Theoretical Analysis of Metal Addition on Paraffin Based Hybrid Rockets

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Abstract

Metal addition to solid rocket propellants has been proven as beneficial. This research looks into the effects of adding metals to hybrid rockets. Thermochemical computations were performed using NASA's Chemical Equilibrium with Applications (CEA) software. To achieve this, we wrote Batch CEA (Fig. 1) in MATLAB to run multiple CEA trials.

Fig. 1 – Batch CEA

Introduction

Hybrid rockets consist of a solid fuel and a liquid or gaseous oxidizer[1] (Fig. 2). The energetic performance of a hybrid rocket can be quantified by the density specific impulse (ρI_{sp})[2], which is effected by the properties of the chosen fuels and oxidizers.

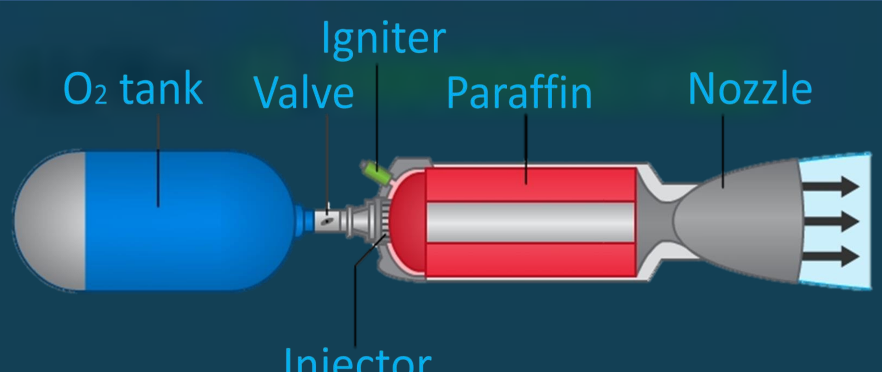

Fig. 2 – Schematics of a hybrid rocket

Batch CEA

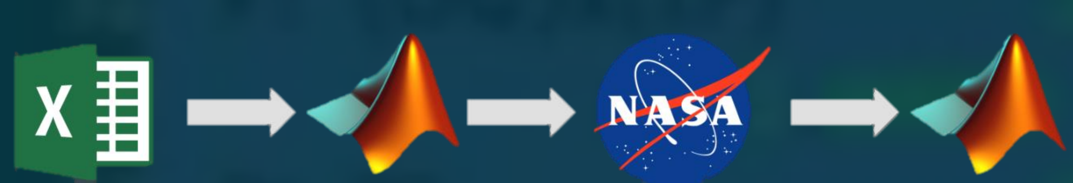

Fig. 3 – Batch CEA algorithm logic

Batch CEA was created to interpret large amounts of data. Selected inputs were fed into CEA and processed, creating outputs for the Batch CEA plotter program as shown in Fig. 3.

Results

Our models evaluated the effect of four parameters on the performance of hybrid rockets: metal addition, oxidizer, metal-wax ratio, fuel-oxidizer ratio. We computed fuels grains with different: aluminum quantities (Fig. 4), oxidizers (Fig. 5), and metals (Fig. 6). In all three figures, density specific impulse (ρI_{sp}) was graphed vs. equivalence ratio (ϕ), the ratio between fuel-to-oxidizer ratio to the stoichiometric value. ϕ=1 represents complete combustion. ϕ>1 indicates a fuel-rich condition, while ϕ<1 represents a oxidizer-rich mixture.

- Fuel grains with higher aluminum compositions also had higher density specific impulse due to aluminum's higher specific heat (Fig. 4).
- Engines with H_2O_2 as oxidizers performed slightly better at optimal conditions, though the density specific impulse dropped much faster when leaving the optimal point (Fig. 5).
- Among the three analyzed elements (Al, Mg, U), uranium and aluminum performed similarly while magnesium provided less energy (Fig. 6).

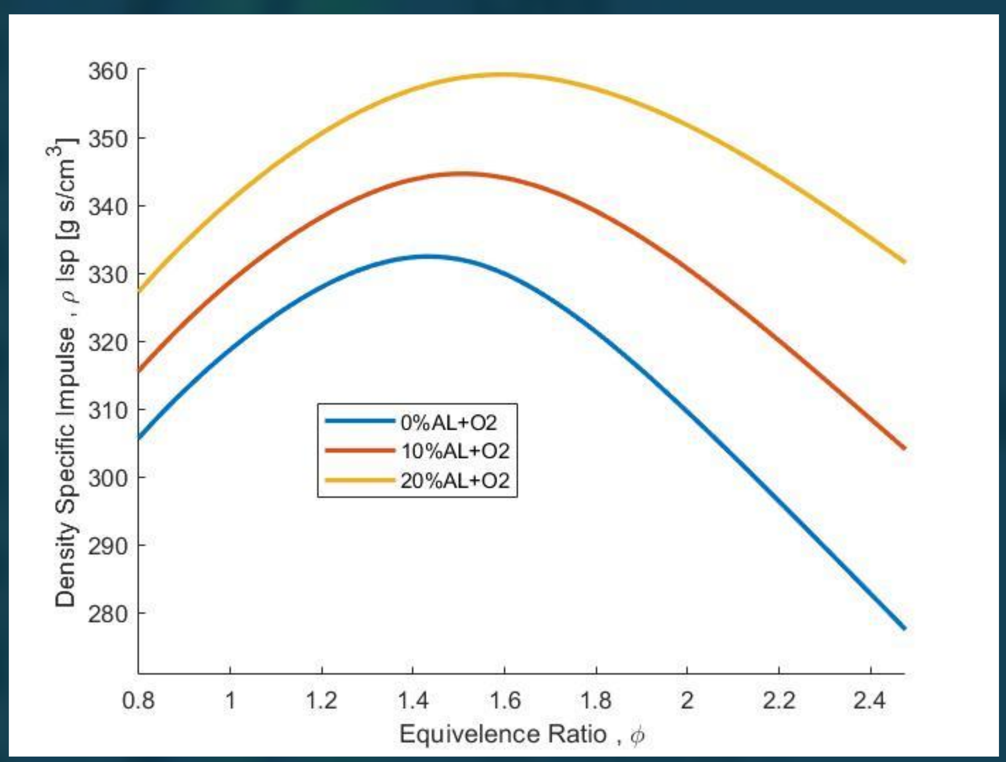

Fig. 4 – ρI_{sp} vs. ϕ for different aluminum quantities

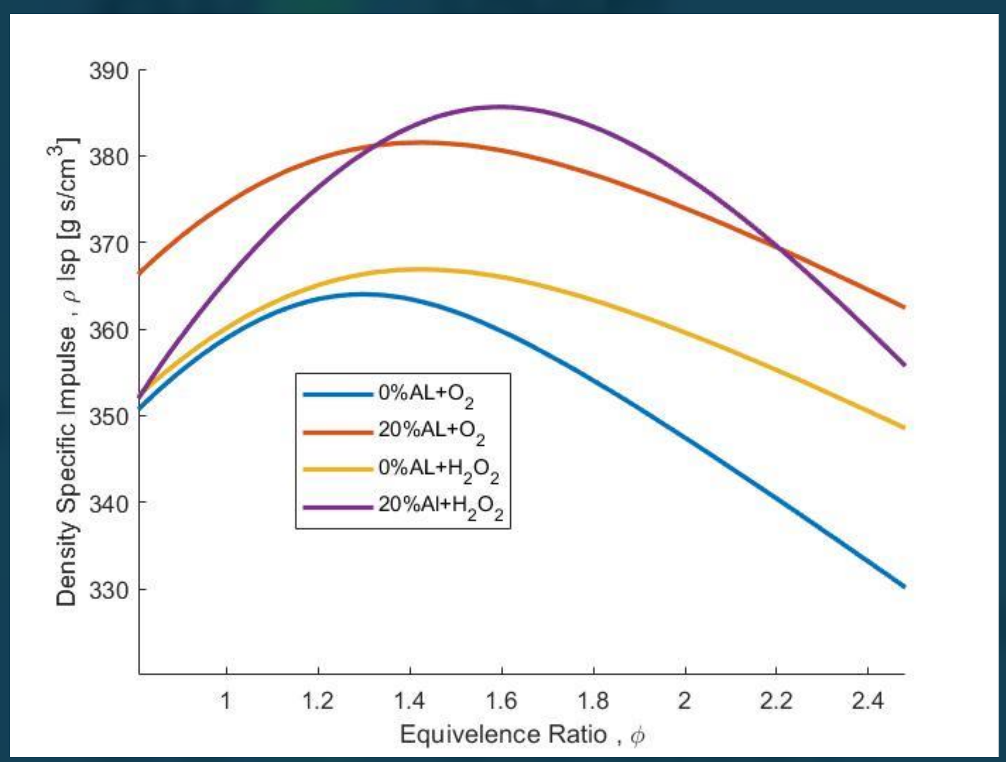

Fig. 5 – ρI_{sp} vs. ϕ for different oxidizers

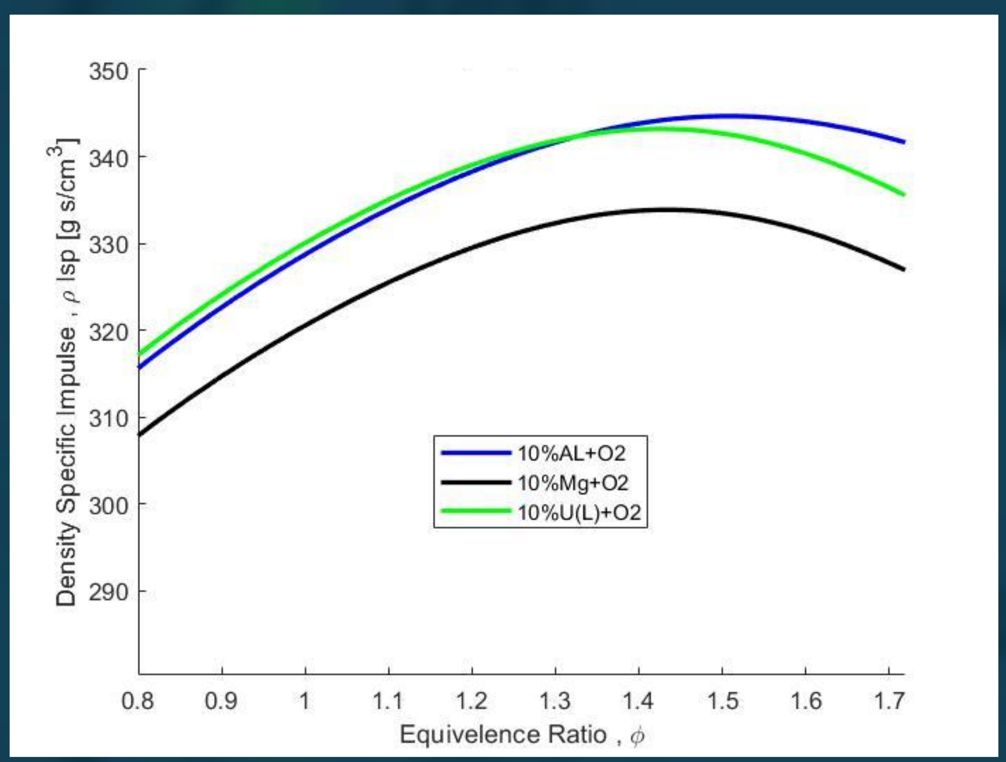

Fig. 6 – ρI_{sp} vs. ϕ for different metal additions

Conclusions

- After running the trials necessary for simulation, Batch CEA has proven to be a stable and versatile graphical user interface for CEA.
- Combining all the data we generated, rockets with a higher composition of aluminum and hydrogen peroxide as oxidizer worked most energetically out of all scenarios.
- Batch CEA was able to run multiple trials at a time with considerably higher efficiency than manual input. This would save fellow researchers time and efforts, and allow more models to be built.

References

1. Altman, D. and Holzman, A., "Overview and History of Hybrid Rocket Propulsion", in: Fundamentals of Hybrid Rocket Combustion and Propulsion, Progress in Astronautics and Aeronautics, Vol. 218, AIAA, pp. 1-36, 2007.
2. Komornik, D. and Gany, A., "Thermochemical Computations of a Paraffin-Aluminum Hybrid Rocket", Proceedings of the 34th Israeli Conference of Mechanical Engineering, Faculty of Mechanical Engineering, Technion I.I.T, Haifa, 21st – 22nd November 2016.

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