Technical Comments

Comment on "Far Field Approximation for a Nozzle Exhausting into a Vacuum"

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BROOK[1] presents an approximate method for determining flowfields extending tens of nozzle-exit radii downstream from a nozzle exhausting into a vacuum. By modifying the Hill and Draper[2] method, the presented results show additional regions of remarkable agreement with the corresponding solutions of the method of characteristics.

The acceptance of solutions from any approximate method also imposes acceptance of the method's uncertainties, in addition to the uncertainties usually present in some of the parameters themselves.[3] If one is to apply these solutions successfully, these uncertainties must be bounded,[3,4] in particular, as to the method's 1) applicable region(s), 2) accuracy, 3) sensitivity to parametric changes, and 4) possible worst combination of parameters. Obviously, 3 will affect 4, and both, in turn, will affect 1 and 2. If it is not possible—as is the case—to maintain the same degree of accuracy within a flowfield based on one set of parameters,[2] then one may also expect to see a shift in the region of best accuracy, i.e., closest approach to characteristics' solutions, with different sets of parameters. Since acceptable accuracy depends on the tolerable margins drawn by criteria pertaining to the individual situation, a knowledge of realistic maximum deviations from a reference forms the basis for passing judgment on the acceptability or unacceptability of results.

In addition, one must recognize that this method (as is true of all others restricted to expansion into a vacuum) cannot take into account environmental pressure, although this parameter exerts a pronounced effect on the plume profile, as dramatically evidenced by the launch phase of Apollo 11. As a result, impingement effects will be indicated where a flowfield is nonexistent. Similarly, these methods fall short where an object pierces the boundary shock—nonexistent in the vacuum approach. Brook himself clearly states simplified methods yielding low axial densities (by comparison with exact calculations) and thereby implying higher densities in some regions away from the centerline may lead to possibly unacceptable estimates of impingement forces. The extension of this insight to the aforementioned comments is obvious.

One of the stated motivations for developing approximate methods stems from encountering computational difficulties with the method of characteristics at far downstream distances. An encounter with such difficulties, however, need not take place. The method can and has been programed free from such computational defects and readily maps the flowfield hundreds and even thousands of nozzle-radii downstream.[5]

A second consideration stems from the comparatively substantial computer time involved. However, since the development of the flowfield is only a means to an end, i.e., one's main objective and interest being the ascertaining of impingement effects on objects affected by the stream, a comparison of efforts is realistic only from an over-all point of view, i.e., from initial input to desired end results. If one considers that judicious coupling of the characteristics' method with an impingement-effect subprogram[6] results in obtaining a print-out of a parametric study of such effects within 1 to 2 hr, intermediate handling included, then a comparison of the common denominator may not necessarily favor the approximate method. If one adds to this the immediacy, completeness, and accuracy of the results the comparative ease with which approximate methods can be applied must be weighed against the known and unknown limitations of their results.

References

[1] Brook, J. W., "Far Field Approximation for a Nozzle Exhausting into a Vacuum," *Journal of Spacecraft and Rockets*, Vol. 6, No. 5, May 1969, pp. 626–628.

[2] Hill, J. A. F. and Draper, J. S., "Analytical Approximation for the Flow of a Nozzle into a Vacuum," *Journal of Spacecraft and Rockets*, Vol. 3, No. 10, Oct. 1966, pp. 1552–1554.

[3] Rute, L., "Effect of Ratio of Specific Heats on Plume Characteristics," MSD TM-S250-67-32, June 19, 1967, Avco Corp.

[4] Rute, L., "Effects of Large Ratios of Specific Heats on Plume Characteristics," MSD TM-K250-67-43, 21 Aug. 1967, Avco Corp.

[5] Rute, L., "Method of Characteristics—Computer Program for Rocket Plume Definition," MSD, TR-S250-66-33, Dec. 28, 1966, Avco Corp.

[6] Rute, L. and Winans, L., "IBM 360 Program for Determining Impingement Effects (Forces and Moments) on Cylindrical Bodies in Rocket Exhaust Plumes," MSD TM-K250-67-47, Sept. 12, 1967, Avco Corp.

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Reply by Author to L. Rute

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AS I interpret Rute's comments, he is advocating caution in applying approximate methods of calculation. I would certainly agree. However the use of approximate analytical expressions, based on gross conservation laws, is preferable to more elaborate computations in many cases.

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