Project 073 Fuel Composition Impact on Combustor Durability

University of Dayton Research Institute

Project Lead Investigator

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University Participants

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- PI: Steven Zabarnick, Ph.D.
- FAA Award Number: 13-C-AJFE-UD, Amendment 029
- Period of Performance: August 11, 2020 to September 30, 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.
- Period of Performance: August 10, 2021 to February 10, 2022 – Amendment 036

Project Funding Level

Amendment No. 029	$299,148
Total	**$299,148**

Cost sharing will be provided by fuel producers and engine/airframe OEMs. The cost share will be given in fuel provided for testing and in fuel performance data provided for the evaluation.

Investigation Team

Project Director/PI: 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 those in familiar petroleum-based fuels. For petroleum-based fuels, it is known that higher aromatic levels contribute to greater radiative heat transfer and reduced combustor liner lifetimes. 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 must be evaluated for their radiative heat transfer characteristics. The measurements taken in this project will provide insight into the effect of fuel type on liner lifetime. Several fuel types will be investigated, including a synthetic aromatic kerosene (SAK), a baseline Jet A fuel, and a fuel that is high in cycloparaffins (e.g., Shell IH[2] fuel). Diagnostic methods to be used in the investigation include the measurement of wall and gas temperatures and the use of infrared (IR) cameras and radiometers.

Task 1 – Perform Measurements 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. This study will assure that candidate drop-in fuels will perform satisfactorily in jet engines and not increase the need for engine maintenance or decrease flight safety. This study may also indicate which 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 aromatic species levels have shown that these properties increase with overall aromatic 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 aromatic species types has not been well studied (2). Candidate alternative fuels may meet the overall limits for aromatic species but may 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 affecting 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 liner durability (3). Intense heating can cause problems with low cycle fatigue, cracking, and buckling of the liner and, in extreme cases, can lead to localized melting of the liner. The combustor walls can be convectively cooled by effusion or film cooling; however, film cooling typically imposes a cycle performance penalty, along with elevated levels of CO and unburnt hydrocarbons, particularly at low power settings. Because of 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 and
2. Luminous radiation from particulates (principally soot) (5).

Non-luminous radiation corresponds to the infrared region and has a spectral distribution, whereas the luminous radiation is broadband, with a fraction of the radiation appearing at visible wavelengths. Typically, as the pressure is increased, the luminous radiation from soot particles becomes the dominant source of heat flux to the liner walls. While the convective component of the wall heat transfer depends 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 = characteristic length factor, which is a function of combustor geometry
T_g = gas temperature, K
q = fuel-to-air ratio
L = 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. Several relations for the luminosity versus fuel type have been reported 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, provisions have 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).

Milestone(s)

Below is a list of the anticipated major milestones and planned due dates.

Milestone	Planned Due Date
Test plan provided	December 1, 2020
Testing performed for a range of fuels	August 1, 2022
Final report	August 31, 2022

Major Accomplishments

Planning and purchasing tasks for this project have been ongoing. Sapphire IR windows were purchased to enable IR access to the referee combustor. We have developed hardware plans for installing surface thermocouples and an IR camera/radiometer in the system. We are also working with AFRL to plan for piggy-back runs on the referee rig with AFRL cooperation. Discussions are ongoing with Shell to obtain sufficient volumes of the IH^2 fuel for testing.

Publications

None

Outreach Efforts

None

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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