Hybrid Rocket Propulsion

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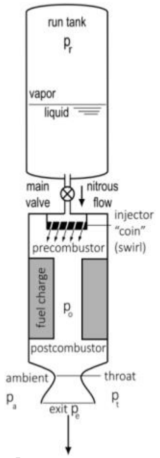
Hybrid Rocket Propulsion Overview

Rocket engines are often classified according to the physical state of the reactants used in the combustion process. In solid engines, the oxidizer and fuel are mixed and cured to create a solid grain that, when lit, burns to produce exhaust gasses. In a liquid engine, both are stored in liquid form and vaporized upon entering the mixing chamber. In a hybrid engine, one reactant is stored in a liquid form, and the other (usually fuel) is stored as a solid.



Advantages

Requiring only one liquid state reactant, hybrid engines are much simpler and cheaper to manufacture, yet still exhibit the same throttling capabilities that make liquid bi-propellant engines so attractive. Furthermore, fuel and oxidizer are initially separated in hybrid systems, making them much safer, and less sensitive to grain discontinuities than solid engines.

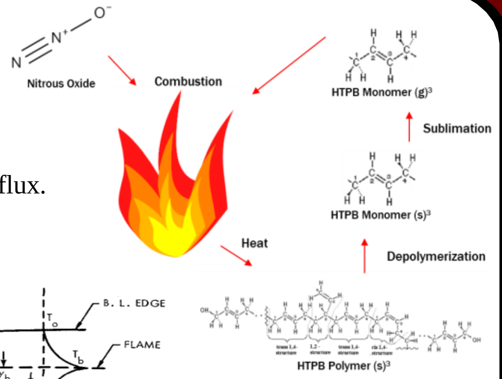
Disadvantages

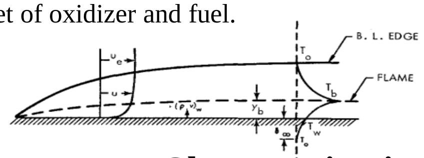
The hybrid combustion mechanism is comprised of many individual processes that are extremely coupled, this leads to a very complicated interaction and means each port geometry and fuel/oxidizer pair will exhibit unique behavior, making general characterization of hybrid systems very difficult. One of these interactions is the decreased heat transfer to the fuel grain with increased production of gasified fuel products to the flow, this is known as "blocking". This process limits the regression rate of the fuel, the maximum thrust, and ultimately, the applications for hybrid propulsion systems.

Combustion Mechanism

In the case of hydroxyl terminated polybutadiene and nitrous oxide (the reactants used in this study), heat is initially introduced into the fuel grain in the form of a solid ignitor, which breaks down and sublimates the polymerized fuel grain to create a flow of gaseous fuel towards the center of the port. Pressurized oxidizer then flows along the center of the grain creating combustion. After a short transient period, combustion can be modeled by a thin film diffusion flame suspended in a turbulent boundary layer some distance above the grain wall.

Throughout the duration of the burn, the fuel grain wall recedes, changing the geometry of the port and the characteristics of the burn. Often this regression rate is modeled as a power law of the oxidizer mass flux. This relationship gives rise to characterization of the burn for a given set of oxidizer and fuel.





Characterization

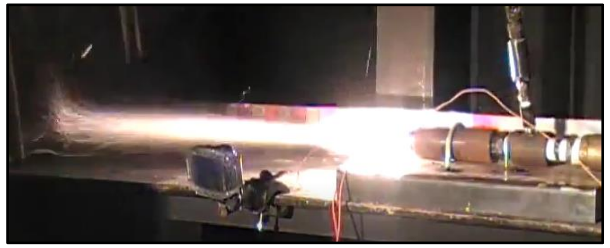
Texas A&M's Sounding Rocketry Team has built a testing facility for their hybrid rocket engine allowing for direct measurements of the thrust produced, as well as pressure before and inside the combustion chamber. The geometry of the exit nozzle is known, the regression rate can be approximated from a post-burn grain regression analysis, and the ratio of specific heats of the combustion products can be estimated from the reaction chemistry. With this information and models previously mentioned, it is possible to perform a mass balance analysis, characterize the engine performance, and estimate the temperature inside the combustion chamber without direct measurement. Furthermore, the G_{ox} power law constants can be calculated to best fit the model observed.

Combustion Temperature Modeling

A small engine has been developed for SRT in order to rapidly test the hybrid engine process under a variety of different conditions. This setup was originally created to test the effect of additive introduction on the combustion performance; however, future modifications will allow for a more direct way of measuring the flame temperature of HTPB and nitrous oxide in the hybrid engine configuration. Temperatures inside the combustion chamber of a rocket engine are too hot for direct measurement with thermocouples, this means one of the most important performance gauges is often left to calculation and approximation.

Experimental Setup

The piping upstream of the combustion chamber will be modified to allow for the introduction of nitrogen gas to the oxidizer flow. Nitrogen gas is inert and will not react with HTPB when entering the combustion chamber. Not only will this drastically reduce the chance of oxidizing the tip of any thermocouples introduced to the flame, but it will also drastically reduce the flame temperature. The level of dilution can then be varied and a model of dilution percentage V.S. flame temperature can be created. Eventually an upper limit will be established as the thermocouple will reach a maximum operating temperature, and then an extrapolation of the data will reveal a close approximation of the combustion temperature. This will allow great insight into the reaction chemistry as the flame temperature is extremely dependent on the departure of the combustion reaction from stoichiometric. Finally, a close approximation of the flame temperature will allow for verification of the hybrid engine model designed to characterize the HTPB and nitrous system and lend further insight into the performance parameters of the engine such as combustion efficiency and reaction equivalence ratio.



References

MARXMAN, G., et al. "Fundamentals of Hybrid Boundary Layer Combustion." *Heterogeneous Combustion Conference*, 1963, doi:10.2514/6.1963-505.

Marxman, G. A. and M. Gilbert, "Turbulent Boundary Layer Combustion in the Hybrid Rocket", IX Intern. Symp. on Combuste [Academic Press Inc., New York, 1963)~. 371.