Low temperature autoignition of conventional jet fuels and surrogate jet fuels with targeted properties in a rapid compression machine

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Abstract

The autoignition characteristics of conventional jet fuels (category A) and alternative fuels with targeted properties (category C) are investigated using a rapid compression machine and the direct test chamber charge preparation approach. The category C fuels were purposefully built to anticipate special property variations that generally occur in alternative fuels. Ignition delay measurements were made to examine the effects of these unique fuels at low compressed temperatures ($625 \, \text{K} \leq T_c \leq 735 \, \text{K}$), a compressed pressure of $P_c = 20$ bar and equivalence ratios of $\phi = 0.25$, 0.5 and 1.0 in synthetic dry air. Chemical makeup of the fuel shows insight into the effect of the amount of branching in isoalkanes and aromatic influences on autoignition. The results show noteworthy variability in the ignition properties at these low temperature and lean conditions. This variability may impact combustion performance when the engine is running outside the normal operational map or for new engine architectures in the future.
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1. Introduction

Increasing difficulties in the extraction of crude oil and concerns over energy security have resulted in a growing interest in the use of alternative fuels.

Both military and commercial sectors desire that any alternative fuel be a drop-in replacement, requiring no retrofitting of current combustion devices to accommodate new fuels. Recently, a large number of alternative jet fuels from various sources have been widely introduced into the market. The Federal Aviation Administration Center of Excellence (ASCENT), in collaboration with the Air Force Research Laboratory, has established the National Jet Fuel Combustion Program (NJFCP),

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which has tasked itself with determining the suitability of alternative fuel options. Within the program, the tested fuels have been divided into three general categories: A, B, and C. Category A fuels are the current petroleum-based fuels used in commercial and military applications. Category B fuels are alternative fuels that have already undergone strenuous analysis and testing. Category C fuels are alternatives with little to no testing, but also include purposefully built surrogates made to anticipate special property variations that generally occur in alternative fuels, such as narrow boiling range, limited components, and blending effects, whose impacts are poorly understood [1]. Chemical kinetic data for these fuels in the form of ignition delay measurements is a key piece of information needed for verification and aid in developing accurate simulations. However, a lack of data has created a push for the characterization of the ignition properties of new alternative fuels to support integration of these fuels into existing systems. Recent studies include those of Fischer-Tropsch (FT), hydroprocessed renewable jet (HRJ), alcohol to jet (ATJ), and direct sugar to hydrocarbon (DSHC) fuels [2–10] and references therein.

The objective of this work is to provide data investigating the autoignition characteristics of category C jet fuels and to compare their autoignition properties against conventional aviation (category A) fuels under low-temperature (<750 K) conditions in a rapid compression machine (RCM). Ignition delay measurements provided in this study will be important for validation of kinetic models, while examination of ignition delay chemistry based on chemical structures will enhance understanding of combustion; both of which will contribute toward the successful integration of next-generation bio-derived fuels with existing aviation systems.

2. Experimental methods

2.1. Test fuels

The focus of this study is to compare the combustion properties of category C fuels to the currently used category A fuels. Three category A fuels: land-based jet propellant, JP-8 (A-1), a commercial airline and soon-to-be military fuel, Jet A (A-2), and sea-based jet propellant, JP-5 (A-3) are included in this study. In addition, the study will examine six category C fuels: a highly branched isoparaffinic ATJ which consists primarily of isododecane and isocetane (C-1), a "bimodal" blend of 84% vol. tetradecane and 16% vol. 1,3,5-trimethylbenzene (C-2), blend of 64% vol. A-3 and 36% vol. farnesane (C-3), blend of 40% vol. C-1 and 60% vol. high-temperature FT isoparaffinic kerosene (C-4), blend of 73% vol. decane and 27% vol. 1,3,5-trimethylbenzene (C-5), and a DSHC fuel that contains 2,6,10-trimethyl dode-

Table 1
Category C fuels composition.

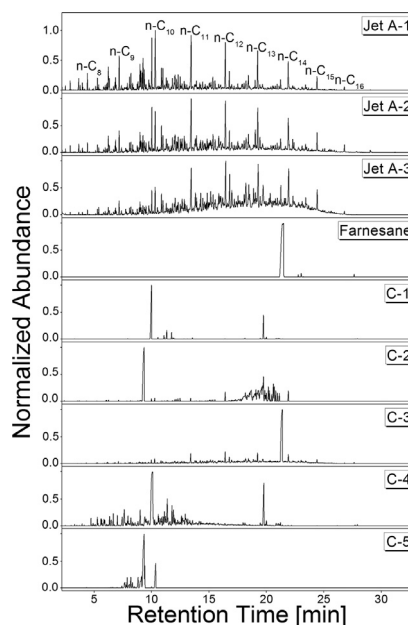| Fuel	Blend composition (% vol.)
C-1	100% highly branched ATJ fuel
C-2	84% tetradecane and 16% 1,3,5-TMB
C-3	64% Jet A-3 and 36% farnesane
C-4	60% isoparaffinic FT and 40% Jet C-1
C-5	73% decane and 27% 1,3,5-TMB

Fig. 1. Total ion chromatograms of all test fuels.

cane (farnesane). For reference, a summary of the fuel blends studied is provided in Table 1. All fuels were obtained from the U.S. Air Force Research Laboratory. As previously mentioned, category C fuels have unique features that will be described briefly, although they are not fully understood. C-1 represents a low cetane fuel with an unusual boiling range, while also exhibiting highly branched species for analysis. C-2 will highlight the issue of potential dominance of particular fuel chemistry in the more volatile part of the boiling range, in this case, C9 aromatics [1]. C-3 allows for the examination of a high viscosity fuel (8.3 cSt at −20 °C). C-4 represents a wide-boiling blend with a low cetane number because of the presence of C-1, which contains highly branched alkanes [11]. C-5 will examine a narrow boiling fuel, in the lower boiling range of conventional jet fuels. Farnesane is proposed as a blending component for use with category A and C fuels. These unique features of the category C fuels are more clearly displayed in Fig. 1 and Table 2, which are explained further below.

Figure 1 shows normalized total ion chromatograms of the category A and C fuels being