Investigation of Green Propellants for In-Space Propulsion
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Introduction
Bipropellant thrusters for in-space attitude control have traditionally used fuels such as hydrazine (N₂H₄), monomethyl hydrazine (MMH), and unsymmetrical dimethyl hydrazine, and oxidizers such as nitrogen tetroxide (NTO), mixed oxides of nitrogen and nitric acid mixtures. These propellants provide good performance, are non-cryogenic, and form soot-free products. Above all, these propellant combinations are hypergolic (self-igniting on contact), eliminating the need for a separate ignition source and thereby increasing reliability. However, these propellants are carcinogenic and/or highly toxic, which increases the cost and safety issues associated with handling. Therefore, propellant combinations with comparable performance and hypergolicity are desirable which exhibit reduced human threats.

Purpose and Hypothesis
The purpose of this study is to investigate the degree to which various fuel/oxidizer combinations are hypergolic in order to provide alternatives to current state-of-art propellants which will reduce handling costs and improve safety related to spacecraft preparation and launch. Specifically, an initial focus will be on two fuels: ammonia and paraffin wax doped with lithium aluminum hydride (LAH) at various loading factors. The reaction of these fuels with various concentrations of nitric acid will be explored in order to determine ignition times if hypergolic ignition indeed occurs. Figure 1 shows the theoretical performance of LAH-doped paraffin wax with 80% nitric acid.

Materials and Methods
The primary manner in which performance will be initially quantified in this experiment is by measurement of ignition delay times for the various propellant combinations, assuming hypergolic ignition is observed. For this purpose, a combustion chamber was designed which will allow for a droplet of nitric acid to be injected into the chamber and deposited onto a sample of paraffin wax doped with LAH. The loading factor of LAH will be varied in order to understand the anticipated inverse correlation between loading factor and ignition time. Previous research showed spontaneous ignition of LAH-doped paraffin wax with nitric acid at LAH concentrations in the wax above 30%. A similar test will be run with ammonia as the fuel by removal of the paraffin sample holder allowing for flow of ammonia through the combustion chamber. Both of these tests will be run initially at atmospheric pressure. However, chamber design allows for testing at pressures exceeding 200 psi.

In addition to temperature and pressure measurements taken in the chamber, the combustion chamber provides numerous ports for optical viewing of the reaction in progress. Optical diagnostic methods are currently being explored which will allow imaging of the flame front immediately following ignition. Different optical diagnostic techniques may be used depending upon the object of interest within the flame. Techniques such as Planar Laser Induced Fluorescence (PLIF) Imaging can be used to identify the concentration of CH radical within the flame – an approach which can locate the flame front to a high degree of accuracy. Absorption spectroscopy, including infrared spectroscopy, as well as chemiluminescence can be used to identify various intermediate species of the combustion process which will assist in validating chemical kinetic models of the reaction.

Analysis and Future Work
In addition to the experimental portion of the research, chemical kinetic modeling needs to be conducted in order to understand the intermediate reactions which lead to sustained combustion if indeed these propellants are found to be hypergolic. There is open debate related to the cause of the ignition event in the case of LAH and paraffin reacting with nitric acid. One modeling study suggested that the ignition event was initiated by the autoignition of paraffin wax entering the vapor phase. However, chemical kinetics software will be used to gain insight into the mechanisms driving the ignition event in order to better predict what other fuel/oxidizer combinations may exhibit hypergolicity.

Figure 3 shows a performance comparison of two novel fuels which may be investigated in future work, against that of ammonia. Nitric acid in 80% concentration would be used initially as the oxidizer in an investigation with these fuels.

Summary
Novel hybrid and liquid propellants will be tested in order to assess their potential to replace hydrazine and nitrogen tetroxide and their derivatives, thereby reducing spacecraft preparation and launch costs and improving human safety for those working around launch preparations. Ammonia, lithium aluminum hydride doped paraffin wax, and nitric acid are the primary propellants considered in this study.

Acknowledgments
This work was carried out under a research grant from the KACST Center for Research Excellence

Bibliography

Further Information
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