On the efficacy of imploding plasma liners for magnetized fusion target compression

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Abstract. A new theoretical model is formulated to study the idea of merging a spherical array of converging plasma jets to form a “plasma liner” that further converges to compress a magnetized plasma target to fusion conditions. [Y.C.F. Thio, et al., “Magnetized Target Fusion in a Spheroidal Geometry with Standoff Drivers,” Current Trends in International Fusion Research II, ed. E. Panarella, (National Research Council Canada, Ottawa, Canada 1999]. For a spherically convergent plasma liner shell with high initial Mach number \( M = \text{liner speed/sound speed} \) the rise in liner density goes as \( \rho \sim 1/r^2 \), for any constant adiabatic index \( \gamma = d\ln p/d\ln \rho \). Accordingly, spherical convergence amplifies the ram pressure of the liner on target by the factor \( A \sim C^2 \), indicating strong coupling to its radial convergence \( C = r_m/R \), where \( r_m(R) = \text{jet merging radius (compressed target radius)} \), and \( A = \text{compressed target pressure/initial liner ram pressure} \). DT plasma liners with initial velocity \( \sim 100 \text{ km/s} \) and \( \gamma = 5/3 \), need to be hypersonic \( M \sim 60 \) and thus cold in order to realize values of \( A \sim 10^4 \) necessary for target ignition. For optically thick DT liners, \( T < 2 \) eV, \( n > 10^{19} - 10^{20} \text{ cm}^{-3} \), black-body radiative cooling is appreciable and may counteract compressional heating during the later stages of the implosion. The fluid then behaves as if the adiabatic index were depressed below 5/3, which in turn means that the same amplification \( A = 1.6 \times 10^4 \) can be accomplished with a reduced initial Mach number \( M \sim 12.7(\gamma - 0.3)^{4.86} \), valid in the range \( 10 < M < 60 \). Analytical calculations indicate that the hydrodynamic efficiency for plasma liners produced with current jets is \( < 4\% \). A new similarity model for fusion \( \alpha \)-particle heating of the collapsed liner indicates that “spark” ignition of the DT liner fuel does not appear to be possible with low areal density \( (\rho R) \) magnetized fusion targets.