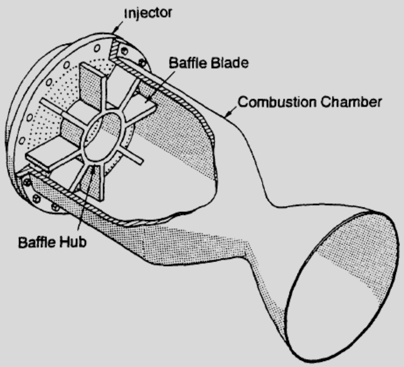




Combustion instability oscillating in the combustion chambers acoustic eigenmodes

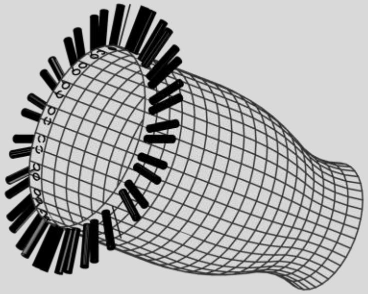
Influence parameters and counter-measures:

- Combustion chamber geometry and hot gas determine the eigenfrequencies
- Propellant combination has tremendous influence on the risk of instabilities
- Proper design of Injection system reduces risk
- Stabilization devices can be used

Baffles:
protect the flame and provide damping




Acoustic absorbers/liners:
provide damping at their tuning frequency



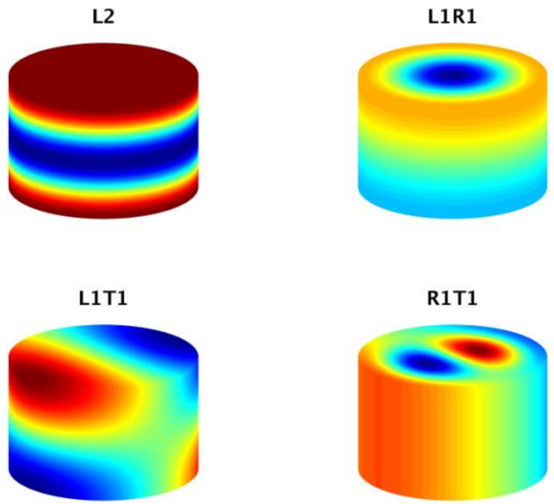
Knowledge of the acoustic eigenfrequencies is required

# 1 / Can COMSOL predict the combustion chamber eigenfrequencies?

Evaluation of off-the-shelf-COMSOL modules w/o modifications

Features to be considered

- Presence of mean flow (non-negligible Ma-Number)
- Presence of gradients
- (Presence of absorbers or baffles)

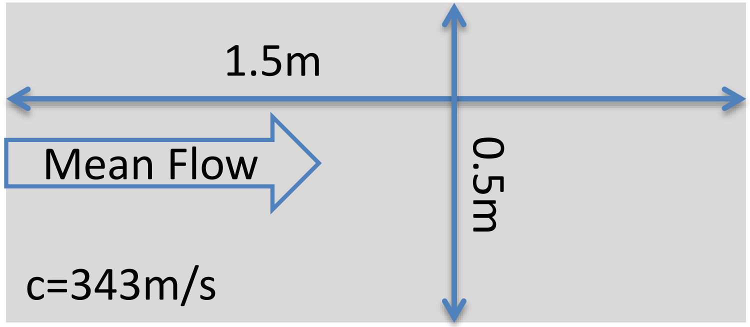



Stepwise approach with increasing complexity

The results have been de-dimensionalized for confidentiality reasons

# 2 Comsol Calculations

## Eigenfrequencies of a 2D Duct with and w/o mean flow




| Eigen mode | Analytic solution | |
|---|---|---|
| Mach | 0 | 0.2 |
| L1 | 114.3 | 109.8 |
| L2 | 228.7 | 219.5 |
| L3 | 343.0 | 329.3 |
| T1L1 | 361.6 | |
| T1L2 | 412.2 | |

Analytic solution:

$$\omega_{lm} = c\pi\sqrt{\left(\frac{l}{L}\right)^2 + \left(\frac{m}{H}\right)^2} = c\sqrt{\alpha_l^2 + \beta_m^2}$$

## Eigenfrequencies of a 2D Duct with and w/o mean flow

Physics module:
*Linear Euler, Frequency Domain*

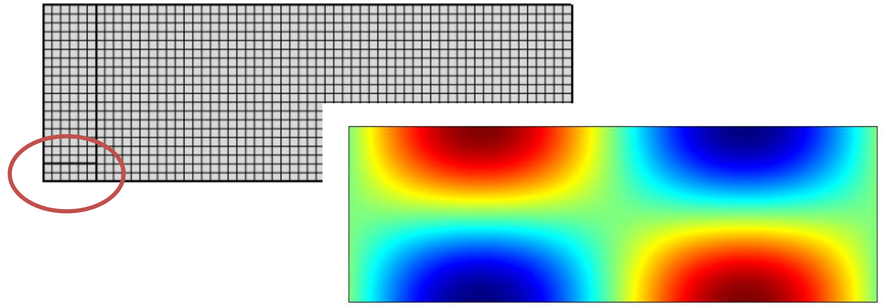
Acoustic source:
*Domain Source*

Study:
*Frequency Domain*
Direct solver: MUMPS

Mesh:
Quadrilateral mapped mesh
Max. element length: 0.025m

➔ Set up is correct

| Eigen mode | Analytic solution | | COMSOL (Step: 0.25Hz) | |
|---|---|---|---|---|
| **Mach** | 0 | 0.2 | 0 | 0.2 |
| **L1** | 114.3 | 109.8 | 114.3 | 109.8 |
| **L2** | 228.7 | 219.5 | 228.8 | 219.5 |
| **L3** | 343.0 | 329.3 | 343.3 | 329.5 |
| **T1L1** | 361.6 | | 361.8 | 353.5 |
| **T1L2** | 412.2 | | 412.5 | 401.5 |

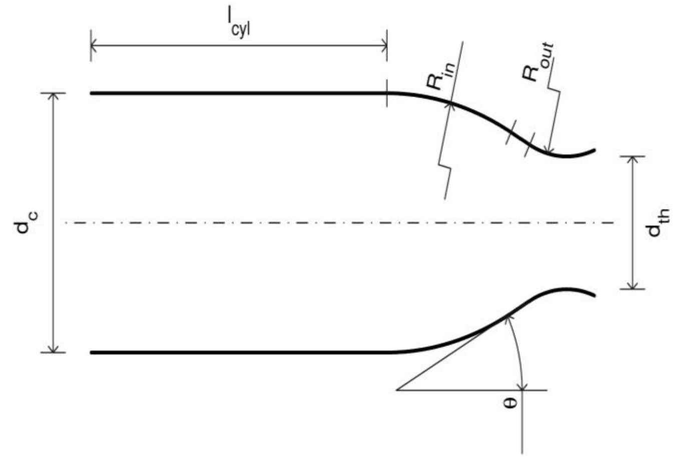


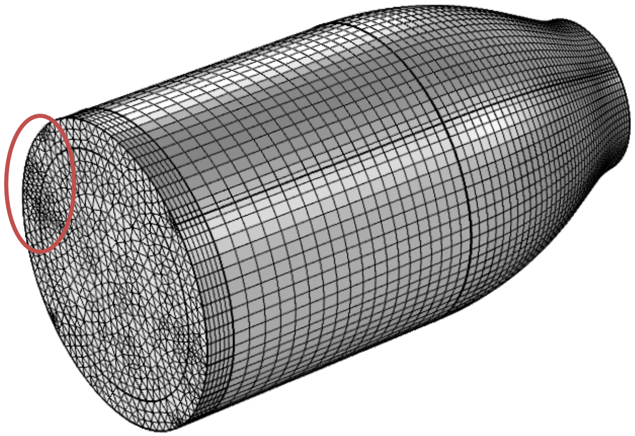
# 2 / Rocket Engine Test Case

Physics module:
*Linear Euler, Frequency Domain*

Boundary Conditions:
Chamber wall and inlet: *Rigid wall*
Chamber outlet: *Asymptotic far-field radiation + Outflow boundary*

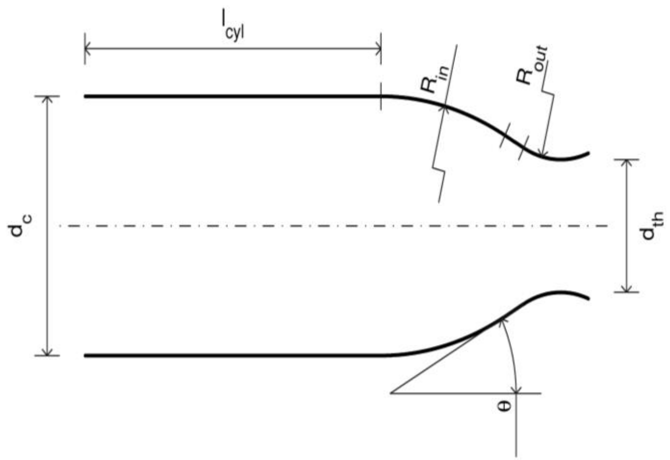
Acoustic source:
*Domain Source*

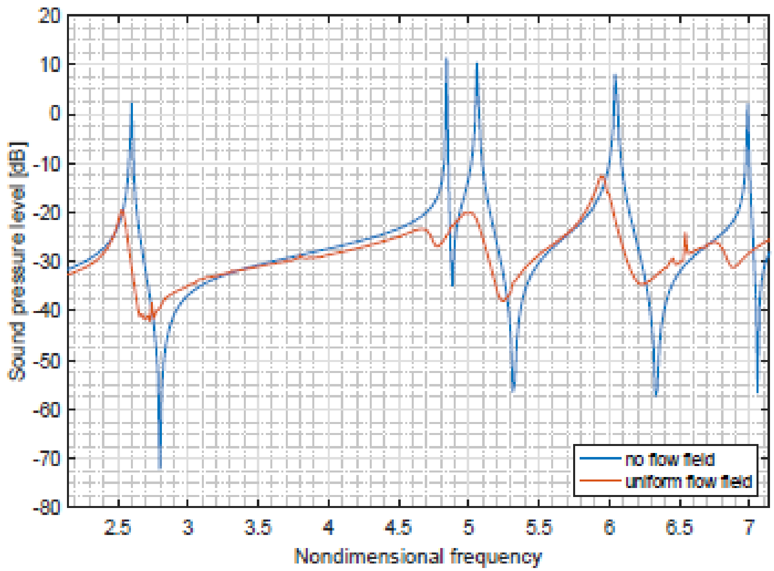


# 2 / Quiscent medium / uniform flow field

- Zero Mach number and homogeneous medium
- Simple, constant axial velocity (unphysical at nozzle)

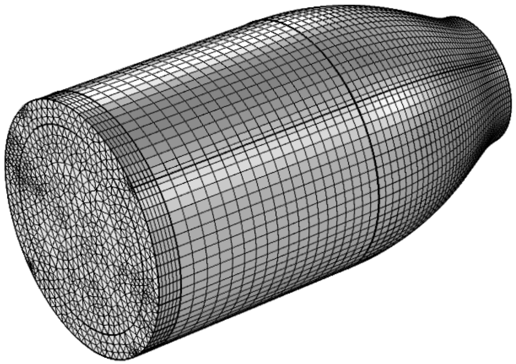


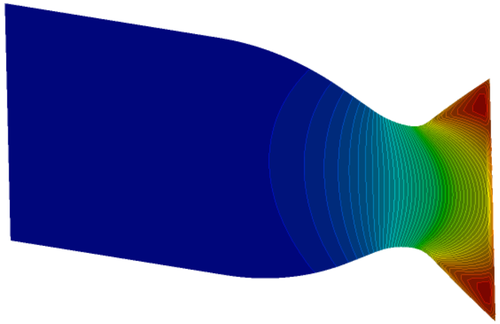



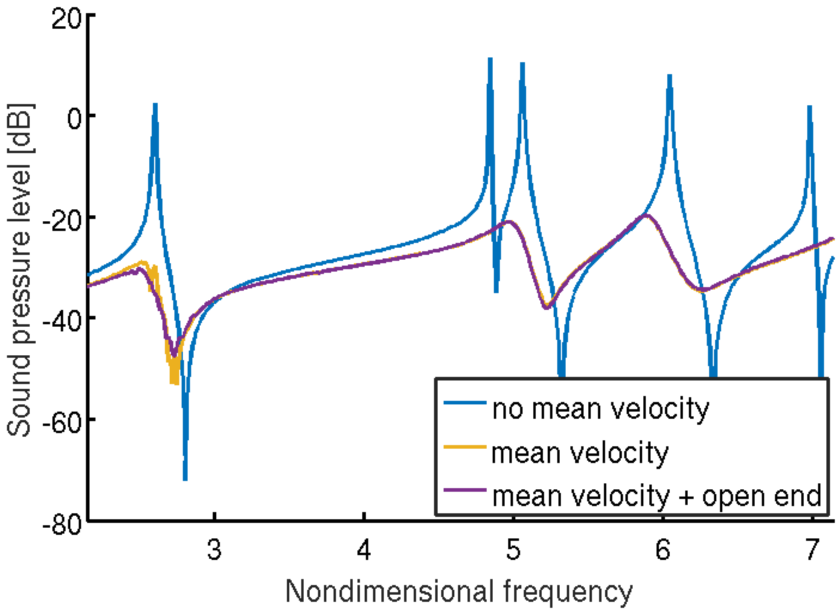

Frequency shift and additional damping when mean flow is present

# 2 / Physical mean flow of hot gas

- COMSOL domain is truncated to keep Ma number below 1








→ Damping increases, double peak reduces to single peak, some spurious oscillations

# 3 Summary

- COMSOL has been applied to calculate the acoustic properties of confined domains
- Cases with and without mean flow have been chosen
- The eigenfrequencies can be calculated using a domain source and a frequency sweep
- Mean flow increases damping and promotes spurious oscillations
- Frequency shift for mean flow can be observed