ASCENT Project 51

Combustion Concepts for Next-generation Aircraft Engines

Massachusetts Institute of Technology

PIs: Raymond Speth, Jayant Sabnis, Steven Barrett

Students: Yang Chen, Jad Elmourad, Shayan Zahid

PM: Roxanna Moores

Cost Share Partner: NuFuels, LLC

Objective:

Evaluate performance characteristics of novel fuel, combustion, and engine technologies such as **water injection** and addition of **fuel additives**.

Use detailed combustion chemistry models to understand the impacts of these technologies on emissions.

Project Benefits:

New engine designs with higher efficiency and lower emissions offer the potential to increase the economic efficiency of the aviation sector.

Research Approach:

The research targets three sections for screening future engine technologies:

- Engine cycle thermodynamic analysis
- Combustor chemical kinetic modeling
- Overall emission analysis

The performance outputs of the cycle analysis, as well as the emissions outputs of the combustor model, are to be used to calculate the overall emissions impact for various missions.

Major Accomplishments (to date):

A thermodynamic cycle analysis for water injection was performed for a high-bypass turbofan engine, and the combustor chemistry model is being developed.

Future Work / Schedule:

Complete combustor and emissions analysis for various water injection strategies. Investigate fuel composition and additives as another means for emission reduction. Evaluate aircraft mission-level impacts on fuel consumption.

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project 51 through FAA Award Number 13-C-AJFE-MIT under the supervision of Roxanna Moores. Any opinions, findings, conclusions or recommendations expressed in this this material are those of the authors and do not necessarily reflect the views of the FAA.

Introduction

Changes to the thermodynamic cycle, fuel properties, and combustor design could increase efficiency and reduce emissions of future engines

Evaluate **water injection** at various locations in the engine to increase fuel efficiency or reduce emissions

Change **fuel properties** or introduce **additives** to expand operability or reduce emissions during specific phases of flight

Emissions Reduction Methods

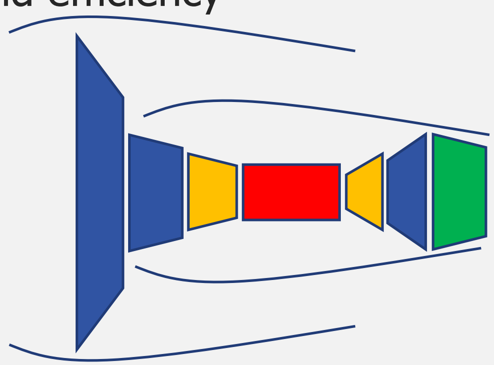
Emissions can be reduced by changing chemical kinetic pathways, reducing peak combustor temperatures, and reacting with pollutant species through various strategies:

- **Liquid water injection** can cool down the working fluid through evaporation, reducing the temperatures
- **High-reactivity additives** can allow leaner operation, reducing concentrations of soot precursors
- **Inert additives** decrease the adiabatic flame temperature

Thermodynamic Cycle Model

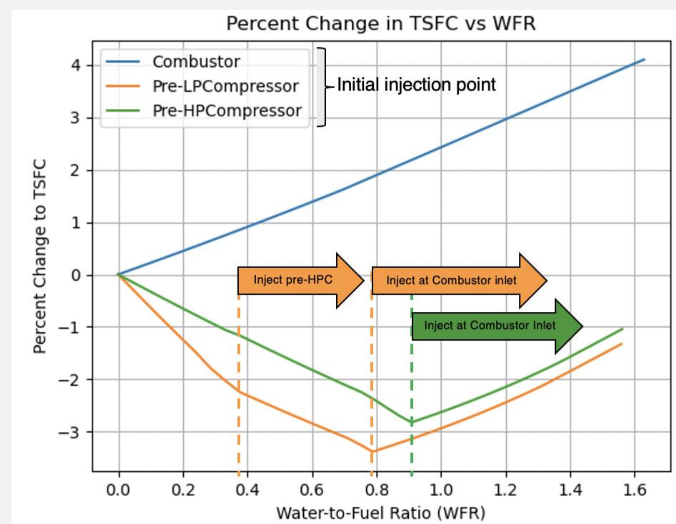
Engine cycle deck

- Engine cycle modeled in PyCycle with modifications
- Component maps for compressor and turbine determine performance over a range of operating conditions
- Provides inlet conditions (temperature, pressure, fuel flow rate) to combustor model
- Solve mass and energy balances to determine effects on thrust and efficiency

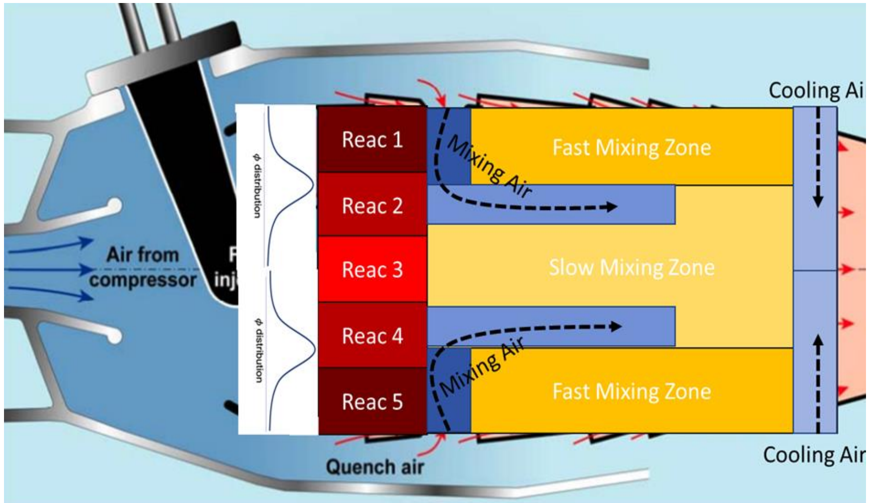


Model Results

- Three water injection schemes studied based on saturation determined via psychrometry:
  - Inject pre-LPC, then inject pre-HPC, followed by combustor inlet
  - Inject pre-HPC, followed by combustor inlet
  - Inject at combustor inlet
- Water injection upstream of LPC and HPC leads to TSFC improvement
- Water injection upstream of combustor inlet leads to increased TSFC



Combustor Model - PyCaso



Primary Zone

$$\frac{dm}{dt},\ \frac{dY}{dt},\ \frac{dT}{dt},\ \frac{dN_{soot}}{dt},\ \frac{dM_{soot}}{dt} \rightarrow \int \rightarrow m,\ Y,\ T,\ N_{soot},\ M_{soot}$$

Secondary Zone

$$\frac{d\dot{m}}{dz},\ \frac{dY}{dt},\ \frac{dT}{dt},\ \frac{d\dot{n}_{soot}}{dt},\ \frac{d\dot{m}_{soot}}{dt} \rightarrow \int \rightarrow \dot{m},\ Y,\ T,\ \dot{n}_{soot},\ \dot{m}_{soot}$$

Reaction Mech: Polimi_Fuels_HighT-adj.cti
Fuel : $nC_{12}H_{26} + nC_7H_{14} + iC_{16}H_{34} + C_7H_8$

- RQL burner with primary zone PSR and secondary zone PFR reactors
- Imperfect mixing captured by primary zone sub-reactors with different φ's
- Incomplete quench air penetration captured by fast & slow secondary mixing zones
- Conservation equations for mass and energy captures both the **thermodynamic** and **chemical effects** of water injection
- Reaction mechanisms involve soot, water, and NO_x

Emission Reduction with Water Injection

- Increasing water injection **reduces** NO_x production
- Pre-LPC water injection **reduces** NO_x more than pre-HPC and pre-combustor cases
- NO_x reduction as a result of decreasing $\mathbf{T_3}$ and $\mathbf{T_{max}}$ inside the burner
- Over-injection of water can lead to **burner blow-out**