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Comment on “A new approach for the design of hypersonic scramjet inlets” [Phys. Fluids 24, 086103 (2012)]

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In a recent work, Om Prakash Raj and Venkatasubbaiah (referred to as R&V from hereon) proposed a new approach for the design of mixed compression scramjet intakes with high total pressure recovery (TPR) for a prescribed design freestream Mach number.[1] They employed one-dimensional (1D) gas dynamic relations for design of the intake and assessed its performance using two-dimensional (2D) inviscid and viscous numerical simulations. The goal of this Comment is to highlight some of the inaccuracies in the conclusions drawn by R&V in their study.

The one-dimensional design approach proposed by R&V[1] combines the ideas of maximizing total pressure recovery by imposing the shock-on-lip condition along with prescribing the Mach number at the beginning of the isolator. They showed that their proposed approach results in intakes with a higher TPR than those obtained by Smart's method, which attempts to only optimize TPR[2] (see Fig. 3 in the original work[1]). The differences between the two approaches were also found to be significant at large Mach numbers in their studies. Unfortunately, this claim is based on an erroneous interpretation and comparison of data—while R&V employed n as the number of external shocks, Smart used the same notation for the total number of shocks (the sum of external and internal shocks). We have now revisited the variation of TPR with the design Mach number by making independent computations using their 1D approach, and the correct comparison is now shown in Fig. 1. It must be remarked that the design approach assumes the flow to be isentropic and the fluid to be a calorically perfect gas. A closer look at the plot reveals the following:

1. For a given configuration (the fixed number of external and internal shocks), the approach of R&V does not have a consistently higher TPR than that from Smart's approach. In fact, for a lower range of Mach numbers, the latter shows a higher TPR, while only for the higher range of Mach numbers, does the proposed new approach show a superior TPR.
2. As the total number of shocks $m + n$ increases, the difference in TPR between the two approaches diminishes.

These observations are in complete contrast to the assertion of R&V in their work where they stated that "the deviations in the present and previous approaches in the literature are significant," which is a consequence of their incorrect comparison.

The use of computational techniques for determining the flowfield in hypersonic flows over complex configurations is now a mature field.[3,4] Therefore, to understand the dimensionality (1D vs 2D) and flow (inviscid vs viscous) effects on the intake design, R&V performed two-dimensional computations in inviscid and viscous regimes for their design configurations. They found that the TPR and isolator Mach numbers computed using two-dimensional inviscid simulations were different from those calculated from their one-dimensional design approach (see Tables I and II in the original work[1]). They also demonstrated that the two-dimensional intakes designed for a prescribed freestream Mach number did not satisfy

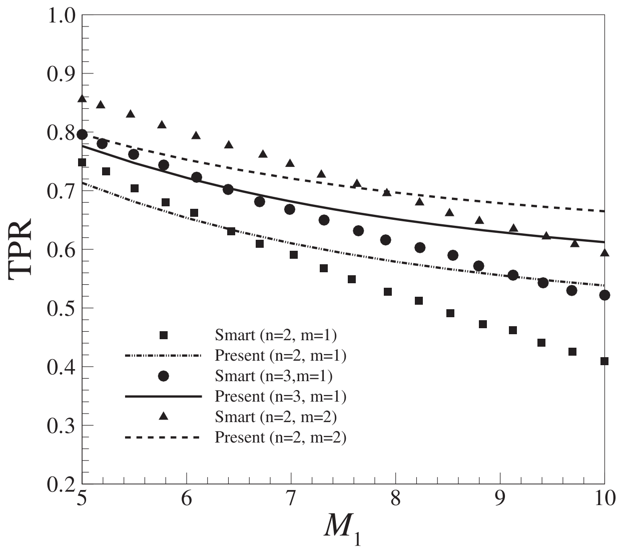

FIG. 1. Variation of TPR with M_1 for three intake configurations. Here, *n* and *m* are the number of external and internal shocks, respectively.

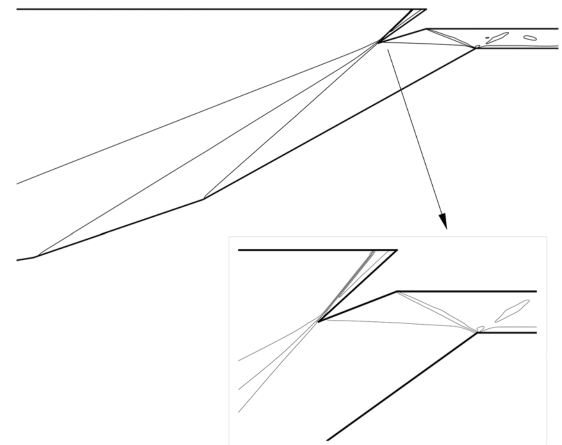

FIG. 2. Mach contours for the $n = 3$ and $m = 2$ configurations at $M_1 = 8$ (min: 3.83, Δ: 0.62, max: 8). The inset shows a zoomed-in view near the cowl lip where the shocks are seen to coalesce.

the shock-on-lip condition, for both inviscid and viscous flows (see Figs. 6, 8, and 10 in the original work[1]). Their simulations were carried out using ANSYS-FLUENT with variable specific heats for the gas. The authors concluded that because their design approach was based on a one-dimensional inviscid flow, both two-dimensional effects and the presence of the boundary layer and its interaction with shocks contributed to the observed deviation in results. We independently performed two-dimensional inviscid simulations for the intake configuration corresponding to $n = 3$ and $m = 2$ at the design Mach number of $M_1 = 8$, which was also investigated by R&V in their work. Our simulations are carried out using an indigenous density-based continuum solver, which has been extensively validated for inviscid flows.[5] The computations are carried out using a second-order accurate AUSM with limiting and variable (temperature-dependent) specific heats,[6] consistent with the simulations of R&V. The flow is assumed to be "frozen" (no reactions), and air is treated as a mixture of two species, viz., nitrogen and oxygen. The computed values of TPR, static pressure ratio (SPR), and Mach number at the isolator are compared with those from one-dimensional calculations and two-dimensional predictions of R&V in Table I. The following conclusions may be arrived at from the analysis:

TABLE I. Comparison of results from 1D calculations and 2D inviscid simulations for $n = 3$ and $m = 2$ configurations at $M_1 = 8$.

	Present (1D)	Present (2D)	R&V[1]
SPR	50.39	47.69	66.41
TPR	0.784	0.855	0.680
M_{is}	4.0	4.11	3.75

1. The results from present computations show a reasonable agreement with the one-dimensional estimates, while the computational results of R&V exhibit appreciable differences. While we compute a higher TPR and M_{is} than those predicted by the 1D design approach, computations of R&V predict a lower TPR and isolator Mach number than those from the 1D approach.
2. Our numerical simulations show that the shocks indeed coalesce nearly at the lip (see Fig. 2). This is in sharp contrast to the observations of R&V who found a violation of the shock-on-lip condition even in their inviscid simulations.[1]

The differences between 1D estimates and 2D computations are therefore due to specific heats being constant and variable, respectively, and are not a consequence of the dimensionality effects as R&V suggested. Moreover, our studies also suggest that the 1D approach gives conservative estimates of TPR for the designed intakes.

The design approach for two-dimensional hypersonic intakes based on 1D relations and numerical computations is indeed a quick and useful preliminary design tool. However, our investigations show that one must necessarily exercise caution when adopting the methodology proposed by R&V. Our findings that contradict the conclusions in R&V's studies are summarized as follows:

1. The configurations obtained by R&V's approach show no significant superiority over those obtained using Smart's optimum TPR method.
2. Euler simulations from our studies demonstrate that two-dimensionality effects solely do not lead to a violation of the shock-on-lip condition.

Despite these observations, we concur with R&V that the design configuration will not satisfy the shock-on-lip condition when realistic viscous flows are considered and a viscous correction similar to that proposed by R&V would then be necessary. Nevertheless, we believe that their proposed linear correction (see Sec. IV C in the original work[1]) must be revised in the wake of the present investigations that conclusively demonstrate that the violation of the shock-on-lip condition is largely due to viscous effects.

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DATA AVAILABILITY

The data that support the findings of this study are available within this article.

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