# Readers' Forum

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## Comment on "Turbulent Flow Analysis of Erosive Burning of Cylindrical Composite Solid Propellants"

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IN Ref 1, the authors have proposed an entrance-region-flow-like model for erosive burning in solid propellant rockets. The developing flow region is modeled as a potential core bounded by viscous boundary layers (transpired) that are in turn bounded by the decomposing solid propellant. The viscous boundary layers are treated with parabolized equations of change and a two-equation ($K$, $\epsilon$) turbulence model. Transition from developing to fully developed flow states is unified by employing integral momentum and continuity relations. The latter *methodology* is innovative; the results of Campbell and Slattery[2] suggest it is also effective. However, the results of other theoretical and experimental studies suggest that the developing portion of the flowfield does not fit the model.

Experiments by Yagodkin,[3] Dunlap et al.,[4] and Yamada et al.[5] have shown that for an undisturbed port flow a) there is no potential core (the velocity profile has the inviscid, rotational character calculated by Culick[6]); b) turbulence forms near the centerline (from classic hydrodynamic instability[3,7,8]) and propagates outward toward the decomposing solid propellant; and c) the time mean axial velocity profile retains its inviscid, rotational character even though turbulence fills the port. Comparison of these results with the model of Ref. 1 shows that the irrotational core concept is invalid and the direction of turbulence propagation is wrong. Experiments by Huesman and Eckert[9] show that the flow eventually transitions into a fully developed turbulent flow. The criterion for this transition is roughly $\rho U_b D/\mu \sim 2230 + 55\ \rho v_w D/\mu$, which means that for fully developed flow $x/D > 14$ (Shiskov[10] gives $x/D \sim 20$). Consequently, the flowfield *may* contain four subdomains: (i) an initial laminar domain, (ii) a domain where turbulence is initiated near the centerline and spreads radially outward but does not interact with the propellant combustion phenomenon, (iii) a domain where turbulence interacts with the propellant combustion phenomena, and (iv) a fully developed turbulent flow domain. In domains (i)-(iii) the time mean velocity profile is roughly the rotational, inviscid profile of Culick.

If erosive burning is the result of a near surface turbulence/combustion interaction, there is no erosive burning until domain (iii). Moreover, the initial interaction will be by large scale turbulent surges. Matveev et al.[11] have shown that these *can* lead to negative erosive burning. Therefore, the disparity between the flow modeled by Ref. 1 and that revealed by cold flow experiments may be important to observing negative erosion (since this also appears to be a nonsteady phenomenon, the way the propellant response is time averaged would be crucial to success). Because the rotational, inviscid flow may persist until $x/D \sim 14$, the time mean axial velocity profile at the port exit may change substantially during the burn. Calculations for a nozzleless rocket motor by Glick and Orr[12] suggest that these profile effects can alter performance by roughly 10% relative to one-dimensional predictions.

It should be noted that theoretical work by Beddini[13] provides a more realistic model of the internal flow than that of Ref. 1.

In summary, theoretical and experimental studies suggest that the flow model proposed by Ref. 1 is incorrect in the developing flow region. These errors may impact both erosive burning phenomena and performance ($x/D < 20$).

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