Technical Comments

Comment on "A Comparison of Scramjet Integral Analysis Techniques"

Griffin Y. Anderson*
NASA Langley Research Center, Hampton, Virginia

REFERENCE 1 concludes that a method devised by Billig[2] based on a Crocco power law relationship "... is the preferred approach for prediction of (dual mode) scramjet performance." In fact, the approach recommended in Ref. 1 has several important shortcomings and the preferred approach depends largely on the particular objective desired from the analysis. If parametric performance data are desired, the approach of Billig or any number of other simplified analyses may be adequate. The particular process chosen to compare with the Billig analysis in Ref. 1 is recommended in Ref. 3 for parametric studies because the predicted performance it produces appears to represent an upper limit of the dual-mode performance observed experimentally in free-jet engine tests. On the other hand, for detailed engine design and performance projection, more complete analyses that incorporate at least axial variations of properties within the combustor will be necessary; and provisions to include specific prototype or component development empirical results will be required.

As discussed by Cookson,[4] the Crocco power law is one of several property/area relationships that might be chosen to achieve closure at the same level in a one-step (i.e., "integral") one-dimensional combustor analysis. Cookson points out, however, that the choice of a static pressure (Crocco's) or temperature vs area relationship leads to singularity (that is, a maximum heat addition beyond which a solution is not obtained—thermal choking) at an exit Mach number different than sonic, while the choice of a stagnation pressure or temperature vs area relationship produces a singularity at sonic conditions. Reference 5 gives a more complete discussion of the limitations of Billig's method and points out that the Crocco power law is equivalent to quite special assumptions concerning the physical properties within the combustor, such as static pressure, total temperature, heat release, etc. On the basis of physical arguments, Ref. 5 concludes that an assumed heat release schedule, i.e., stagnation temperature vs area (or distance), might provide a more suitable choice. Reference 6 adopted this same approach; and Ref. 7 showed how heat release distribution could be related to mixing predictions based on detailed injector design considerations, at least for large-scale applications with a reactive fuel (hydrogen) for which mixing controlled heat release can be assumed.

It is interesting to compare the performance predictions from Ref. 1 for the constant-area/constant Mach number process suggested in Ref. 3 with predictions for this process obtained from Ref. 8 (see Table 1). At Mach 3.5, the difference is small (4%) and likely to be within the precision expected from such an estimate. At Mach 6, the difference is significant (+22%). The larger value from Ref. 8 is likely to be the result of a different interpretation of the simplified process assumed.

Received Feb. 11, 1985.

*Acting Head, Hypersonic Propulsion Branch, High-Speed Aerodynamics Division. Associate Fellow AIAA.

Table 1 Estimated thrust coefficient

Mach number/ equiv. ratio	Ref. 1	Ref. 8	Difference,%
3.5/0.76	0.81	0.846	+4
6.0/1.0	0.72	0.875	+22

The heat addition process in Ref. 8 may be completed before the end of the combustor (combustor exit area), if initial conditions allow rather than require constant Mach number heat addition to the combustor exit area as implied in Ref. 1. With heat addition occurring further upstream in a smaller area (and at a lower average Mach number), smaller total pressure losses are incurred and the estimated performance is higher. Based on the comparison with free-jet engine data in Ref. 3, this result implies that performance somewhat higher than that predicted by the method of Ref. 2 might be obtained by proper tailoring of the heat release schedule.

A serious shortcoming shared by all one-step analyses of dual-mode combustion in their inability to accurately represent the observed limits on combustor operation for a wide range of geometries and operating conditions. Operating limits such as combustor/inlet interaction, local thermal choking, combustion mode change, and the maximum (or minimum) operating equivalence ratio at a given flight condition frequently depend on local phenomena within the combustor and not strictly on overall parameters. Multistep analyses such as Refs. 6 and 7 or a more modern computational treatment like that in Ref. 9 constitute better approaches to incorporating real operating limits such as blowout and boundary-layer separation on performance. Generally, the selection of an analysis approach must depend on the nature of the results required and the quality and detail of available input information.

References

[1]Sullins, G. A. and Waltrup, P. J., "A Comparison of Scramjet Integral Analysis Techniques," *Journal of Propulsion and Power*, Vol. 1, March-April 1985, pp. 156-158.

[2]Billig, F. S. and Dugger, G. L., "The Interaction of Shock Waves and Heat Addition in the Design of Supersonic Combustors," *Twelfth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, 1969, p. 1125. (See also Billig, F. S., "Ramjets with Supersonic Combustion," Paper presented at AGARD-NATO PEP Lecture Series No. 136, 1984.)

[3]Heins, A. E. Jr., Reed, G. J., and Woodgrift, K. E., "Hydrocarbon Scramjet Feasibility Program, Free Jet Engine Design and Performance," ARAPL-TR-70-74, Pt. III, Jan. 1971.

[4]Cookson, R. A., "An Analysis of Non-Constant Area Heat Addition Due to Combustion in a Supersonic Air-Stream," Interim Scientific Rept. AFOSR-TR-1483, Sept. 1975.

[5]Ramaty, Y., Spiegler, E., and Timnat, Y. M., "The Self-Adjustment Mechanism Model of Scramjet Combustors," *19th Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, 1982, pp. 549-556.

[6]McVey, J. B., Kennedy, J. B., and Haviland, F. L., "Hydrocarbon-Fueled Scramjet: Combustor Design Procedures," United Aircraft Research Laboratories, East Hartford, CT, Tech. Rept. AFAPL-TR-68-146, Vol. IX, Aug. 1971.

[7]Anderson, G. Y., "An Examination of Injector/Combustor Design Effects on Scramjet Performance," Paper presented at *2nd International Symposium on Air Breathing Engines*, Sheffield, England, March 1974.

[8]Carlson, C. H., "Scramjet Peformance Parametrics for Hypersonic AirBreathing Missile Application," NASA CR 2575, Contract NAS1-15434, July 1982.

[9]Bussing, T. R. A. and Murman, E. M., "A One-Dimensional Unsteady Model of Dual Mode Scramjet Operation," AIAA Paper 83-0422, Jan. 1983.