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Technical Comments

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Reply by the Author to W. H. Heiser and D. T. Pratt

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It is obvious that the purpose of a magnetohydrodynamic-energy bypass high-speed airbreathing engine (MHD-bypass) is to allow the combustor to operate at lower velocities and total enthalpies (temperatures) than a conventional scramjet, hence, hopefully improving combustor performance in terms of decreased losses due to mixing/combustion of fuel and air, skin friction, and heat transfer. This is stated emphatically and repeatedly in Ref. 1. The overriding question is, therefore, what additional losses are incurred in a MHD, bypass scramjet, and whether those identified losses are significant enough to negate the performance/operability gain associated with the cooler, low-velocity core.

In Ref. 1, a detailed analysis is provided of these additional losses, beginning with the inevitable total pressure loss associated with the general inverse cycle engine (of which the MHD-bypass engine is a subset of). This loss is entirely independent of irreversibility, that is, it is completely and properly demonstrable for the ideal cycle (defined usually as in Ref. 1 as an engine with all components reversible). Furthermore, this total pressure loss is rigorously shown to increase rapidly with energy bypassed in such an engine, meaning that any inverse cycle engine, whether ideal or not, will and must suffer from this performance loss. Note that this is only the initial loss mechanism examined in Ref. 1 and, contrary to the charge in Ref. 2, there is no attempt made in this ideal cycle section (and should not be) to compare actual scramjet to actual MHD-bypass performance: The purpose of the section is simply to identify and quantify ideal inverse cycle engine behavior and the cycle loss associated with this engine type. As part of the continuum of ideal inverse cycle engine performance, one can (and should) define the ideal inverse cycle engine with zero energy bypass as the ideal ram/scramjet because that is exactly what it is. Hence the argument advanced in Ref. 2 for a "more appropriate and useful" definition of the ideal scramjet as a nonideal scramjet with mandated Rayleigh-type losses is neither appropriate nor useful to the purpose or results of this particular section of the paper.

In fact, ideal engine analysis of any type for high-speed flight is not of practical interest except to clarify trends and (specifically for the work done in Ref. 1) to identify any inherent, cycle losses not related to irreversibility. It is startling, however, that the authors of Ref. 2 apparently do not believe that the presence of a major inherent cycle loss in a particular type of engine is in any way relevant to the comparative analysis of that engine type with other engine types that do not experience that same type of loss. (See the last sentence of Ref. 2.)

It is also puzzling why the authors of Ref. 2 ignore the bulk of Ref. 1 subsequent to the ideal cycle section. In subsequent sections, the other (irreversible) losses in the MHD-bypass engine are directly and methodically addressed and then detailed comparative (highly nonideal) simulations of both scramjets and bypass engines with all relevant losses modeled are given. These simulations utilize inlet shocks and nozzle losses, fuel injection, wall cooling and thermal balancing, chemical reaction and multiple species, etc. Also addressed in some detail are the highly restrictive design issues such as flowpath area ratio and choking problems associated with a MHD bypass engine. Such issues severely degrade the design feasibility of the MHD bypass engine scheme for significant bypass energies.

Although the authors of Ref. 2 state that the "appropriate" question is "whether or not the improved flow conditions within the combustor outweigh the parasitic losses of the MHD device in the flowpath and external circuits, as well as the burden of carrying it around," they do not define what they mean by parasitic losses. If by such losses they are referring merely to MHD-based Joule heating losses, their list is incomplete. (See Ref. 1, in which loss mechanisms are analyzed in detail.)

In summary, the MHD-bypass engine suffers the following performance problems: 1) a cycle-driven total pressure loss due to the inverse cycle (not related to irreversibility), 2) MHD Joule heating losses due to MHD energy interaction devices, 3) additional frictional/ heat transfer in MHD components, and 4) extreme area ratio and work/thermal choking issues. (See Ref. 1 in its entirety.) Conversely, the MHD-bypass engine operates with a cooler and lower Mach number core than a conventional scramjet, with attendant benefits. However, full engine simulations in Ref. 1 show that the latter advantage cannot make up for the former disadvantages across the flight Mach range examined. The MHD-bypass engine simulations in Ref. 1 also do not take into account the severe system-level penalties associated with "carrying it around." It is not clear to this author why one would want to take that weight penalty for an engine that also delivers less thrust and specific impulse. Furthermore, three-dimensional effects in the MHD devices represent significant operability and performance problems: These issues, however, are not explored in Ref. 1 but certainly would not (in general) help the case for the high-speed airbreathing MHD-bypass engine.

References

[1]Riggins, D. W., "Analysis of the Magnetohydrodynamic Energy Bypass Engine for High-Speed Airbreathing Propulsion," *Journal of Propulsion and Power*, Vol. 20, No. 5, 2004, pp. 779–792.

[2]Heiser, W. H., and Pratt, D. T., "Comment on Analysis of the Magnetohydrodynamic Energy Bypass Engine for High-Speed Airbreathing Propulsion," *Journal of Propulsion and Power*, Vol. 21, No. 6, 2005, p. 1140.

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