AAE 538: Air-Breathing Propulsion

Lecture 27: Supersonic Combustion

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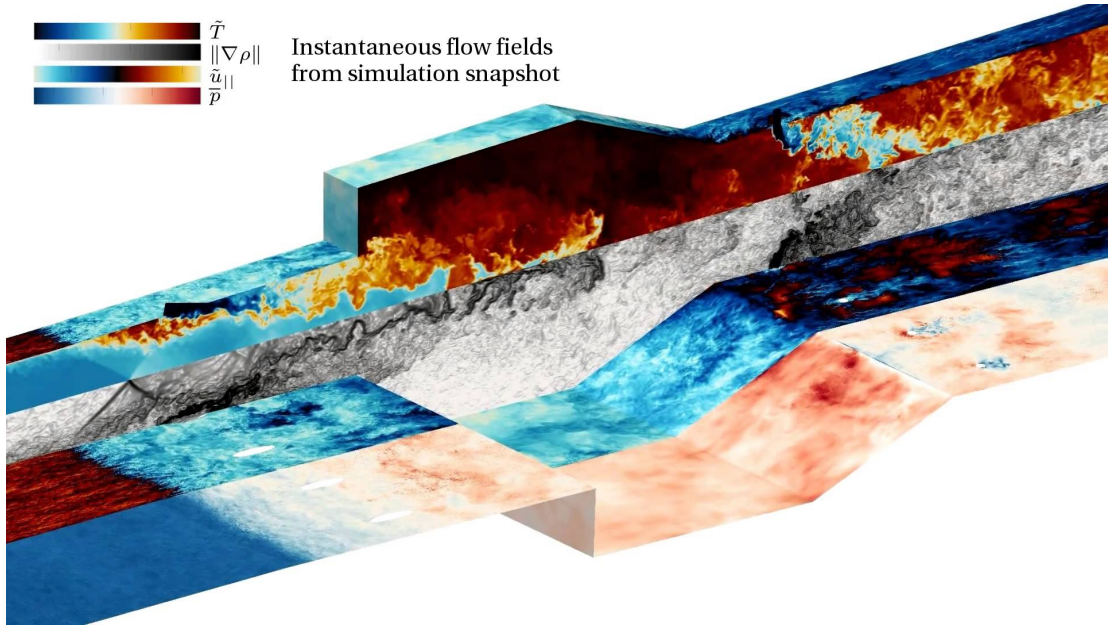
Introduction

Combustion Processes and Components

- Structural and thermal limitations constrain flight to specific altitudes and free-stream conditions: impacts the airframe as well as the propulsion system (the engine-frame)
- Temperature limits related to combustion product gas dissociation dictate:
  - Combustion system entry Mach number
  - Thermo-physical state
- The practical issues of supersonic combustion are vast:
  - Capture a tube of supersonic air
  - Inject fuel
  - Achieve (fairly) uniform mixing
  - Complete combustion
  - … All within a minimal length.



https://www.youtube.com/watch?v=86oAIr1EGfc

'We are still confused, but at a higher level' **- Enrico Fermi**

Aerodynamics and Mixing

- The maximum combustion temperature occurs when the injector fuel molecules are sufficiently mixed with the oxidizer to complete the chemical reaction:

$$C_xH_y + z\underbrace{\left[O_2 + \left(\frac{79}{21}\right)N_2\right]}_{air} \rightarrow x(CO_2) + \frac{y}{2}(H_2O) + z\left(\frac{79}{21}\right)N_2$$

  - Fuels:
  - Oxidizer: $21\%\ O_2$ and $79\%\ N_2$
  - Treating nitrogen as an inert diluent that absorbs some of the sensible thermal energy released by combustion due to its specific heat.

- We understand that the stoichiometric fuel-air ratio is that which results in the greatest liberation of sensible energy from stored chemical energy, where:

  - Actual fuel-air ratio to the stoichiometric fuel-air ratio
  -

Aerodynamics and Mixing

- When we think about combustion in this way, we are making an implicit assumption that the reactants are fully-mixed and burn in a steady, uniform manner
  - This is seldom the case, in practice; particularly in aerospace systems.
- Real combustion is a finite-rate, multi-scale process:
- Scramjets offer extremely low residence times for these processes, so the products look more like:

Aerodynamics and Mixing

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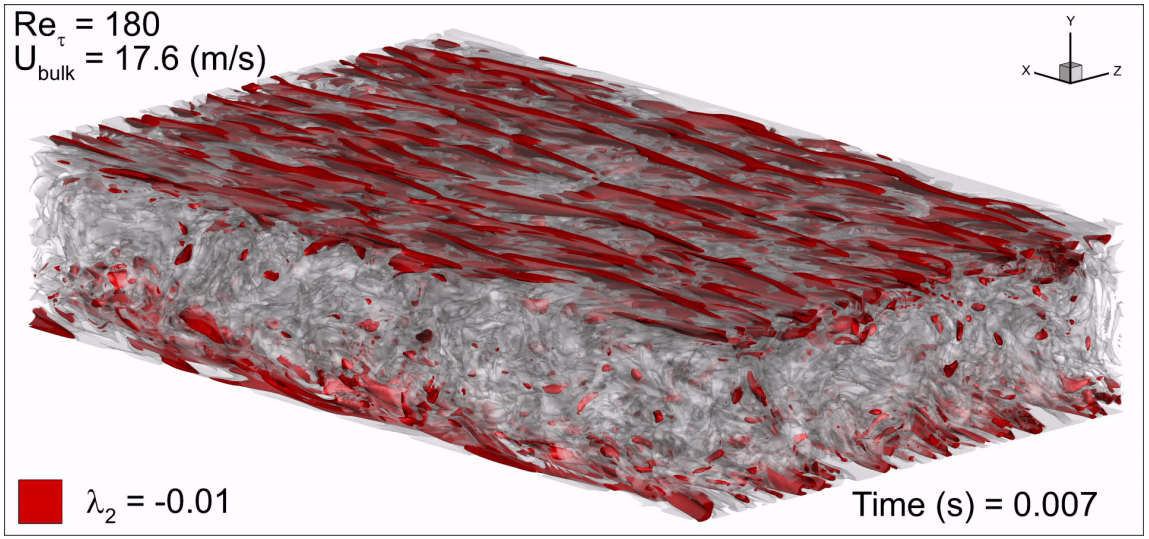
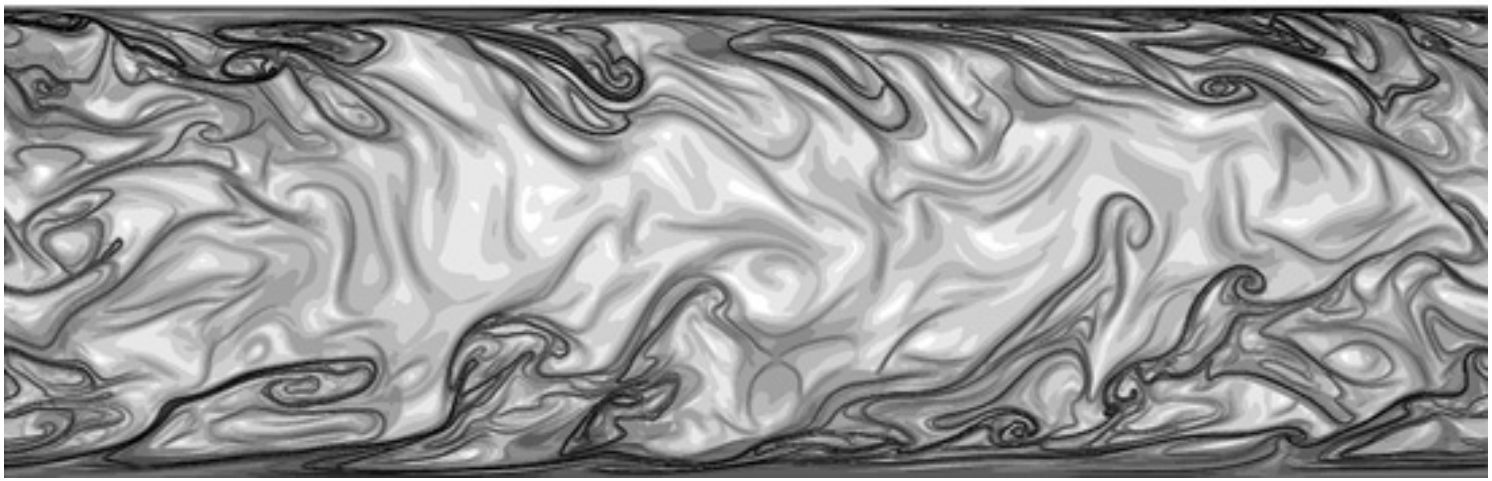
- The flame speed changes as a function of the equivalence ratio
  - Therefore, it is absolutely necessary to achieve rapid mixing and ignition in order to enable combustion completion on a useful time-scale:
- Gas phase chemical kinetics proceed as a consequence of an exchange of atoms resulting from molecular collisions.
  - Mixing must occur at the _____ before the reactions can proceed.
- Mixture Characterizations:
  - Very-fine macroscale mixing:
    -
    -
    -
  - Fully-homogeneous:
    -

Aerodynamics and Mixing

- Transport Physics
  - The turbulence cascade:
    - The action of large-scale motion is to promote
    - The immediate effect of the large-scale mixing
    - The rate of micro-mixing is
  - Fick's first law:
  - Fourier's Law:

Aerodynamics and Mixing



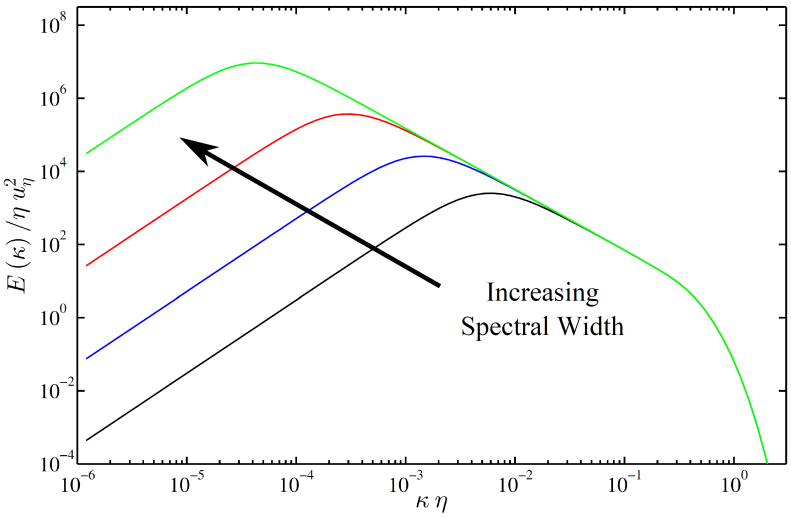


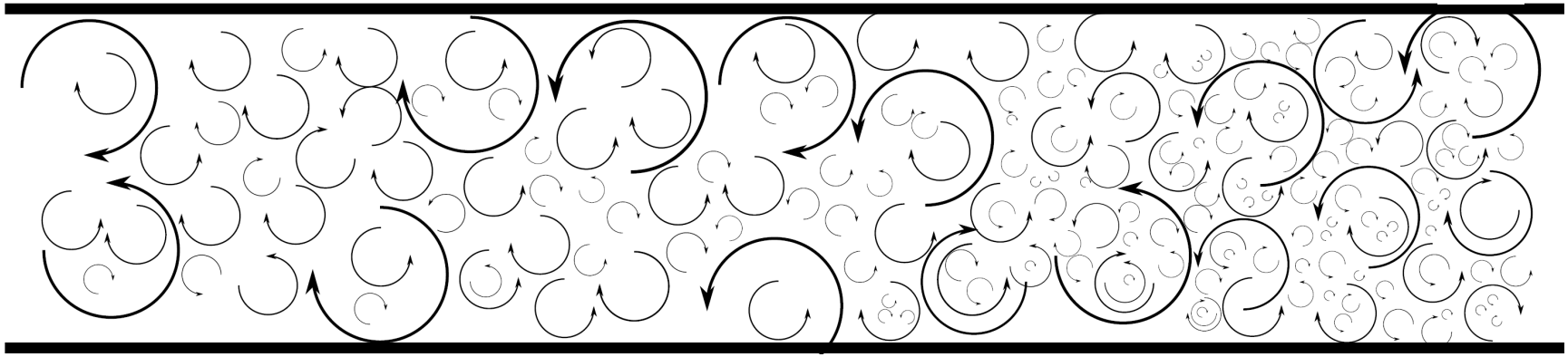
Gruber, NTNU

Aerodynamics and Mixing

Aerodynamics and Mixing

An Interaction of Scales





Aerodynamics and Mixing

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- Injection process must induce a very- effective, high-energy cascade! …where it counts.
  - Compressibility is known to reduce mixing efficiency
  - Devices that enhance mixing generally increase total pressure loss and add drag to the stream
- Maximize the participating area to reduce length.
- Start the cascade with even smaller scales.