SPARK IGNITION OF AVIATION KEROSENE

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Abstract

The ignition of flames in mixtures of air and liquid fuel vapors from commercial aviation kerosene, also known as Jet A, is investigated experimentally. The combustible mixtures are ignited using electrical sparks of different energy. We have measured the dependence of the ignition energy on liquid fuel temperature, initial pressure, mass-volume ratio, and fuel composition.

Introduction

By sufficiently heating a small amount of liquid Jet A in an air-filled vessel, a flammable gaseous mixture is formed. Hence there is an undesirable risk of fire in the ullage of an over-heated airplane fuel tank at sub-atmospheric pressure containing a small amount of liquid fuel. This situation can occur when an airplane with a nearly-empty fuel tank takes off and ascends after an unusually lengthy lay-over on the ground.

Despite the importance of Jet A combustion in aviation safety, there is a lack of extensive combustion data on Jet A vapors. The flammability of Jet A has been studied by [4] and [5], who both performed experiments on Jet A at different pressures but with only a very limited number of spark energies (5 J, 20 J, and continuous arc). The flammability depends strongly on fuel composition which was investigated by Kosvic et al. [1] who describes the composition of the ullage fuel vapor at various temperatures and pressures.

Experimental Details

In the present work, the ignition energy of Jet A is measured in an 1.84 liter aluminum vessel having a cubic interior with a dimension of about 14 cm as shown in Figure 1. Two stainless steel electrodes

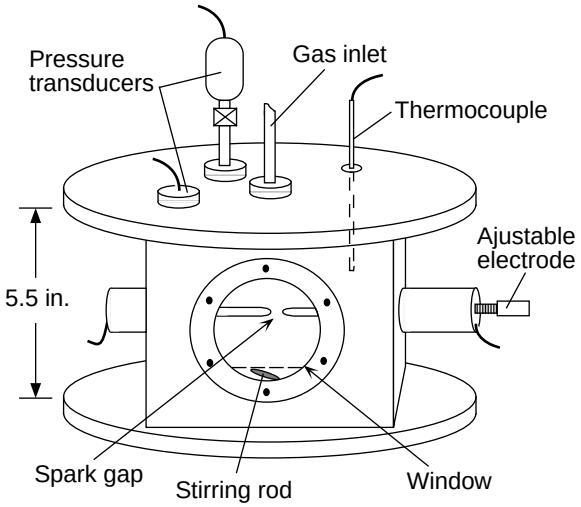

Figure 1: Schematic of the heated ignition vessel used for ignition energy measurements of Jet A vapor with air.

3.3 mm in diameter with rounded tips protrude into the center, forming a spark gap. The combustion pressure and temperature are recorded with a Kulite XT-190 static pressure gauge and a K-type thermocouple respectively, and the flame propagation is filmed using Schlieren video.

The initial temperature of the fuel can be varied between room temperature and 70°C by placing the entire vessel inside a heated chamber of dimensions 46 cm x 37 cm x 62 cm. The flammable mixture resulting from evaporation of the liquid fuel can then be ignited with an electrical spark. Ignition sparks of different strength are generated with a capacitive discharge circuit, and direct measurement of the voltage and current histories of the spark are performed for spark energy calculations.

Results

The ignition energy exhibits a strong dependence on fuel concentration. In the present experimental arrangement, the fuel concentration in the gaseous mixture is determined by the vapor pressure of the liquid fuel. Hence as the temperature increases, the gaseous mixture becomes increasingly fuel-rich. Since the ignition energy of hydrocarbon-air mixtures is known to have a characteristic "U"-shape with a minimum located at a fuel concentration slightly richer than stoichiometric [2], a similar behavior was expected with Jet A as the temperature increased and the fuel concentration increased through the range of flammability of the mixture. For the conditions of a quarter-full vessel (460 ml) at 0.585 bar, the ignition energy was in fact found to decrease sharply from 100 J at 30°C to less than 1 mJ at 56°C (Fig. 2). This trend likely represents the lean part of the "U"-shaped curve, and as the temperature is

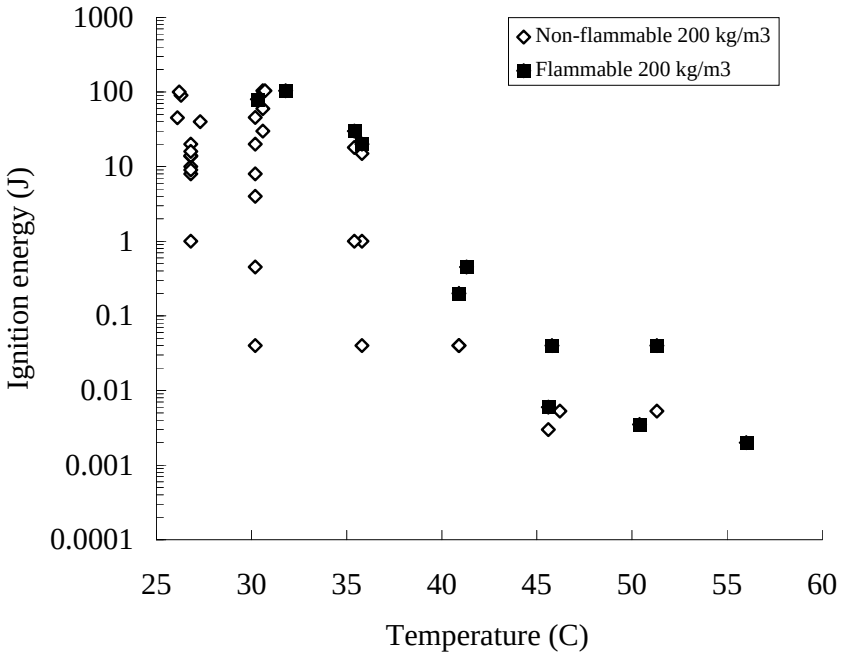

Figure 2: Measured ignition energy for Jet A vapor-air mixtures, at a mass loading of 200 kg/m^3 (460 ml), and an initial pressure 0.585 bar.

further increased, the ignition energy is expected reach a minimum then increase as the rich flammability limit is approached.

The corresponding pressure-time histories of the flame propagation (Fig. 3) show that as the temperature increases from 32°C to 56°C , the peak pressure rise increases from about 1.2 bar to 3.2 bar. These peak pressures were found to be as low as 50% below the Adiabatic, Isochoric, Complete-Combustion (AICC) pressure calculated by representing the Jet A hydrocarbon blend with an average fuel molecule of C_9H_{16} having a specific heat of combustion of 43 MJ/kg. Incomplete combustion due to heat transfer to the vessel walls partially explains this large discrepancy, but it is possible that additional effects are involved.

The flame speed is observed to increase with increasing temperature as indicated by the rates of pressure rise shown in Figure 3. The flame speed can be quantitatively estimated using the "t^3" method described in detail in [7]. The pressure rise rates give burning velocities from 8 cm/s to 60 cm/s, which

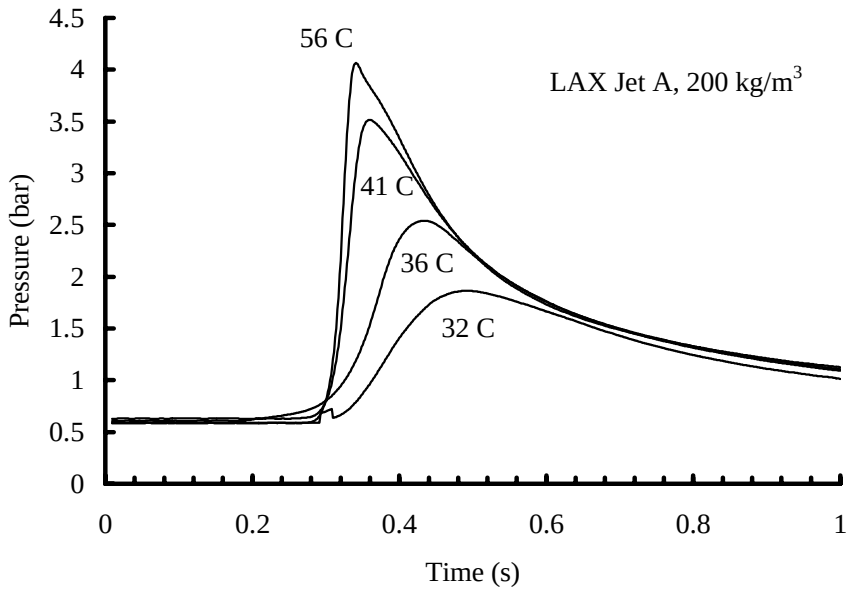

Figure 3: Pressure histories for Jet A-air mixtures at 0.585 bar (200 kg/m^3). In this series of experiments, Jet A from Los Angeles International airport (LAX) was used.

are comparable to the the burning velocities of pure hydrocarbon fuels such as hexane and propane at atmospheric pressure [3].

Discussion

The ignition energy depends strongly on the liquid temperature, which controls the stoichiometry of the combustible mixture. Measurements of the ignition energy between 35°C and 60°C show that it decreases rapidly with increasing temperature, showing the lean regime of flame ignition. The initial pressure also changes the fuel-air ration of the mixture, and the dependence of the ignition energy on the initial pressure is currently being investigated

The combustion properties of Jet A can also depend strongly on the composition of the Jet A vapor. In addition to the intrinsic variability of the Jet A composition due to the fuel refining process, there are two other major processes that can alter the vapor composition in an airplane tank during the normal course of operation: fuel weathering caused by repeated heating and evacuation of the vapors in the ullage, and mass loading which refers to the dependence of the ullage vapor composition on the amount of fuel in a certain tank volume.

Exposing the fuel to various cycles of heating and cooling while evacuating the evaporated gas can preferentially deplete the more volatile hydrocarbon components in the Jet A, particularly those with carbon numbers lower than C9 [6]. This process is sometimes referred to as fuel "weathering". Preliminary tests with "weathered" fuels revealed the ignition energy to be over two orders of magnitude higher than that of fresh fuel.

Due to the multi-component nature of Jet A, the composition of the fuel vapor depends on the mass loading, i.e. the ratio of the mass of fuel in the tank to the tank volume. As the mass loading decreases, the amount of volatile components in the fuel vapor decreases relative to the less volatile components [8]. The present tests show that reducing the mass loading from 200 kg/m^3 to 3 kg/m^3 has only a weak influence on the ignition energy.

References

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