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Instabilities of a jet with stratification and magnetic field: interpretation via over-reflection of internal gravity waves

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The instability of jets in the presence of density stratification and magnetic fields is fundamental to understanding a wide range of geophysical and astrophysical phenomena. We investigate a paradigm problem of interest: the linear instability to three-dimensional disturbances of a plane parallel top-hat jet flow with aligned uniform field, for an incompressible, inviscid and perfectly conducting fluid. We focus on a vertically thin layer, and thus make the magneto-hydrostatic and Boussinesq approximations.

Due to the piecewise-constant flow, it is easy to solve this problem numerically for disturbances with periodicity in the along-flow and vertical directions. However, a plethora of unstable modes exist in the limit of large Froude number F, which successively cut-out as F is reduced. Here we show how these instabilities can be unambiguously understood in terms of the over-reflection of waves trapped in the jet core, and how the resulting growth rates can be predicted using simple physical arguments based upon wave dynamics (reflection and transmission coefficients, and the group speed). In the limit of no magnetic field, the trapped waves are internal gravity waves, and the unstable modes have growth rates of $O(F^{-2})$ for large F. However, in the more general case when the internal gravity waves are modified by a magnetic field, the growth rates are of $O(F^{-3})$ for large F. This stabilising effect can be explicitly traced back to the reduction in the transverse group speed of the internal gravity waves due to the presence of a magnetic field.