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Technical Comments

Comment on "Improved Airbreathing Launch Vehicle Performance with the Use of Rocket Propulsion"

James A. Martin*
University of Alabama, Tuscaloosa, Alabama 35487

REFERENCE 1 shows that using rocket propulsion can improve the payload of an airbreathing single-stage-to-orbit vehicle. The study considered only the performance of the vehicle in terms of propellant mass. It showed, with a detailed analysis of the performance of the airbreathing and rocket propulsion systems, how using the rocket can reduce the propellant mass by first using the rocket concurrently with the airbreather for a period and then using the rocket alone. The purpose of this comment is to point out that other ("nonperformance") aspects of the problem can influence the results of trade studies that attempt to show when the rocket should be turned on.

The first influence that was not included in the study is propellant density. At a mixture ratio of 6.0, typical for hydrogen/oxygen rockets, the rocket propellant has a bulk density over five times as great as that of the hydrogen fuel for the airbreather. The tanks for the propellant are therefore smaller and lighter for the same propellant mass. For reusable vehicles, the structure and thermal protection surrounding the tanks varies with the tank volume. The drag also varies with the tank volume, which is an important factor for airbreathing vehicles.

The second effect that was not included in the study is changing the trajectory to an optimum rocket trajectory after turning on the rocket. The rocket does not need air and does not want drag. After the rocket is turned on, the optimum trajectory is usually higher than the trajectory that would be optimum for the airbreather.

A third effect that was not included in the study is the effect on the optimum size of the airbreathing engine. The mass of the airbreathing engine is significant for vehicles of the type considered, and reductions in this mass can be helpful. If the airbreathing engine is used alone to a high velocity, the optimum size tends to be large because the vehicle needs acceleration at the high velocity. If the rocket is turned on earlier, the optimum size of the airbreathing engine will probably be reduced.

The study correctly concluded that using the rocket can increase the performance of an airbreathing vehicle. The effects that were not considered only accentuate the conclusion. All of the effects discussed have the same effect: lowering the optimum velocity at which the rocket is turned on. The optimum value for this velocity depends on the vehicle design, but it may be in the range of 5 to 6 km/s.

Reference

[1]Kauffman, H. G., Grandhi, R. V., Hankey, W. L., and Belcher, P. J., "Improved Airbreathing Launch Vehicle Peformance with the Use of Rocket Propulsion," *Journal of Spacecraft and Rockets*, Vol. 28, No. 2, 1991, pp. 172–178.

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*Associate Professor, Department of Aerospace Engineering. Associate Fellow AIAA.

Reply by the Authors to James A. Martin

H. G. Kauffman,* R. V. Grandhi,† W. L. Hankey,‡ and P. J. Belcher§
Wright State University, Dayton, Ohio 45435

THE authors of Ref. 1 agree with James Martin and want to thank him for pointing out that there is much more to consider than performance aspects in optimizing the design of airbreathing and rocket propulsion components. The scope of our funded research project did not permit us to alter the design characteristics of the vehicle. Our study objective was to develop efficient methods for determining the optimum operation of a fixed design.

The generic vehicle design data used to demonstrate the methodology had an airbreathing fuel specific energy performance parameter ($Ps/\dot{w}$) that deteriorated rapidly at Mach numbers greater than 20. This parameter is a strong indicator of what size augmentation rocket to use and when it should be turned on. However, the impact on overall design weight, complexity, and cost should be made before concluding that the rocket and airbreathing engines are sized properly.

The effect that the simultaneous operation of rocket and airbreathing engines have on the optimum trajectory was within our study scope and was not included in the paper due to page limitations. The effect was to increase the altitude at which orbital speed is reached by approximately 8 km and to increase fuel savings by an additional 5%.

The performance optimization methods described in Ref. 1, used iteratively with an efficient preliminary design method and realistic data, could provide valuable trade data for sizing the auxiliary rocket needed to achieve orbital conditions with an airbreathing launch vehicle.

Reference

[1]Kaufman, H. G., Grandhi, R. V., Hankey, W. L., and Belcher, P. J., "Improved Airbreathing Launch Vehicle Performance with the Use of Rocket Propulsion," *Journal of Spacecraft and Rockets*, Vol. 28, No. 2, 1991, pp. 172–178.

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*Graduate Student, Department of Mechanical and Materials Engineering.
†Associate Professor, Department of Mechanical and Materials Engineering.
‡Professor, Department of Mechanical and Materials Engineering.
§Research Engineer, Department of Mechanical and Materials Engineering.