Project 073 Fuel Composition Impact on Combustor Durability

University of Dayton Research Institute

Project Lead Investigator

Steven Zabarnick, Ph.D.
Division Head, Fuels and Combustion Division
University of Dayton Research Institute
300 College Park
Dayton, OH 45469-0043
937-229-3961
Steven.Zabarnick@udri.udayton.edu

University Participants

University of Dayton Research Institute

- PI: Steven Zabarnick, Ph.D.
- FAA Award Number: 13-C-AJFE-UD, Amendment 029
- Period of Performance: August 11, 2020 to August 10, 2021
- Task:
    1. Radiation measurements of various fuel types will be performed in the referee combustor to evaluate the function of fuel composition on combustor liner lifetime.

Project Funding Level

Initial Project Funding from FAA- $299,148
Cost share will come from Fuel Producers and Engine/Airframe OEMs. Cost share will be in fuel provided for testing and in fuel performance data provided for the evaluation.

Investigation Team

Project Director/Principal Investigator: Steven Zabarnick
Co-Investigator: Scott Stouffer
Research Engineer: Tyler Hendershott
Technician: Harry Grieselhuber
Graduate Student: TBD
Undergraduate Student: TBD

Project Overview

In this study, the effect of fuel chemical composition on radiative heat transfer and the resulting combustor liner lifetime will be evaluated. Alternative fuels contain ratios of hydrocarbon types that may be quite different from familiar petroleum-based fuels. For petroleum-based fuels, it is known that higher aromatics levels contribute to greater radiative heat transfer and reduced combustor liner lifetime. As a result, aromatics are limited to 25 vol% in the ASTM D1655 jet fuel specification. Some candidate alternative fuels contain synthetically produced aromatics and cycloparaffins which need to be evaluated for their radiative heat transfer characteristics. The measurements taken in this project will provide insight into the effect of fuel type on the liner lifetime. Several fuel types will be investigated including an SAK (Synthetic Aromatic Kerosene), a baseline Jet A fuel, and a fuel that is high in cycloparaffins (e.g., the Shell IH^2 fuel). Diagnostic methods to be used in the investigation include the measurement of wall and gas temperatures, infrared (IR) cameras, and radiometers.

Task 1 – Measurement of Radiative Heat Transfer in the Referee Rig

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Objective

The objective of this program is to provide insight into the effect of fuel type on engine combustor liner lifetime. The study will assure that candidate drop-in fuels will perform satisfactorily in jet engines and not increase engine maintenance nor decrease flight safety. The study may also show where fuel composition changes may reduce radiative heat transfer and therefore increase combustor liner lifetime.

Research Approach

It is well known that fuel chemical composition strongly affects soot formation, smoke production, and radiative heat flux in gas turbine combustors (1). Studies of petroleum-based fuels with varying aromatics species levels have shown that these properties increase with overall aromatics species content. Other parameters such as hydrogen content, hydrogen: carbon (H/C) ratio, and smoke point have also been correlated with liner temperatures, but the effect of individual aromatics species types has not been well studied (2). Candidate alternative fuels may meet aromatics species overall limits but contain individual species or mixtures of species that are very different from those in petroleum-derived fuels. Radiation heat transfer to combustor liners is a major issue in the durability and operational envelope of gas turbine engines. Radiation can cause high heat fluxes resulting in localized heating, hot spots, and high thermal gradients along and across the liner. Increases in liner temperature can decrease the liner durability (3). The intense heating can cause problems with low cycle fatigue, cracking, and buckling of the liner, and in the extreme case can lead to localized melting of the liner. The walls of the combustor can be convectively cooled by effusion or film cooling, however the film cooling typically imposes a cycle performance penalty, along with elevated levels of CO and unburnt hydrocarbons, particularly at low power settings. Because of the concerns about fuel effects on radiation, the radiant heat flux is considered a Figure of Merit (FOM) by aircraft engine OEMs when evaluating alternative fuels for aircraft use (4).

The radiation from a gas turbine flame has two main components:
1. "Non-luminous" radiation from product gases such as CO_2, H_2O, and CO.
2. Luminous radiation from particulates (principally soot) (5).

The non-luminous radiation is in the infrared and has a spectral distribution, whereas the luminous radiation is broadband with a fraction of the radiation appearing in the visible wavelengths. Typically, as the pressure is increased, the luminous radiation from the soot particles becomes the dominant source of heat flux to the liner walls. While the convective component of the wall heat transfer is dependent on the fluid dynamics and gas temperature distribution near the walls, the peak radiant fluxes are related to the combinations of high temperature gas and particulates.

The emissivity of the combustion gases is typically related in an expression such as:

$$\epsilon_g = 1 - exp\left[-aPL(ql)^{0.5}T_g^{-1.5}\right]$$

Where P = gas pressure, kPa
l = a characteristic length factor, which is a function of combustor geometry
T_g = gas temperature, K
q = the fuel-to-air ratio
L = the luminosity factor

The luminosity factor is set to one for gaseous emissivity. For sooting flames, associated with liquid aviation fuels, the luminosity is greater than one and can be correlated with the fuel composition. There are several relations for the luminosity versus fuel type in the literature (6-8). In general, the relations show a drop in the luminosity factor with increases in H/C ratio and decreases in the aromatic content of the fuel. Other correlations in the literature also address the relationship of correlation to smoke point and naphthalene content. While there has been use of IR as a diagnostic tool in basic flame experiments (9), there has been very little work reported in the literature using multiple radiometer and/or planar measurements of IR emissions in practical combustors. The Referee Rig Combustor is an ideal rig for assessing radiation heat transfer because the walls are heavily cooled, a condition that tends to suppress the convective component and thus the background radiant heating from opposing walls, so that the wall heat transfer is primarily from the flame radiation. Furthermore, the provision has been made for radiometer access to the combustor walls in the referee rig.

The team for the proposed effort has developed and used the Referee Rig Combustor to conduct experimental combustion research. Highlights of previous contributions to the evaluation of alternative fuels include:

1. Experimental measurements of lean blowout (LBO) for fuels at a condition of interest to the OEMs and the National Jet Fuels Combustion Program (NJFCP), which have resulted in an unexpected finding of a high correlation between the derived cetane number (DCN) and the LBO limit.
2. Experimental measurements of boundary conditions for the combustor including air flow splits to support numerical combustion modeling efforts.
3. Development of cold air and cold fuel capabilities for the facility to enable atmospheric cold start ignition experiments to be conducted over a range of conditions.
4. A further extension of the facility capability to enable altitude relight experiments to be conducted with a range of fuels at simulated altitudes of 25,000 ft.

The work with the Referee Rig Combustor has resulted in publications that detail cold start ignition (10), ignition at elevated temperatures (11), LBO characteristics (11-15), particulate and gaseous emissions (12), flow through the liner effusion passages (13), acoustic response (11-17), spray characteristics (16), and altitude relight (19).

Milestones
List of the anticipated major milestones and planned due dates.

Milestone	Planned Due Date
Test plan provided	1 Dec 2020
Testing performed over range of fuels	1 Aug 2021
Final report	31 Aug 2021

Major Accomplishments
The project has only just begun so there are no accomplishments yet.

Publications
The project has only just begun so there are no accomplishments yet.

Outreach Efforts
The project has only just begun so there are no outreach efforts yet.

Awards
None

Student Involvement
None

Plans for Next Period
The bulk of the project will be planned, conducted, analyzed, and reported in the next project period.

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