Response to "The invalidity of a Mach probe model" [Phys. Plasmas 9, 1832 (2002)]

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Hutchinson gives a nice analysis of the (in)validity of Hudis and Lidsky's unmagnetized Mach probe theory.[1] We agree with his main assertions, which are that (1) a one-dimensional model is incapable of properly describing unmagnetized ion collection by a Mach probe and (2) any experimental agreement with theories based on Hudis and Lidsky should not be interpreted as physical validation of their model.

Therefore, even though our Mach probe measurements of ion flow speed V_i were checked against independent spectroscopic measurements, Eq. (A3) of our paper,[2]

$$V_i = \sqrt{\frac{T_e}{T_i}}\sqrt{\frac{T_e}{m_i}}\tanh^{-1} K, \tag{1}$$

where $K \equiv (I_{\text{upstream}} - I_{\text{downstream}})/(I_{\text{upstream}} + I_{\text{downstream}})$, should not be interpreted as a rigorously correct unmagnetized Mach probe model. Any agreement between Eq. (1) and independent measurement of V_i may be due to an arbitrary calibration factor being in the correct neighborhood (as Hutchinson suggests), but it also may be for other reasons not yet understood (e.g., geometric effects, etc.). Nevertheless, the fact that our independent spectroscopic measurements of V_i *do agree* reasonably well with Eq. (1) could be a useful piece of empirical information for future studies of the unmagnetized Mach probe calibration problem. Unfortunately, we did not acquire enough Mach probe data to perform a rigorous study ourselves.

We also wish to emphasize that the central physics conclusions of our paper[2] remain unaffected, namely, that (1) local ion heating is identified and causally linked to the reconnection process, and (2) a significant portion of the ion heating energy source arises from nonclassical effects associated with reconnection. Our Mach probe measurements were verified against independent spectroscopic measurements. However, due to spatial resolution limitations, it is possible that the spectroscopic measurements underestimate V_i. If this is the case, then classical viscous heating due to ion flows would increase, but not enough to account for all of the heating. Therefore, nonclassical effects must still play an important role. This point is discussed in the original text of the paper[2] (last paragraph of Sec. V E).

[1] M. Hudis and L. M. Lidksy, J. Appl. Phys. **41**, 5011 (1970).
[2] S. C. Hsu, T. A. Carter, G. Fiksel, H. Ji, R. M. Kulsrud, and M. Yamada, Phys. Plasmas **8**, 1916 (2001).

