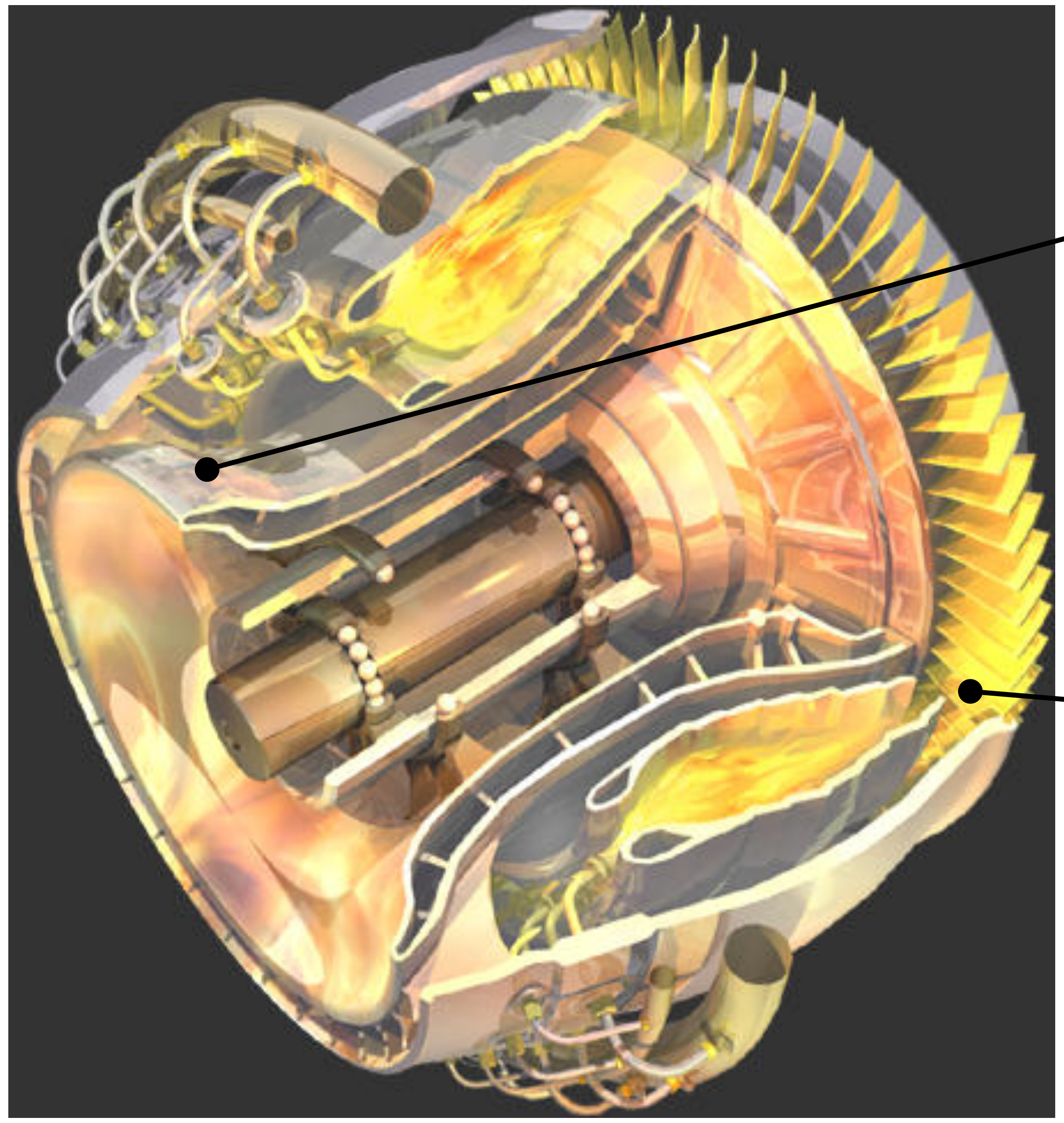
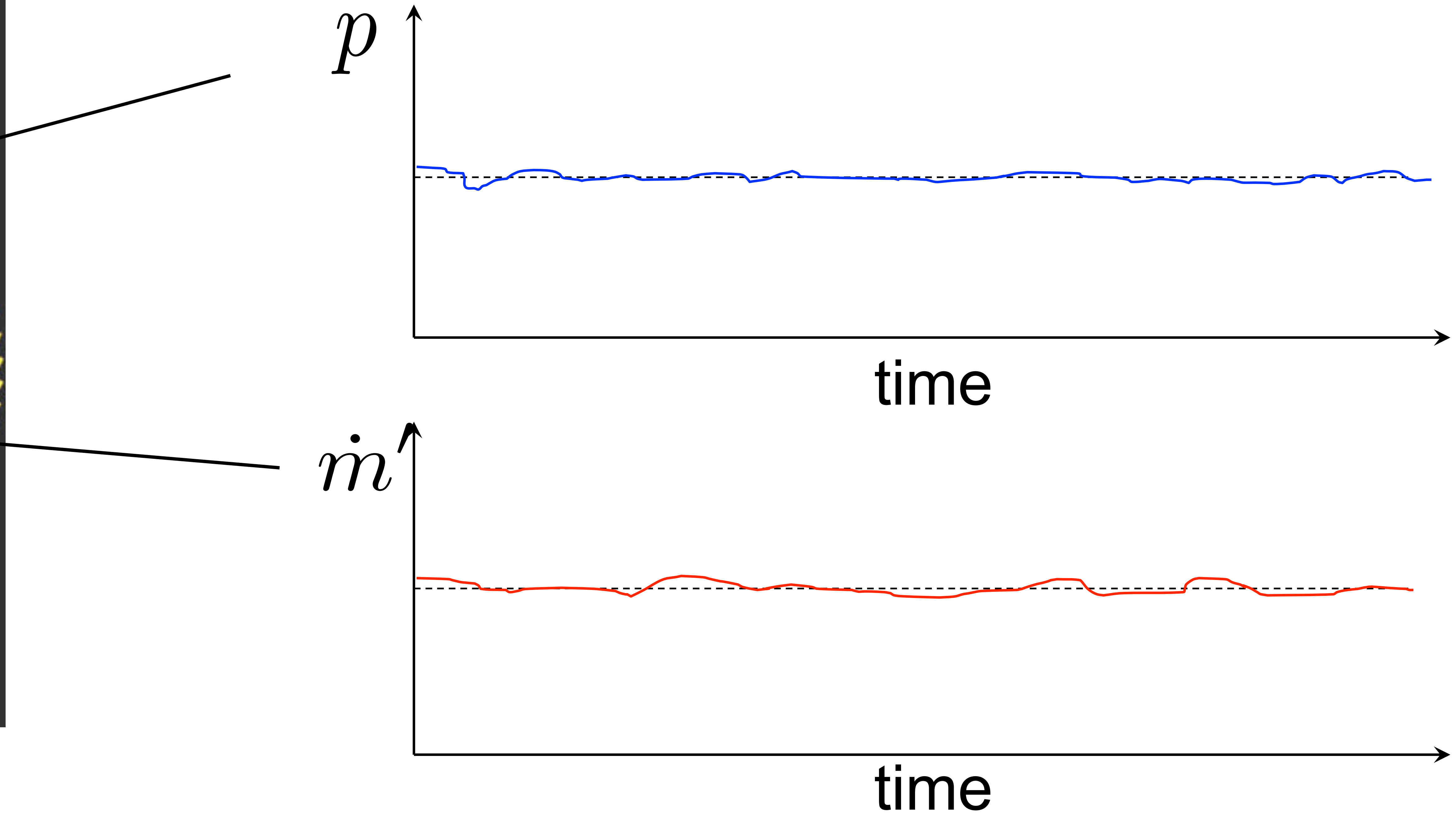
Generalities of thermoacoustic instabilities

Camilo F. Silva

April 27, 2022

We want to build gas turbines with a wide range of operating conditions





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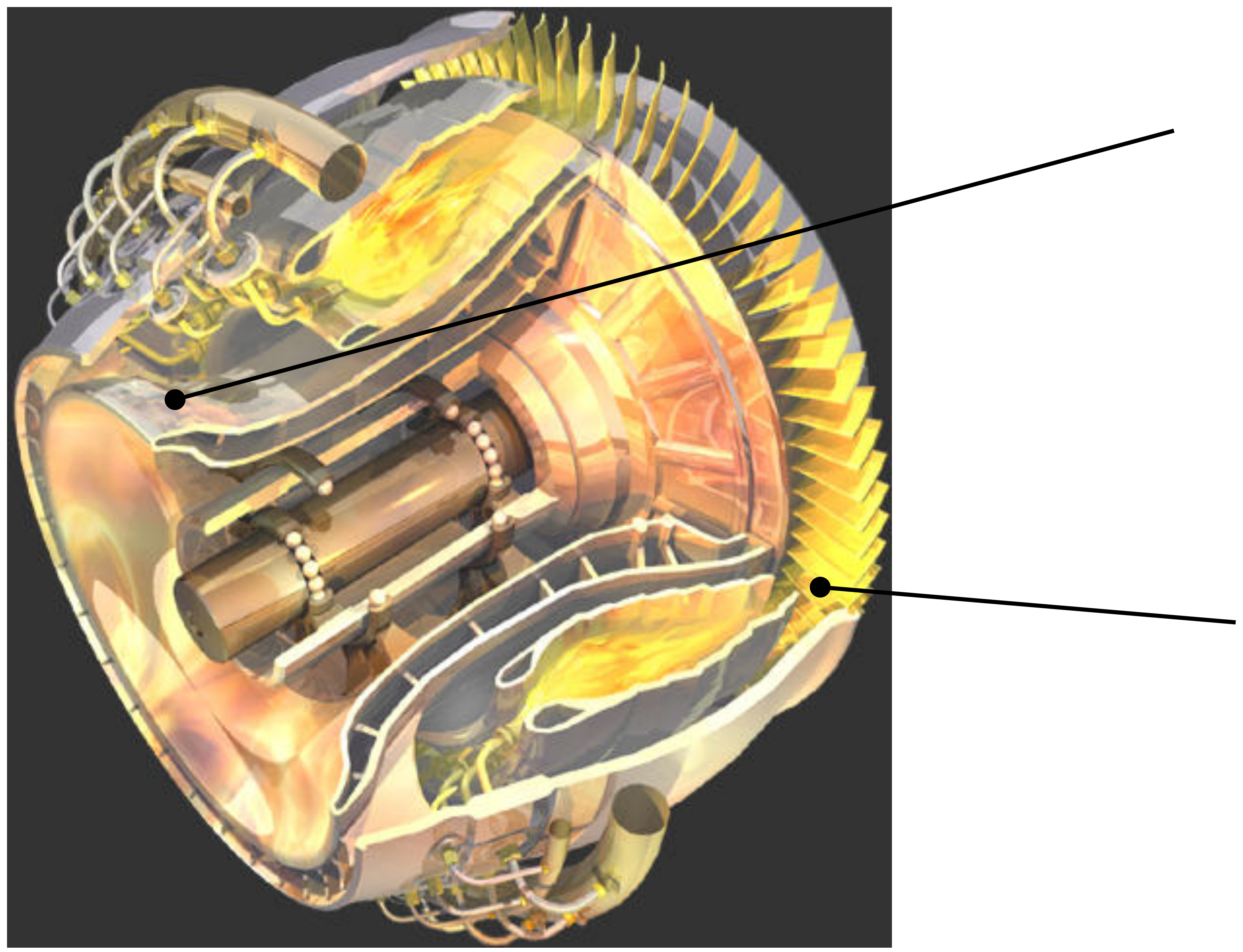

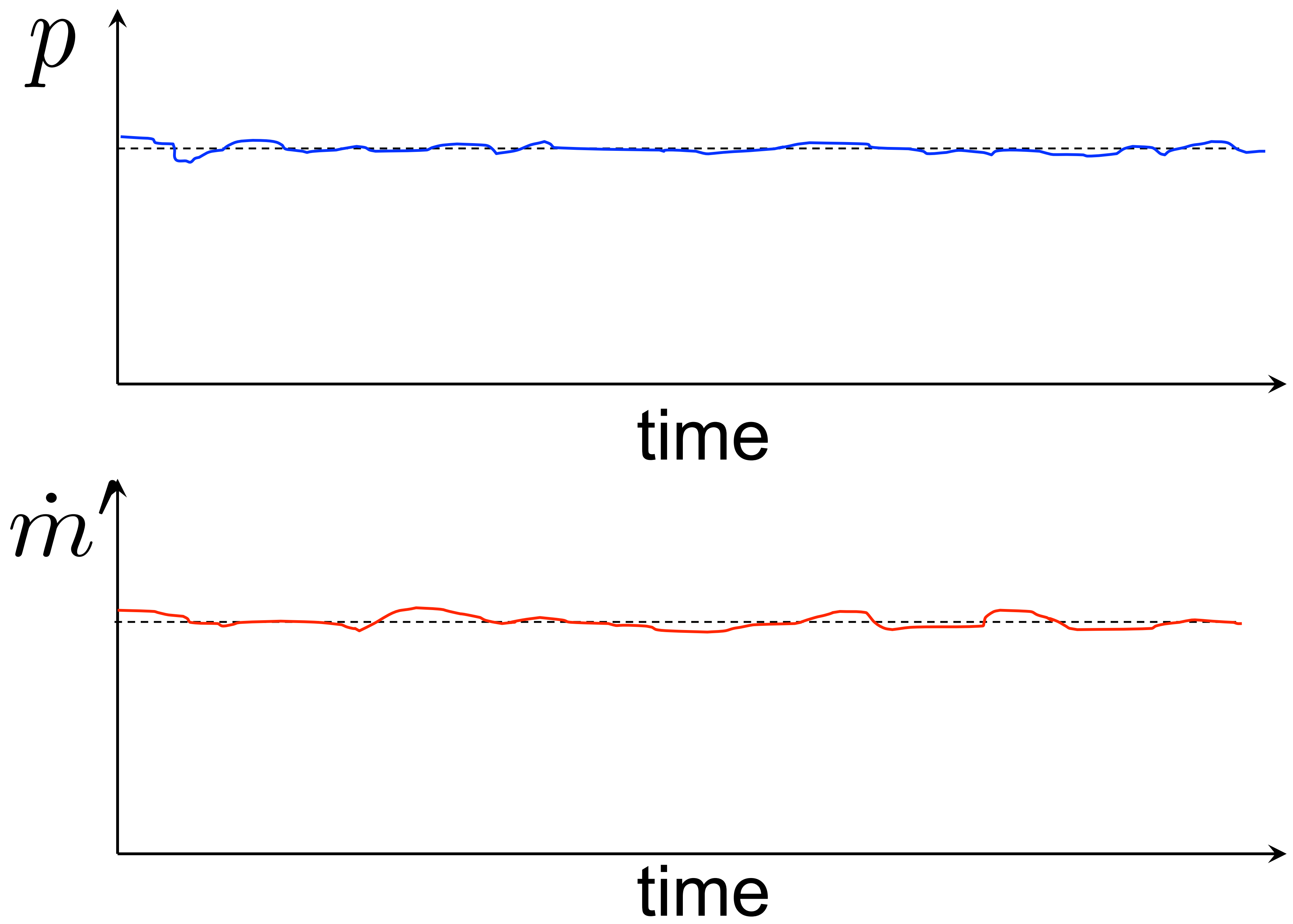

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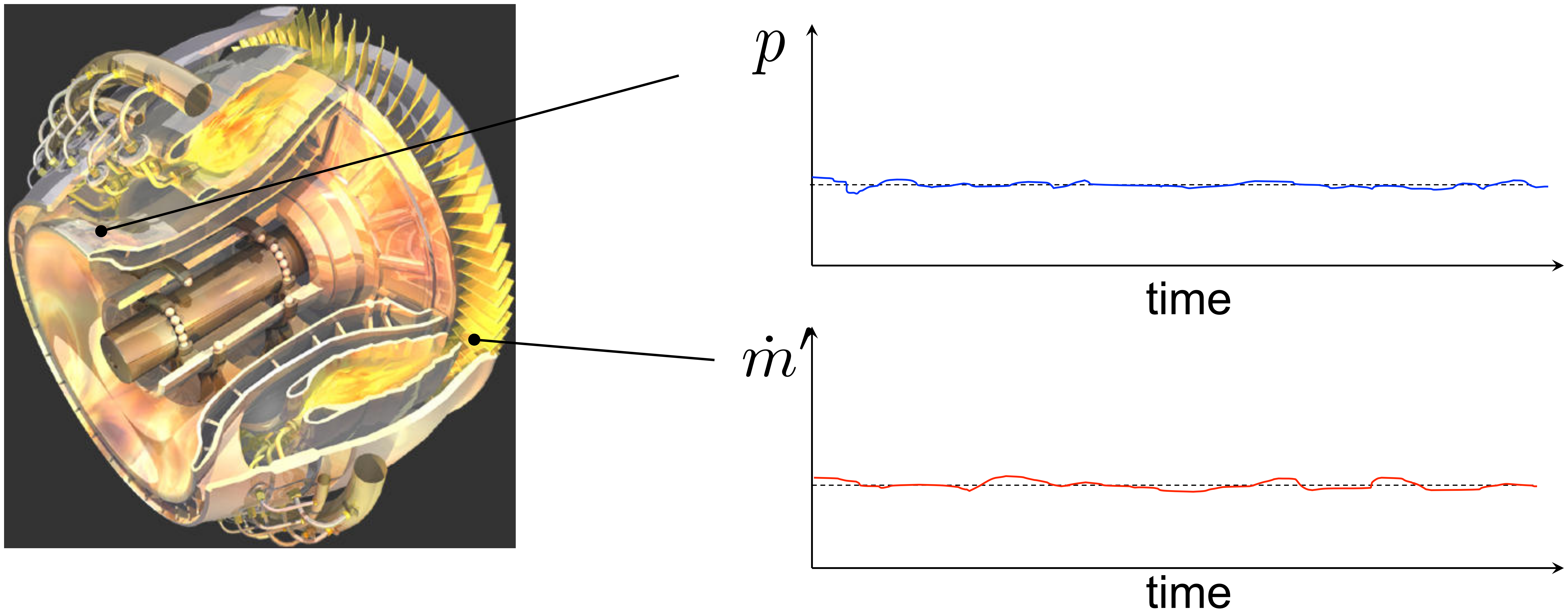
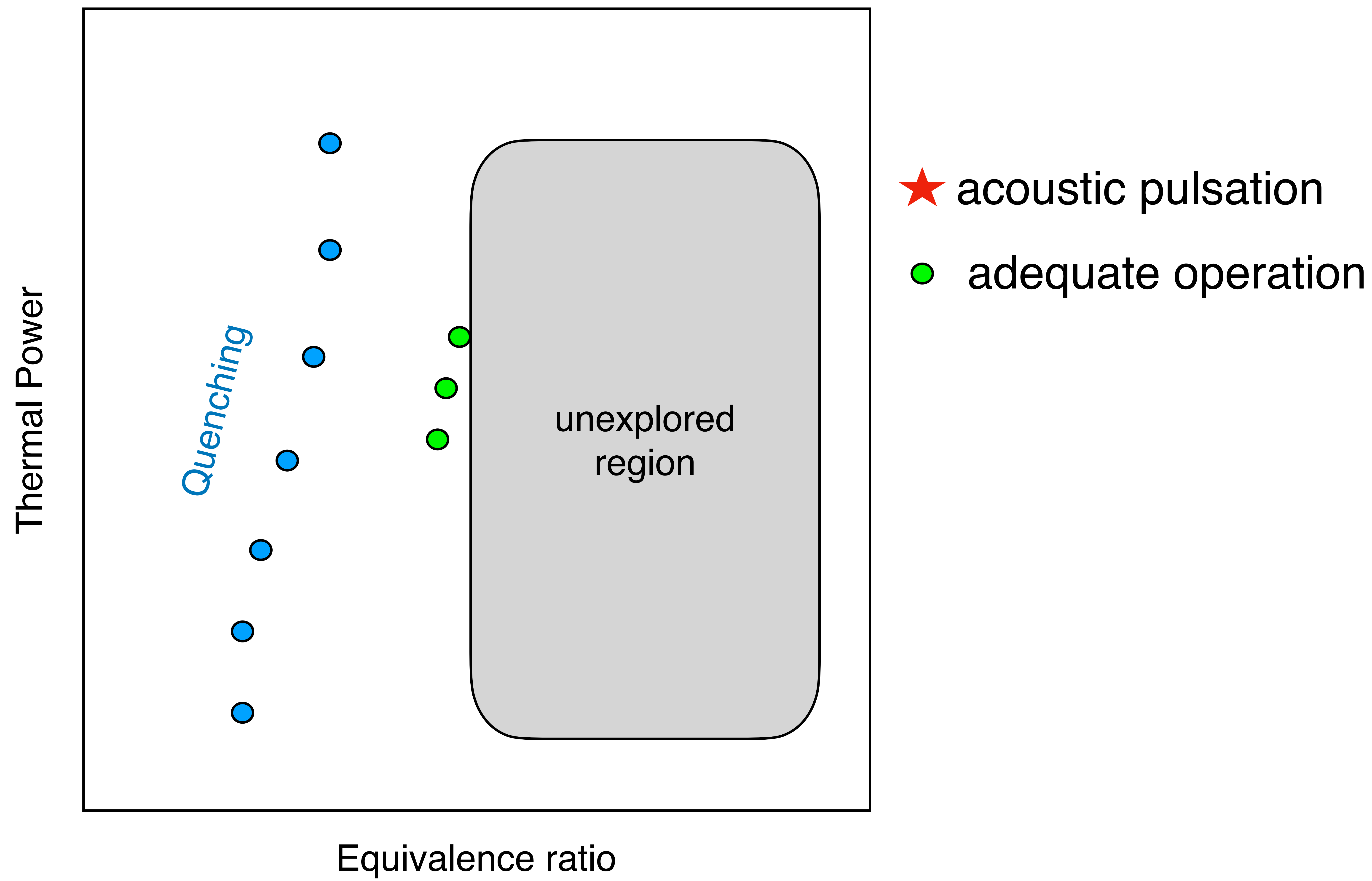


Walking in the jungle: getting to know your combustion system

Example of stability map for two operating parameters



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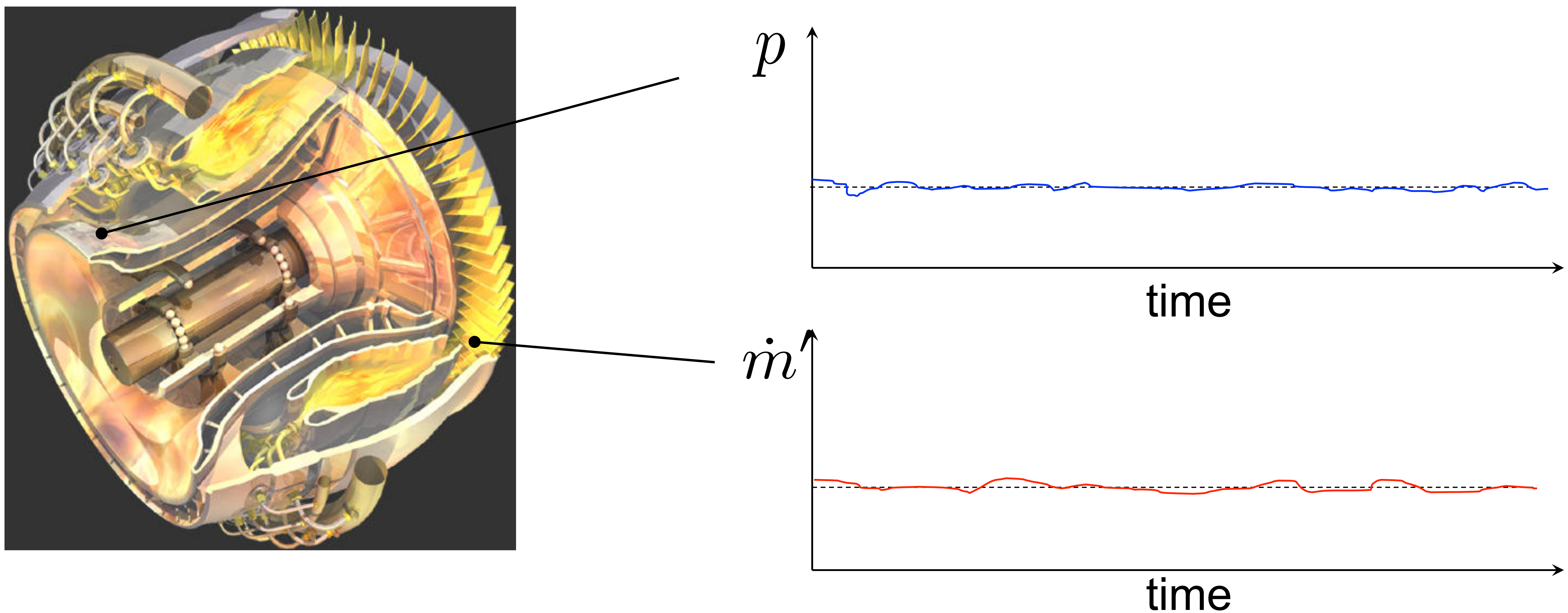

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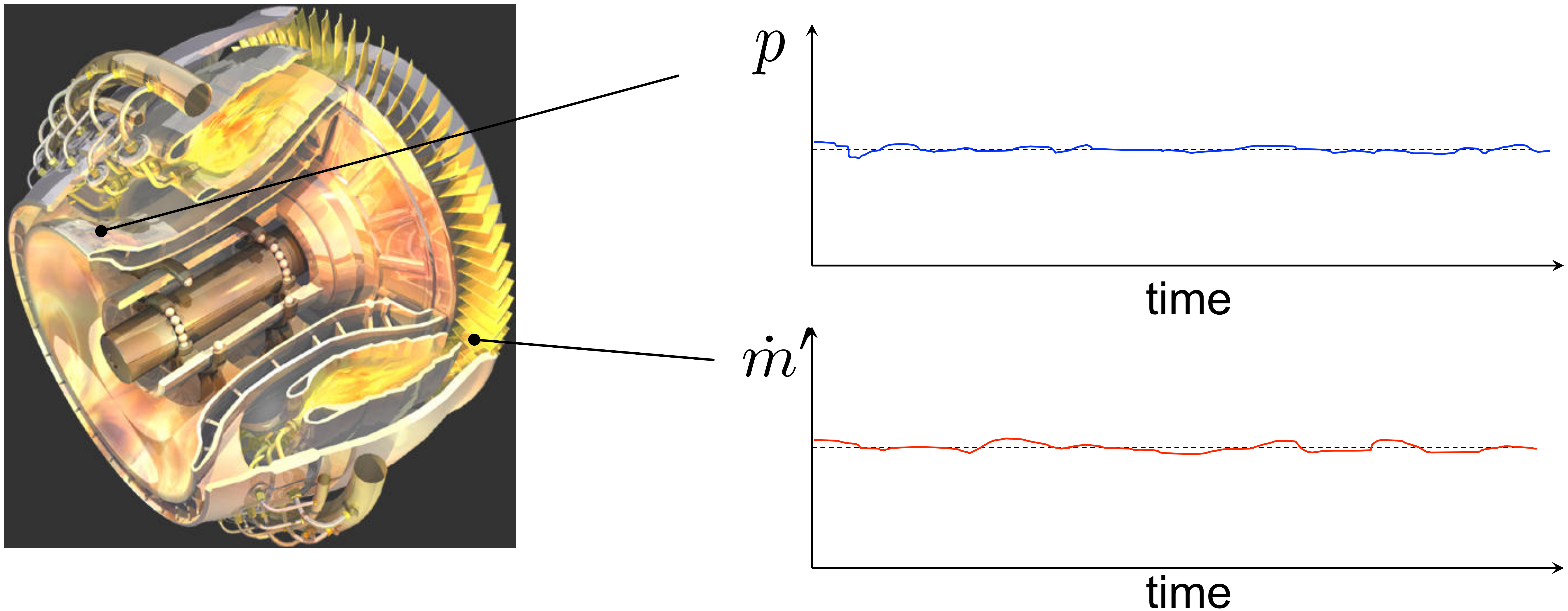
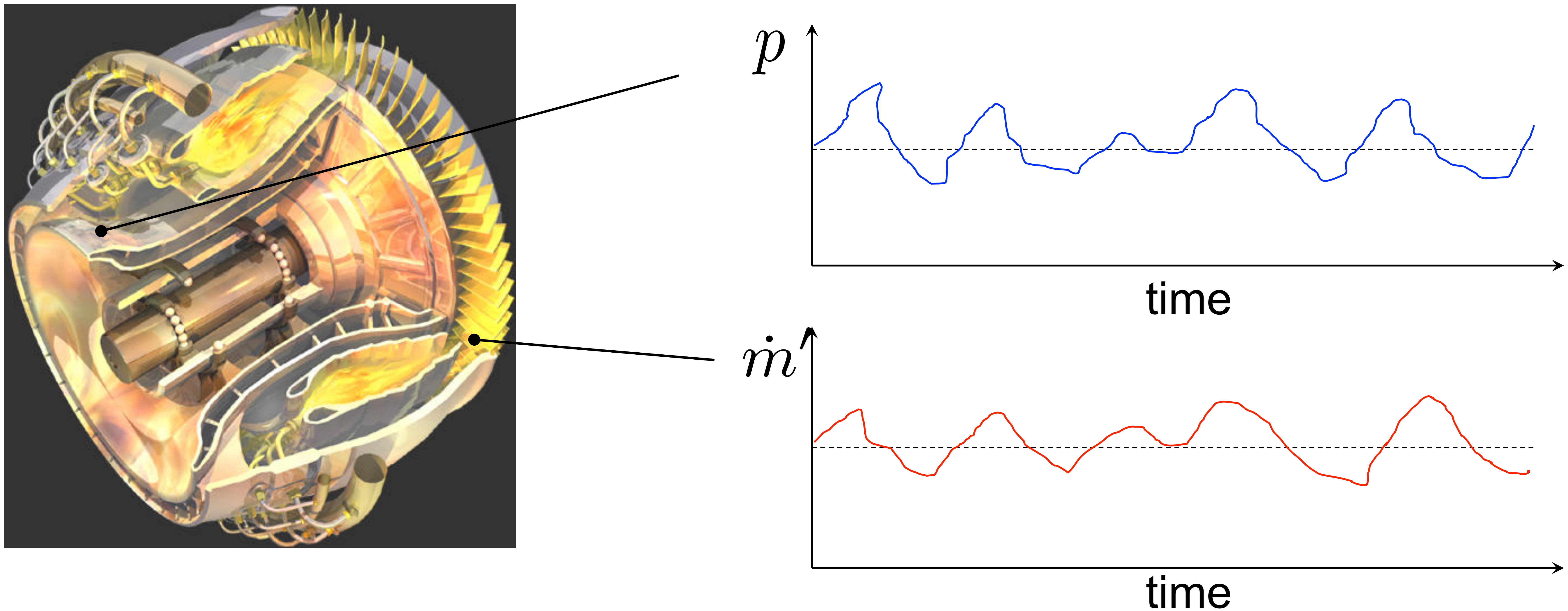


Strong oscillations in some physical quantities make some operating conditions non-viable



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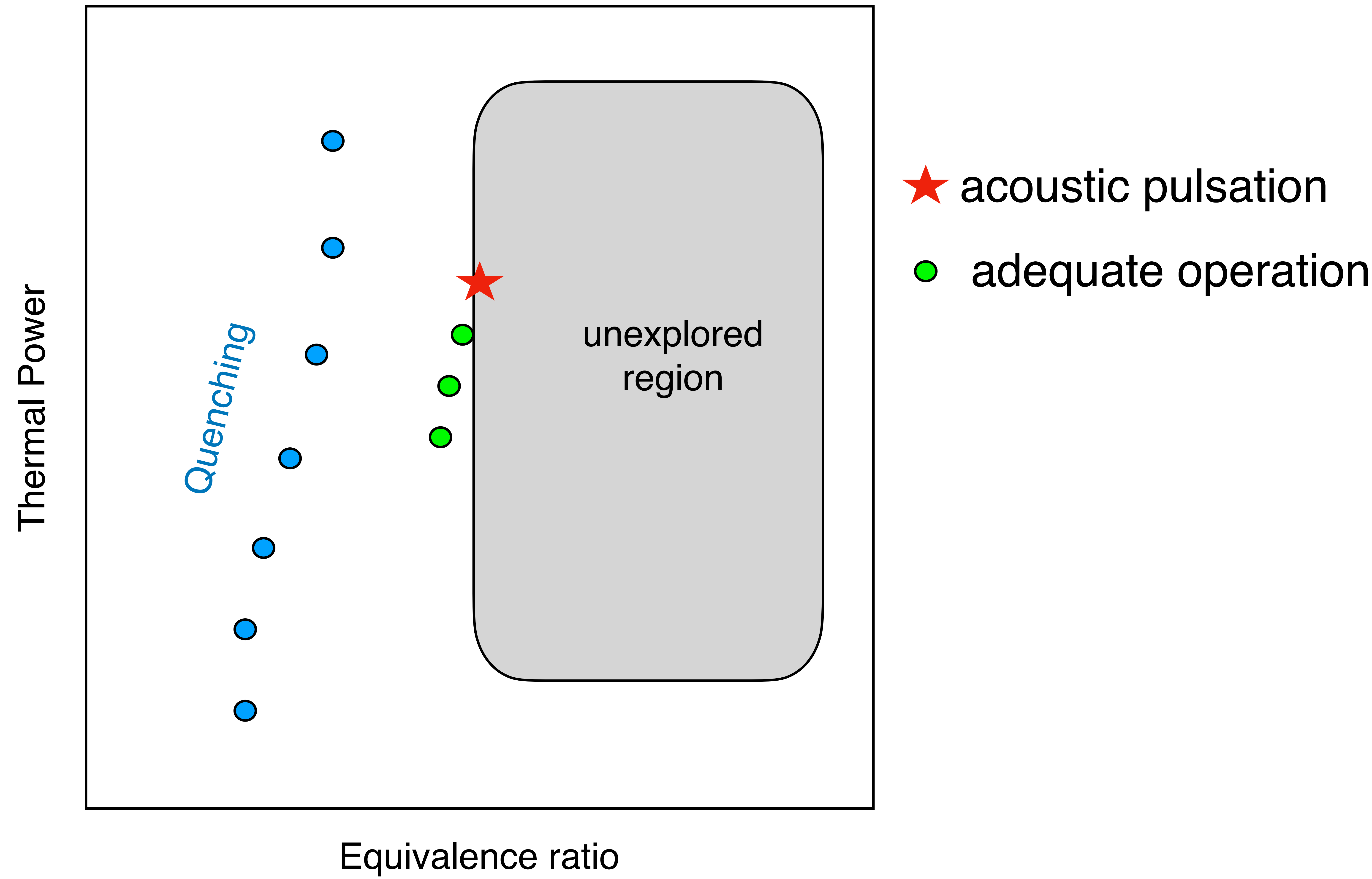
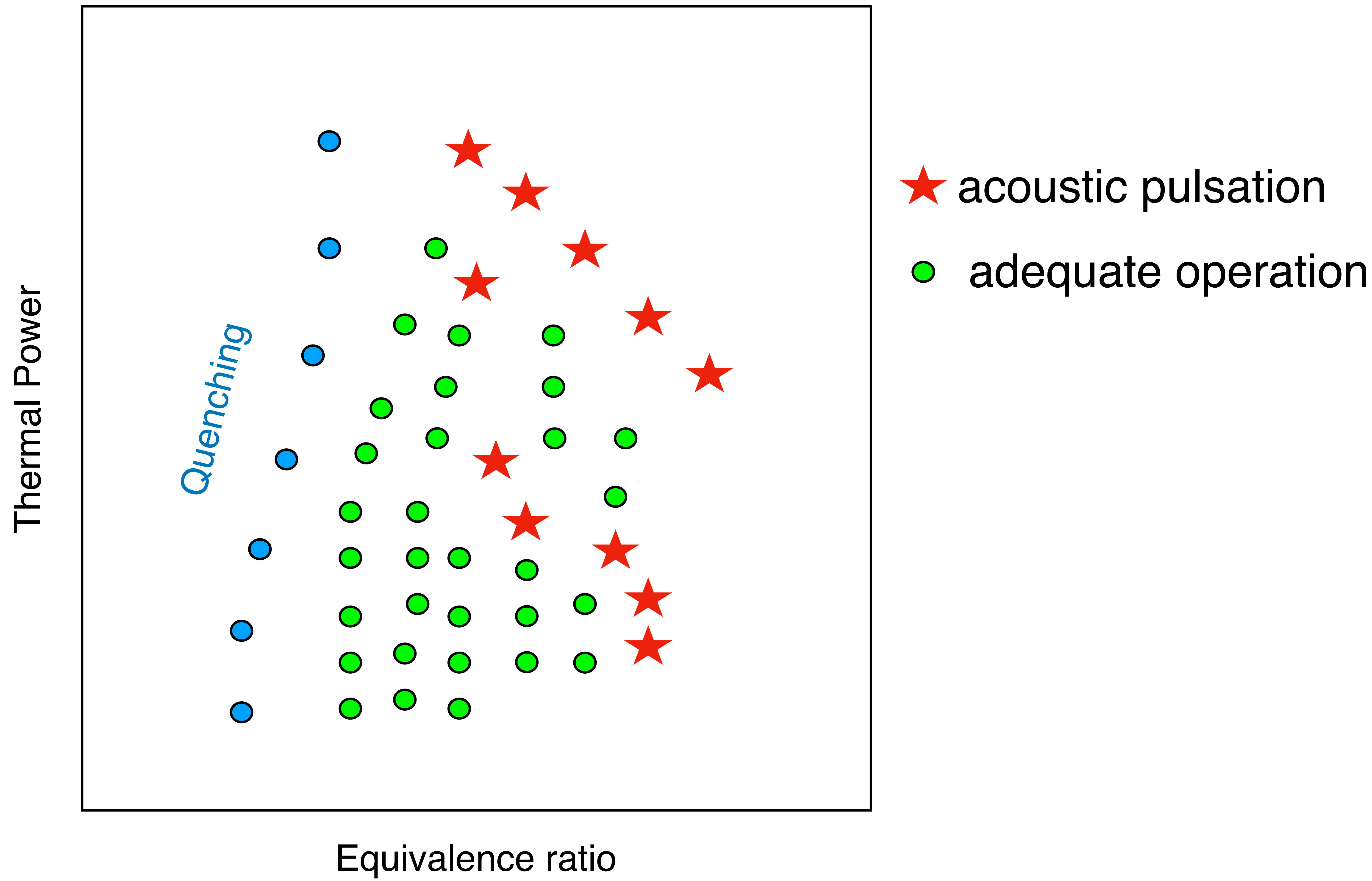
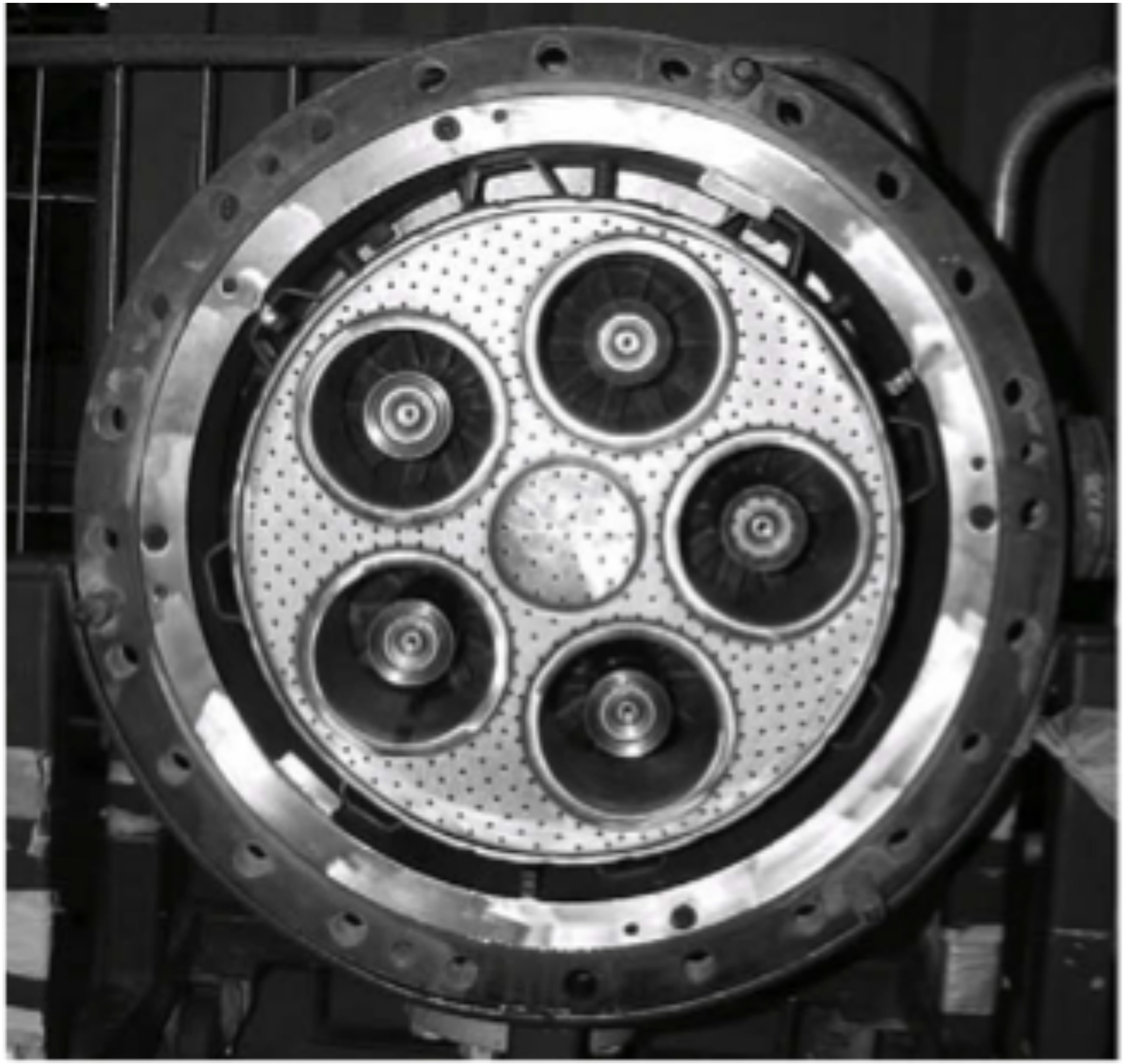


After an experimental campaign a stability map can be constructed (with a lot of empty spaces -> usually there are tens of operating parameters to consider!)

Example of stability map for two operating parameters



Thermoacoustic instabilities in gas turbines imped the development of low-emission, fuel-flexible, reliable engines for power generation and propulsion



Modern gas turbines are prone to thermoacoustic instabilities!

- Low Emissions NOx and COx
- Low noise

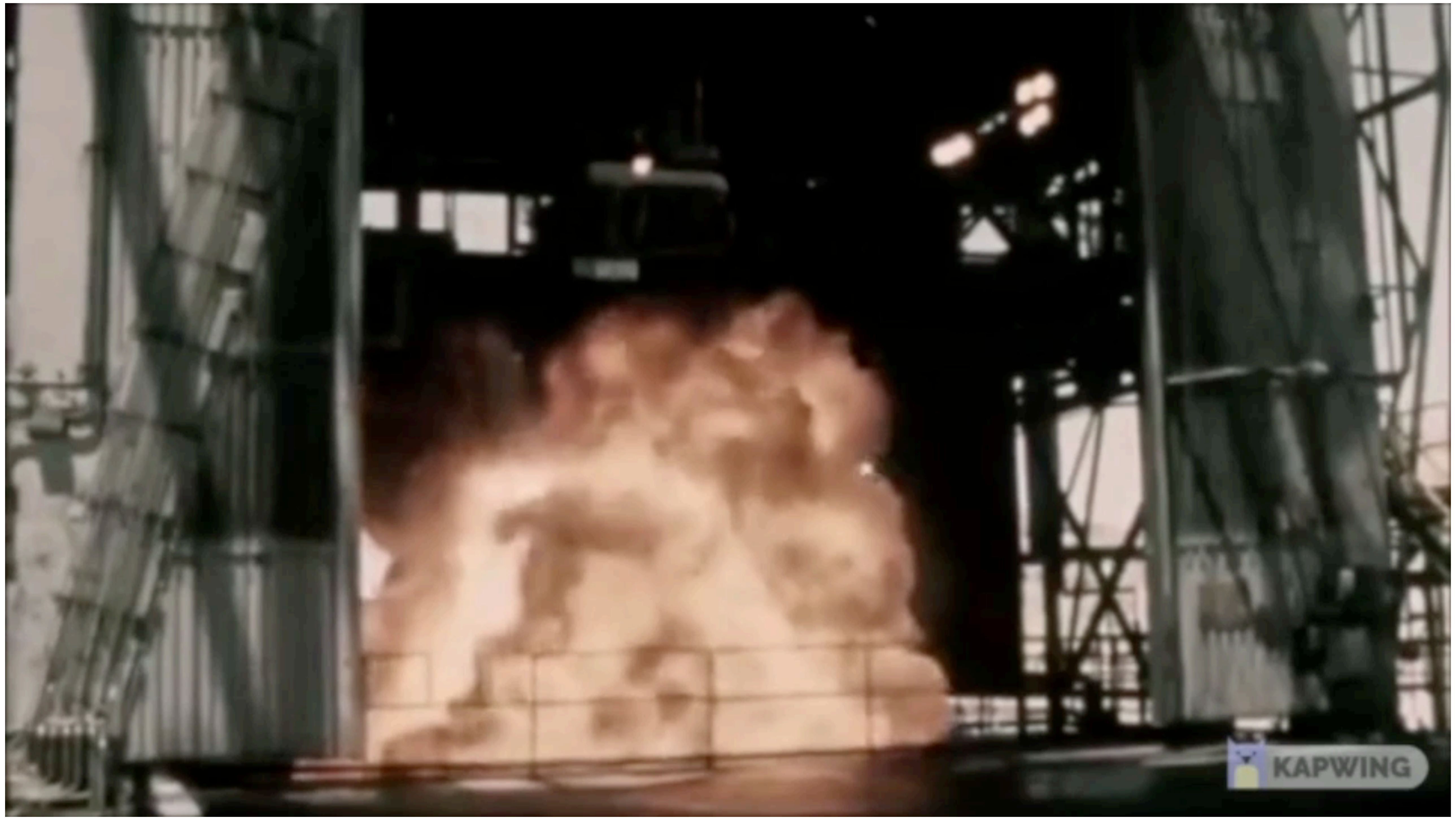
Lean combustion (low equivalence ratio)

contradictory

- High flexibility in operation

These systems are prone to
combustion instabilities

Undesired pulsations is the monster in the jungle: you ‘never’ know how and when it will appear



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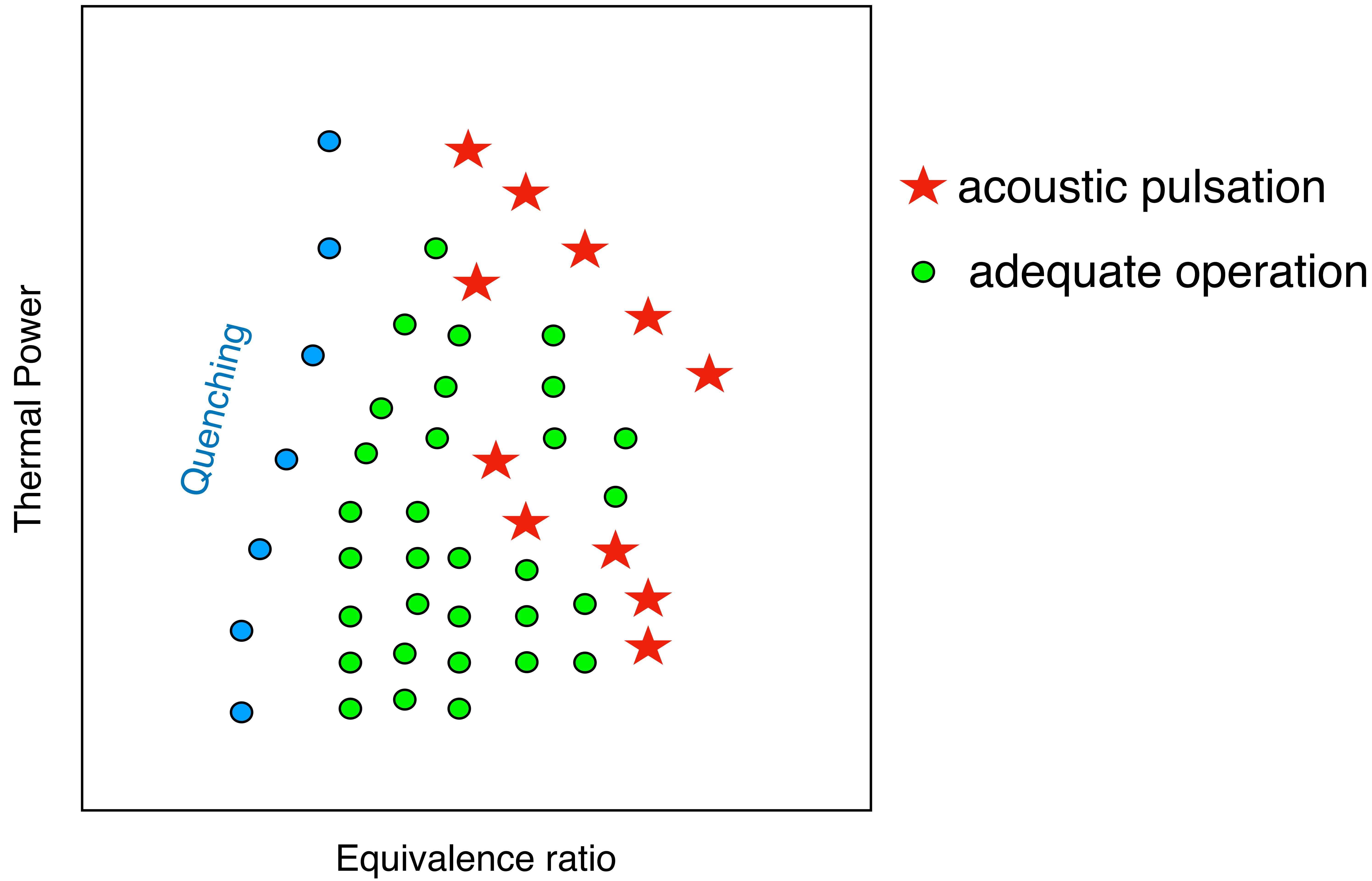
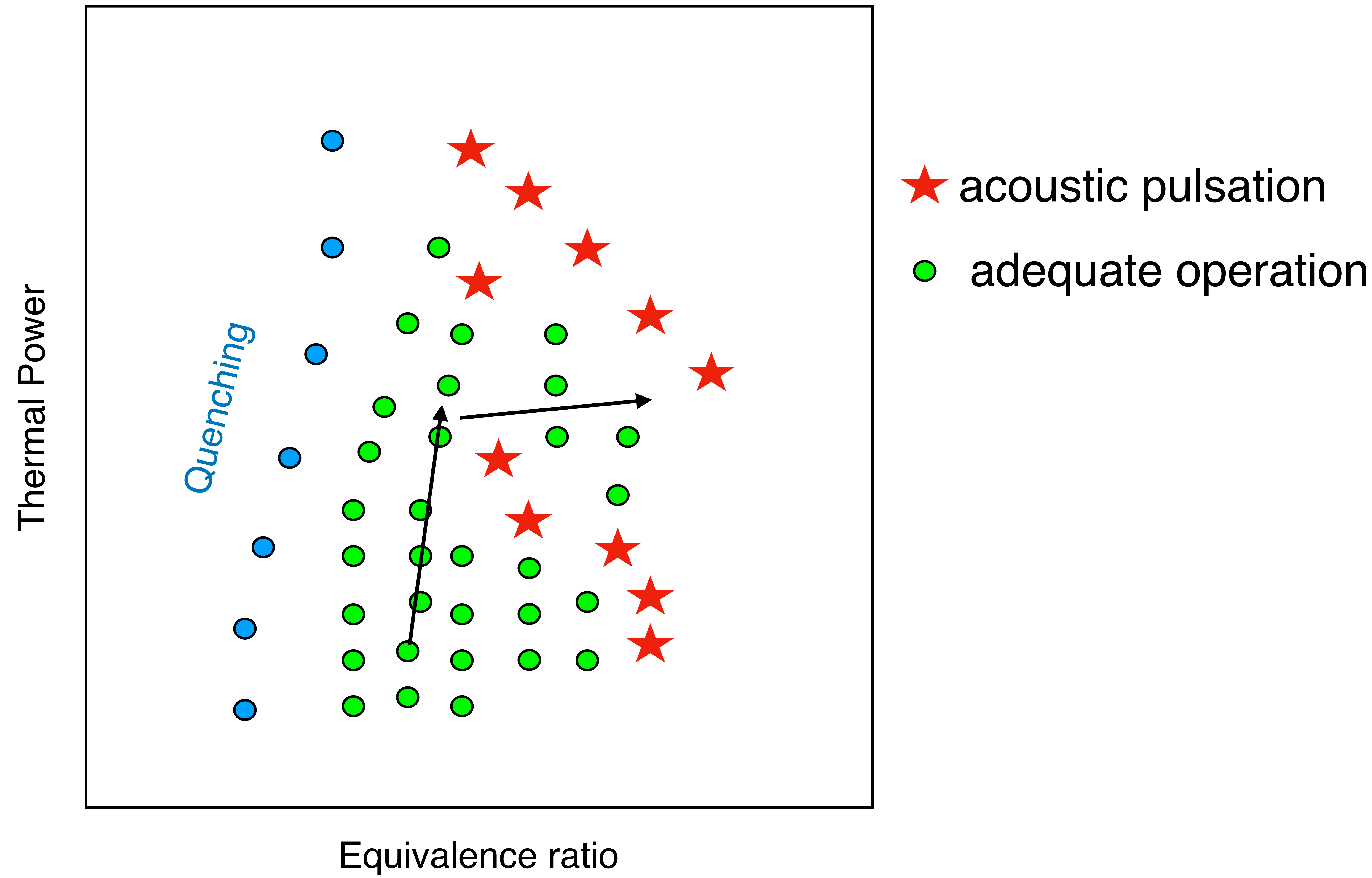


Walking in the jungle: let us walk in zic zac!

Example of a stability map for two operating parameters



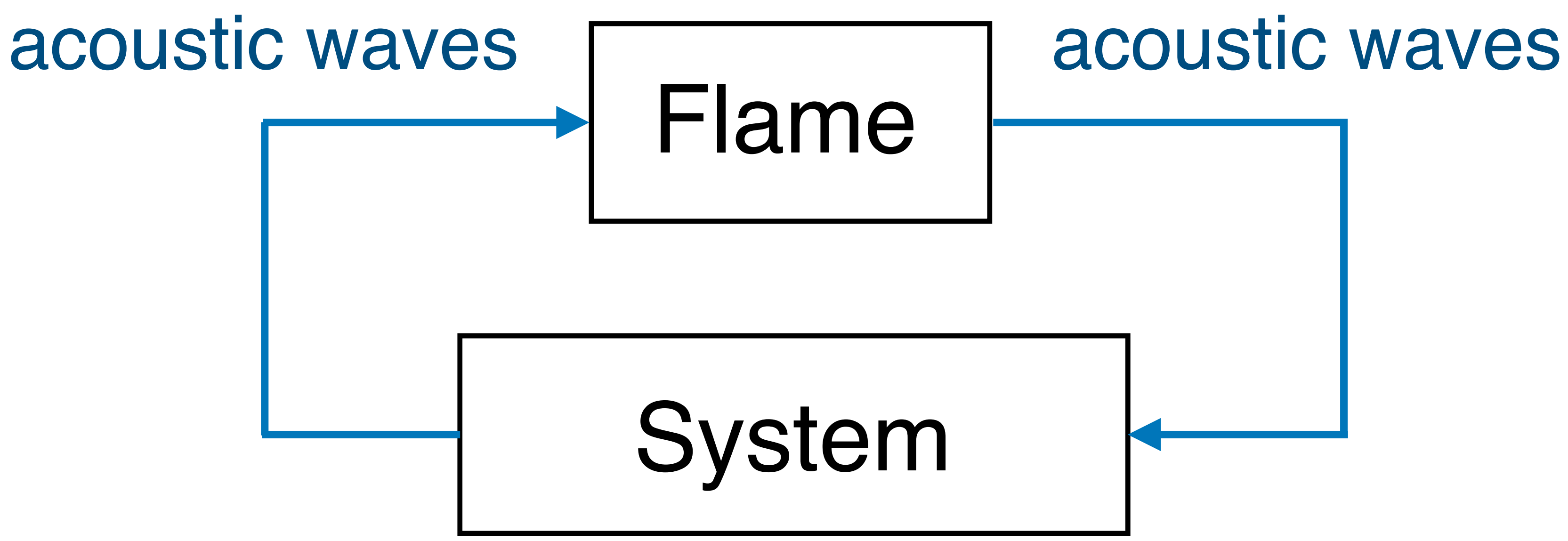
What if thermoacoustic instabilities cannot be avoided?

⇩

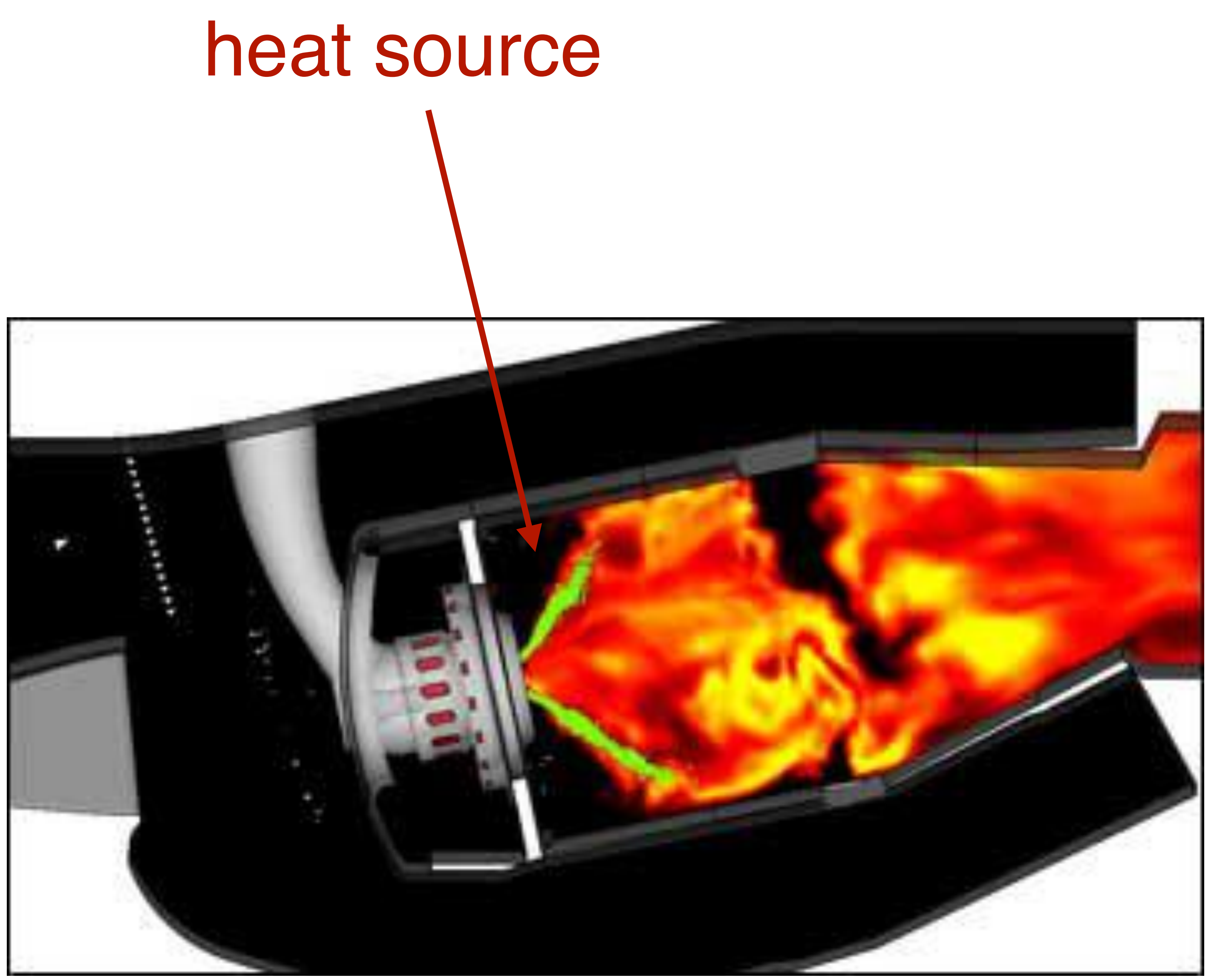
Well … we have to **understand** them if we want to ‘kill’ them

In combustion chambers of gas turbines, thermoacoustic instabilities are mainly generated by three mechanisms.

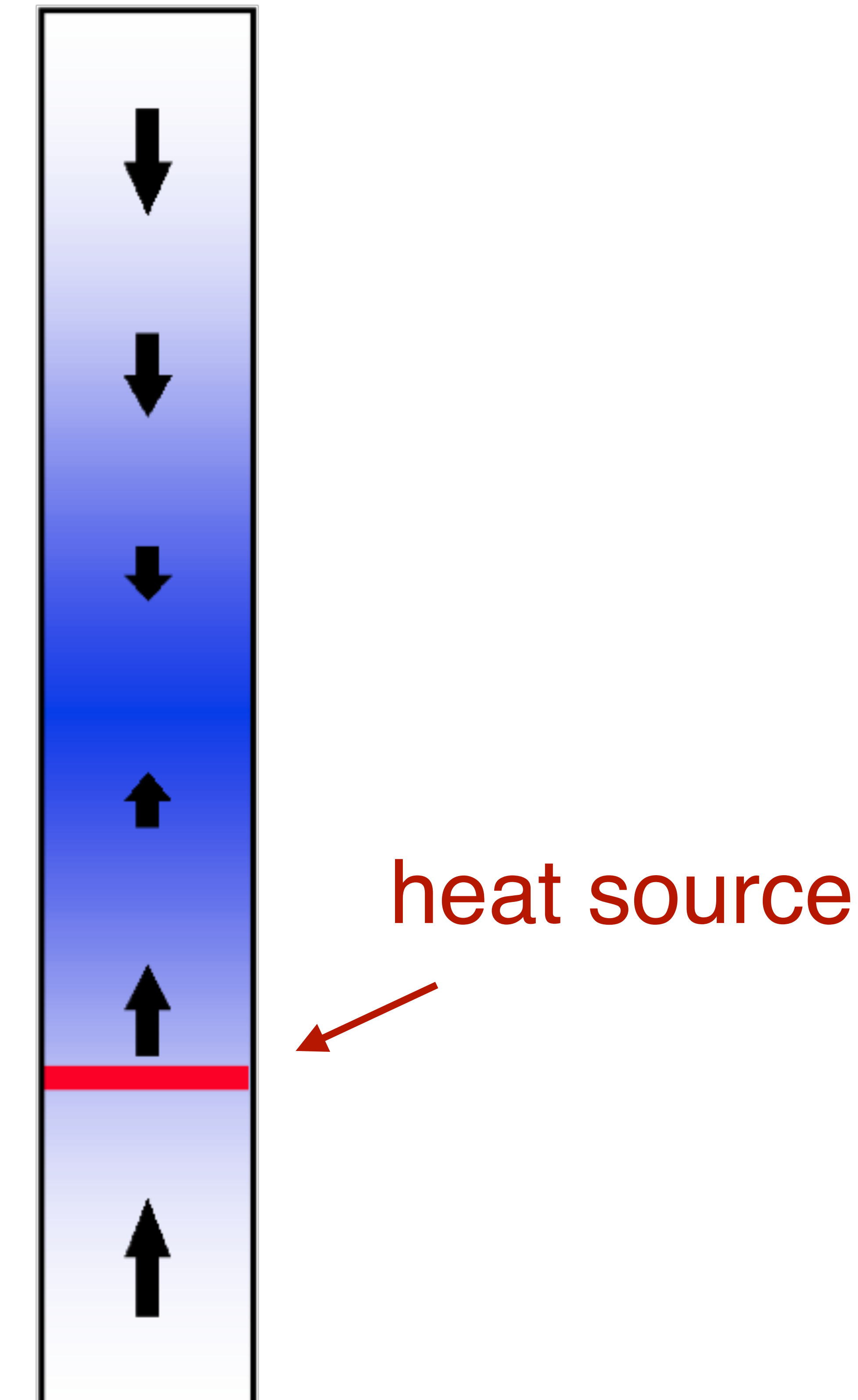
1. Heat release and acoustic coupling



Understanding complexity from simplicity

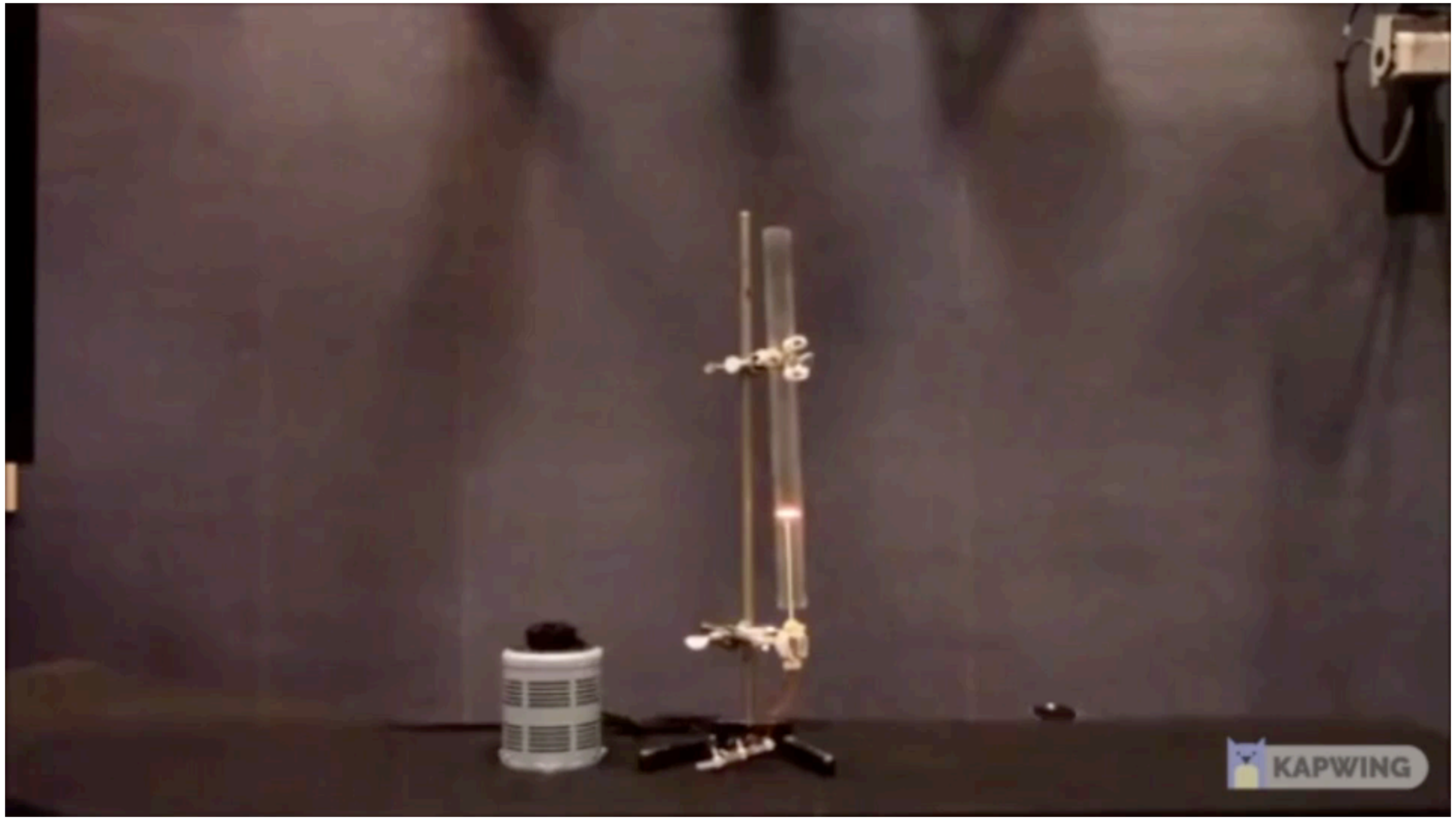


Aeronautical combustion chamber

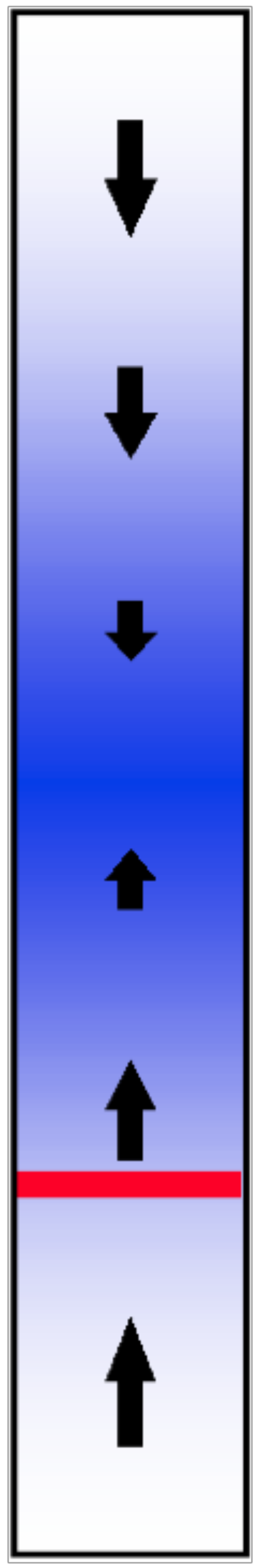


Rijke tube

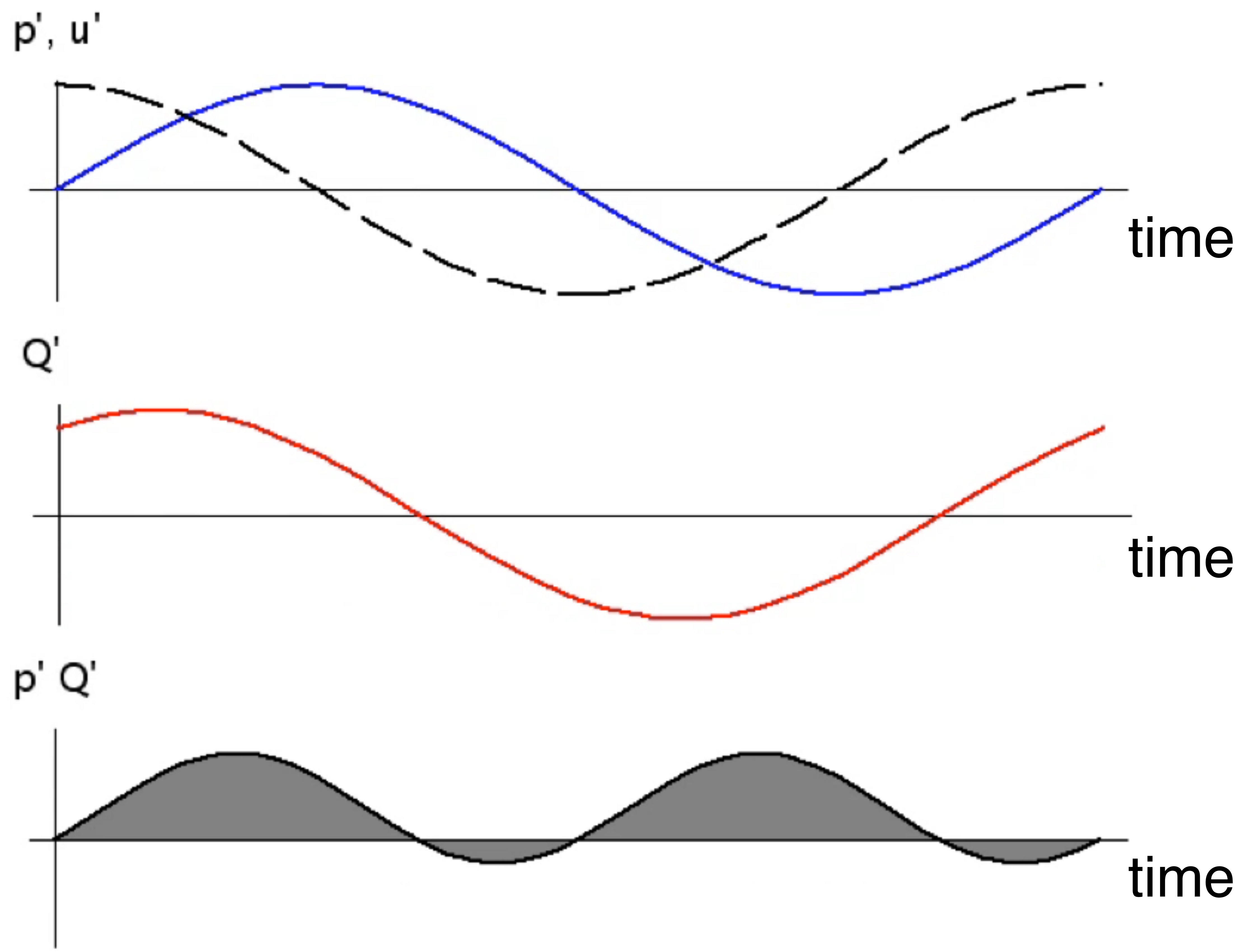
A Rijke tube becomes unstable by heat release - acoustic coupling



Stability criterion: ***The vibration is encouraged if heat be given to the air at the moment of greatest condensation [compression]*** **(Rayleigh, 1878)**



instability possible if $\oint p'\dot{Q}'\,dt > 0$



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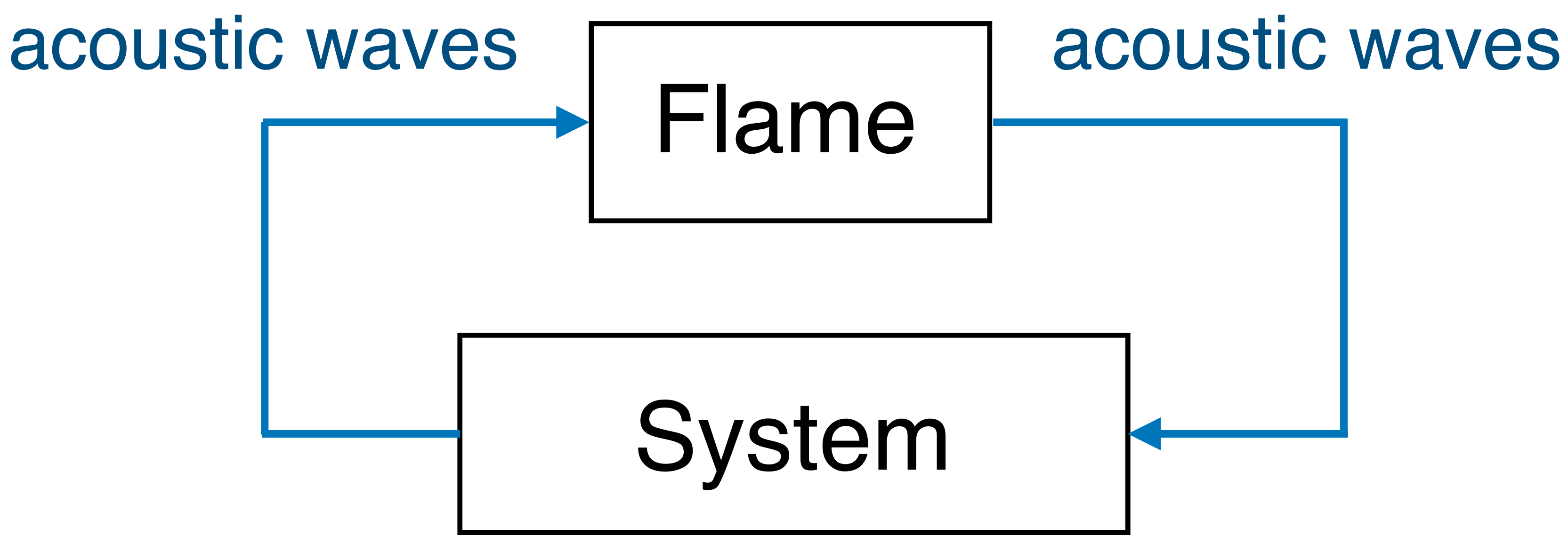
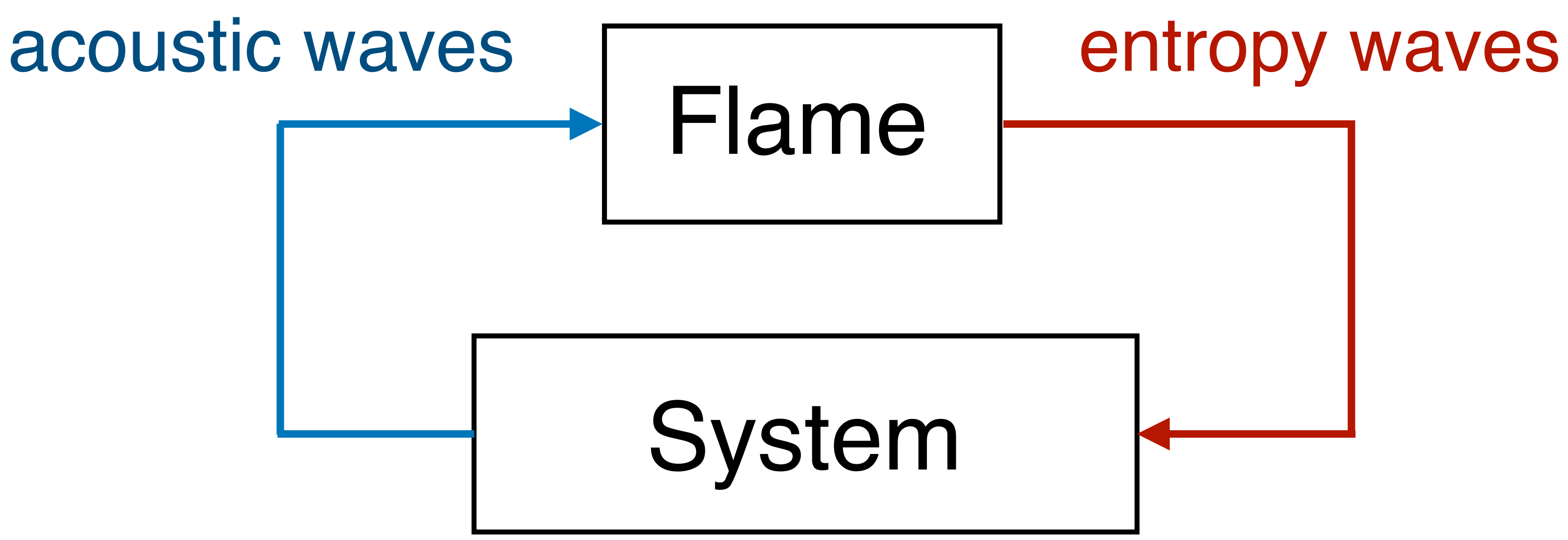
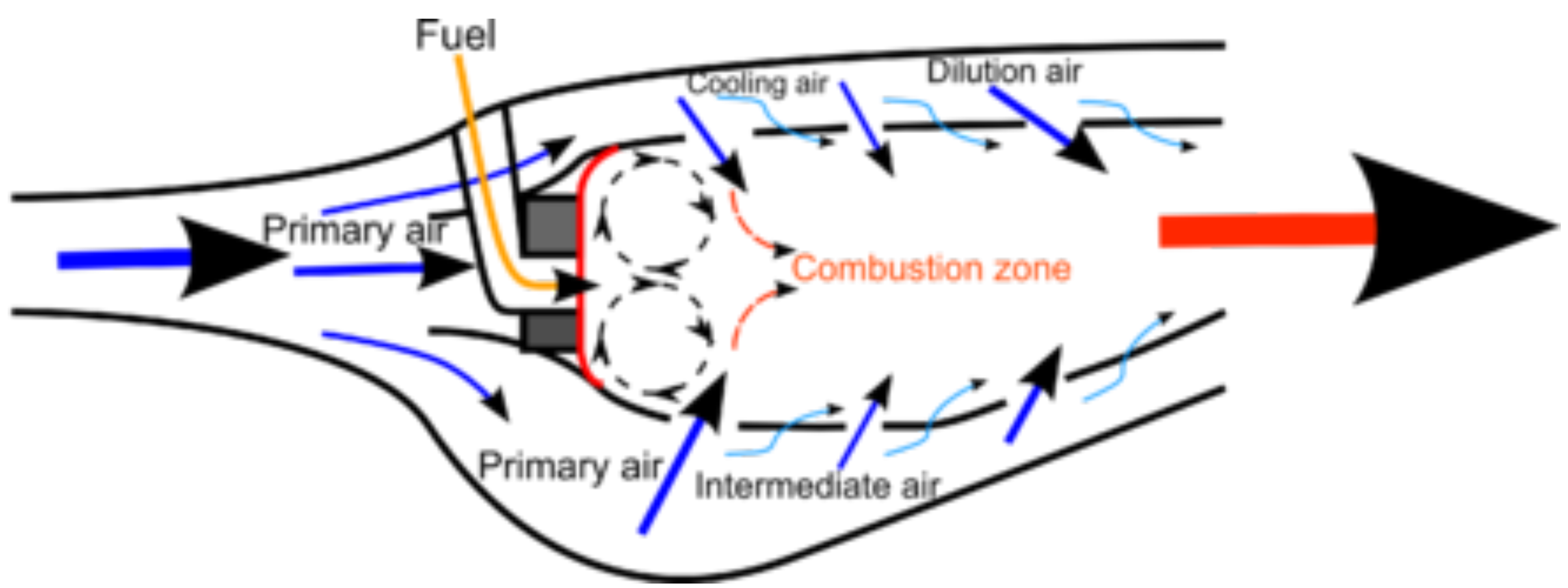
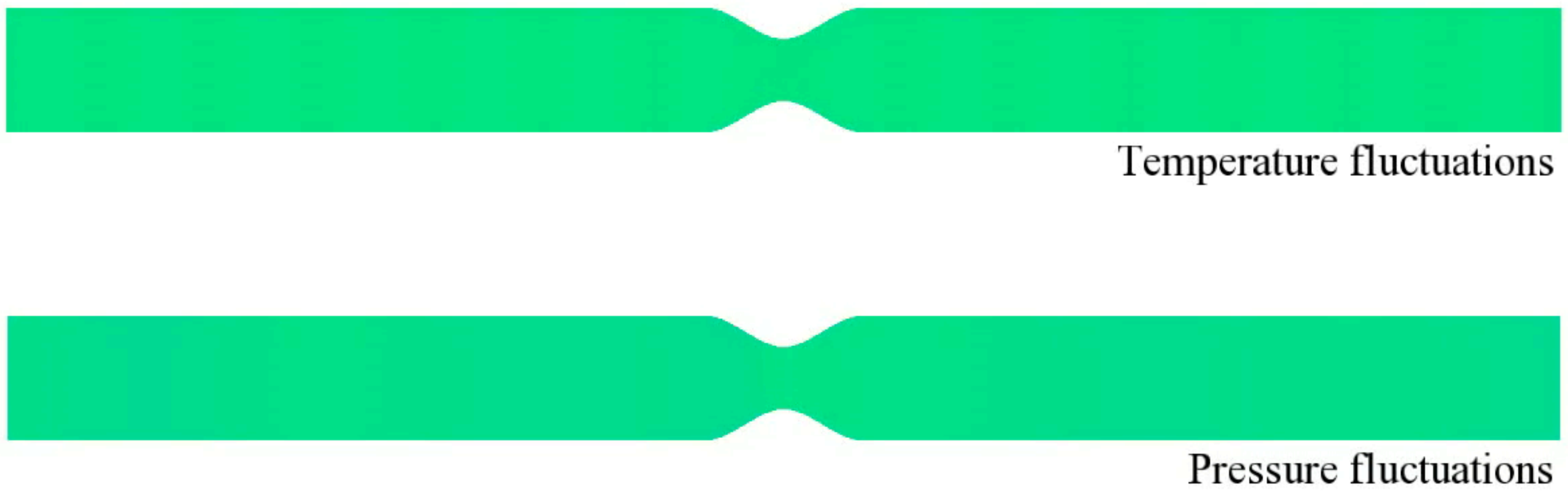


2. Entropy waves and acoustic coupling



Part of the energy carried by entropy waves is transformed into acoustic energy in regions of non-uniform mean flow





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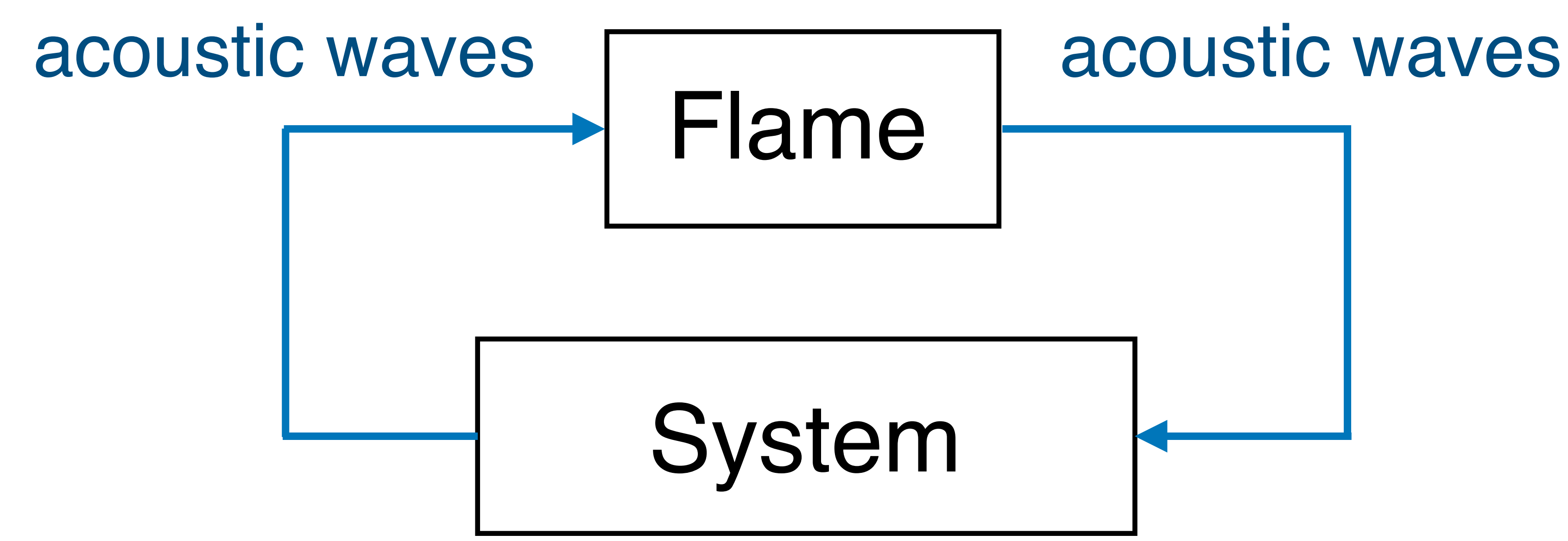

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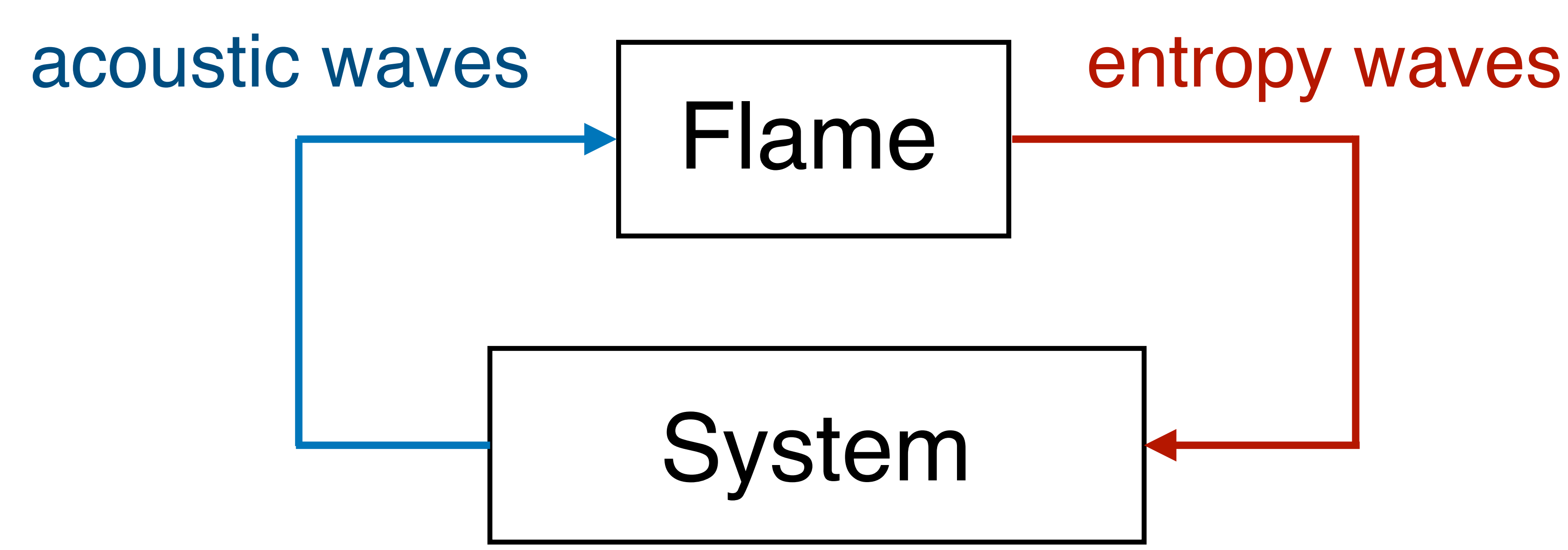
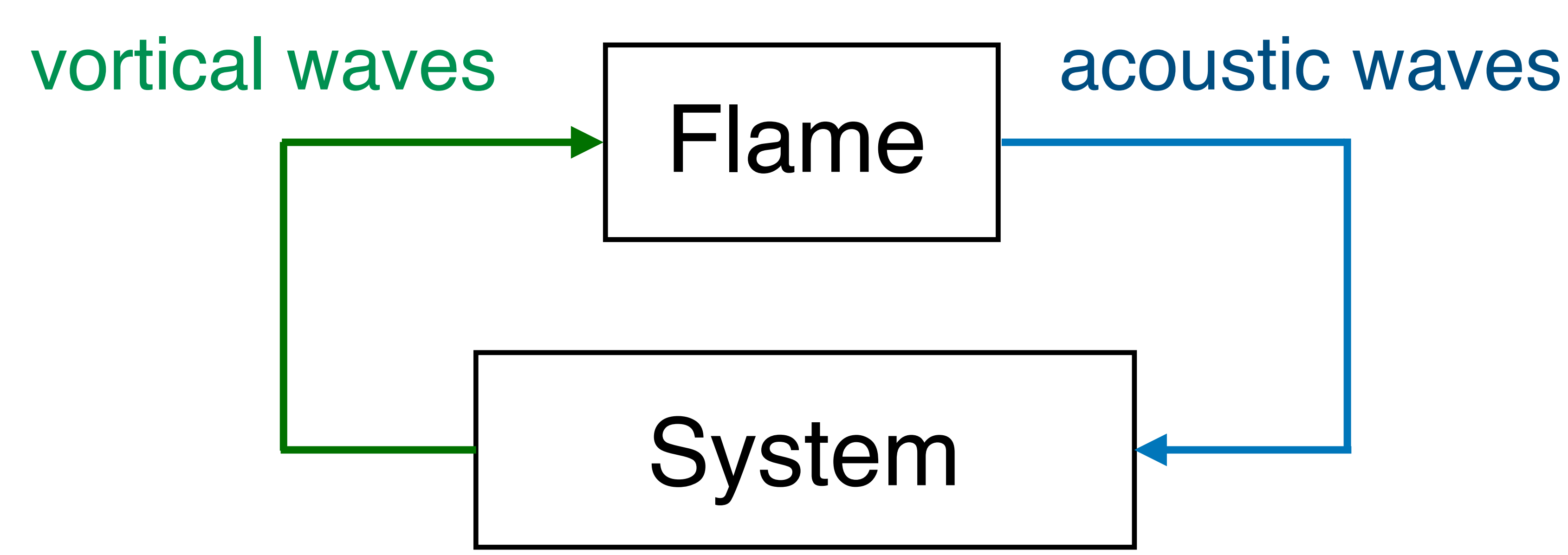
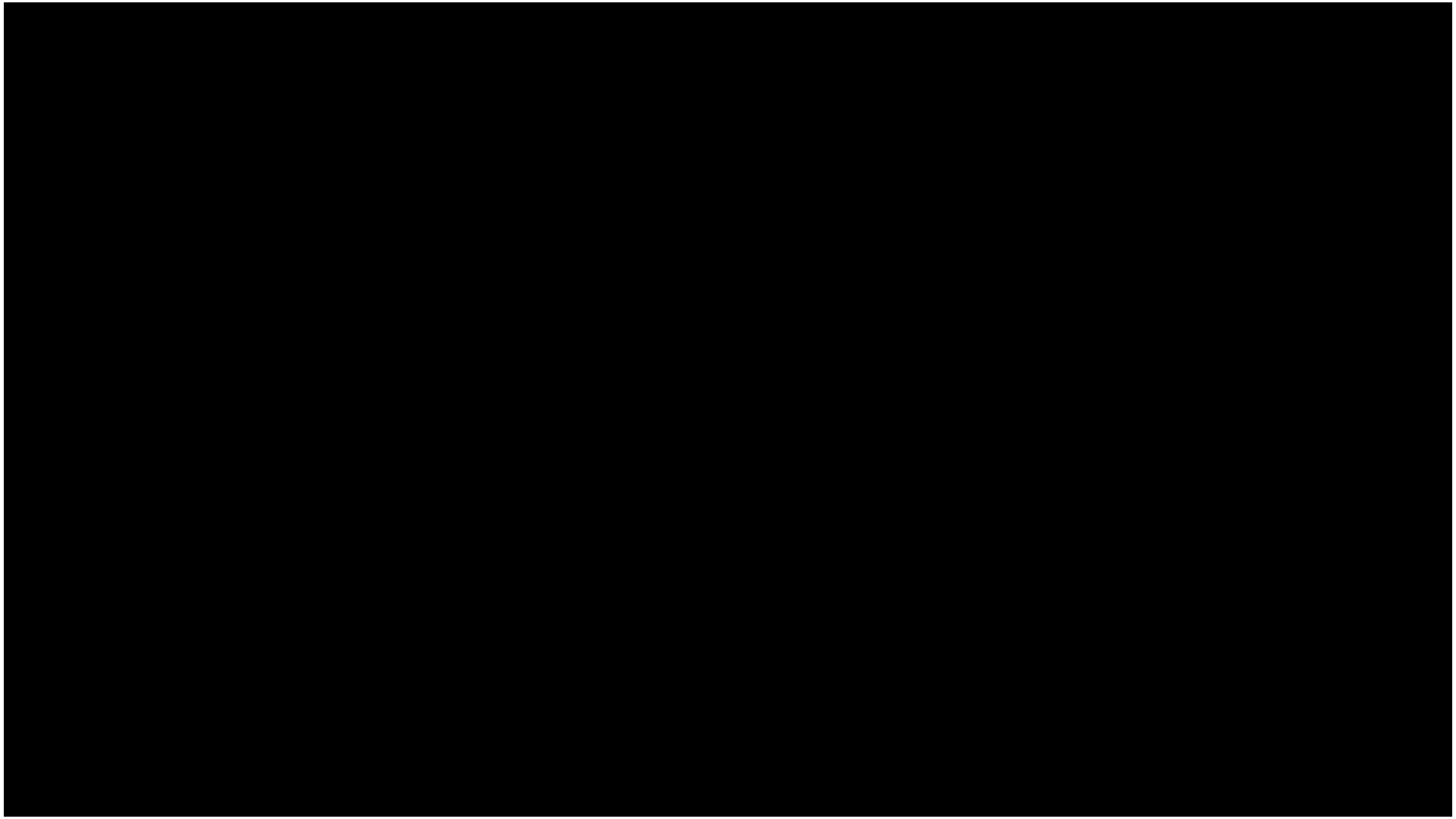


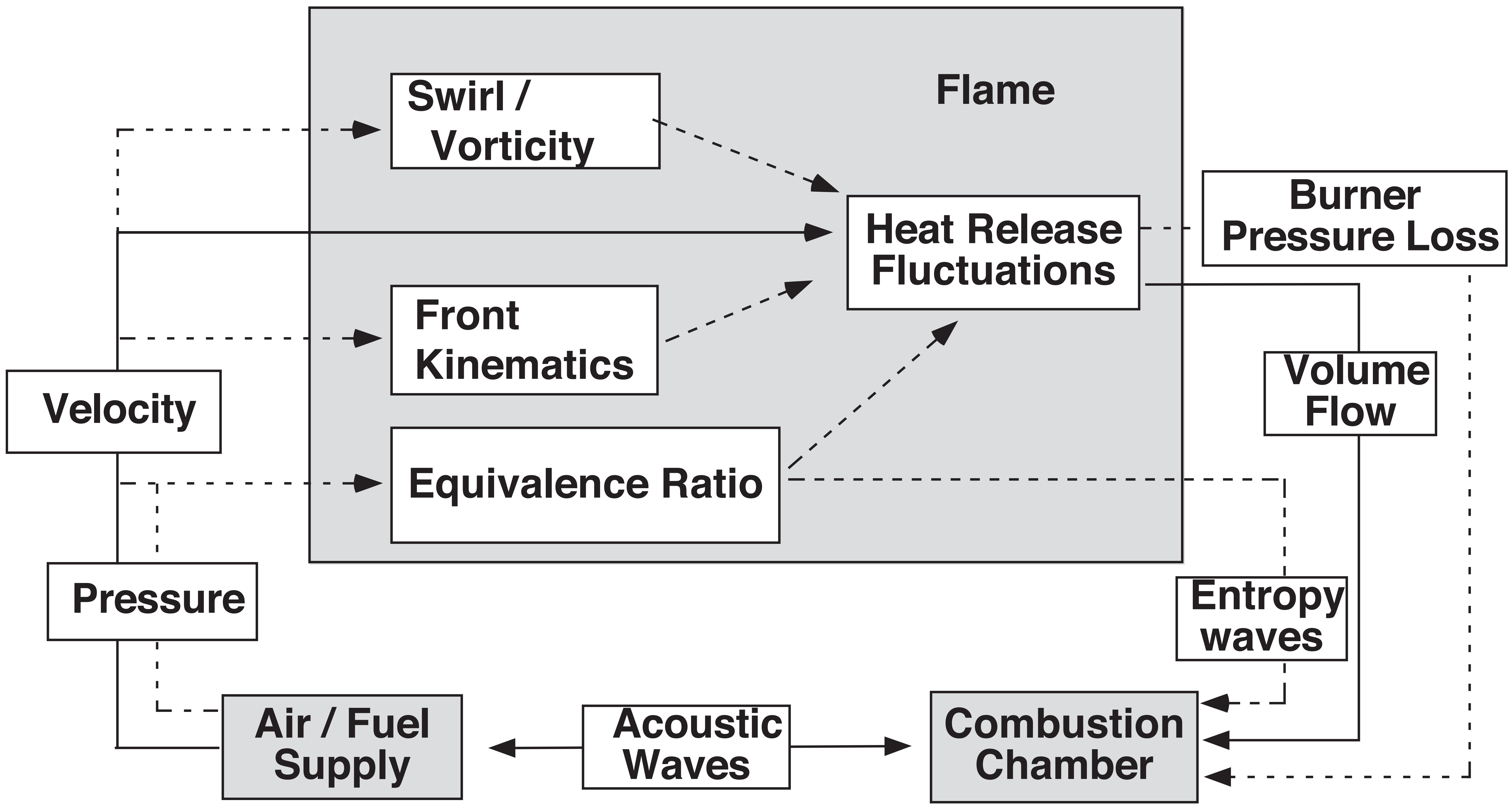
3. Vortical waves and acoustic coupling



Hydrodynamic instabilities do not need acoustics to exist. However, they can couple with acoustics making the global feedback loop unstable



The aforementioned mechanisms can be put together in one figure



Sattelmayer (1997)

We have possible explanations for the observed instabilities

Can we model them?

Outline

- Lecture 1: About the wave equation for reacting flows
  - From the Navier-Stokes equations to the LRF and LNSE
  - From the Navier-Stokes equations to the wave equation
  - Recapitulating: What is the Helmholtz Equation good for?
- Lecture 2: Generalities of thermoacoustic network models
  - From the Navier-Stokes equations to the acoustic jump conditions
  - From primitive variables to acoustic invariants (waves)
  - The state space approach
- Lecture 3: The Galerkin approach to ‘reduce’ models in thermoacoustics
  - Solving the Helmholtz Equation by modal expansion
  - And the state space?
  - About a one mode expansion