The stability of the pristine magnetopause
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*Planetary and Space Science, 2003*

A magnetohydrodynamic theory of combined Kelvin-Helmholtz (KH) and Rayleigh-Taylor (RT) instabilities for a transition layer with two different scale lengths ($\Delta$ and $\delta$ for the variation of velocity/magnetic fields and density, respectively) is presented. The study is motivated by reports of magnetopauses with no low latitude boundary layer, in which a sharp density drop over a distance $\delta \ll \Delta$ is observed (“pristine” magnetopauses (J. Geophys Res. 101 (1996) 49). The theory ignores compressibility effects and applies to subsonic regions of the dayside magnetopause. The RT effect is included to account for temporary periods of acceleration of the magnetopause, caused by sudden changes of the solar wind dynamic pressure. For small wavelengths $\lambda$, such that $\delta << \lambda << \Delta$, a WKB solution shows that the velocity gradient operates, together with magnetic tensions, to attenuate or even stabilize the Rayleigh-Taylor instability within a certain wavelength range. An exact dispersion relation for flute modes, valid for all $\lambda$, in the form of a fourth order polynomial for the complex frequency $\omega$, is obtained from a model with a constant velocity gradient, $dV/dy$ within $\Delta$, and with $\delta \rightarrow 0$. Flute modes are possible because of the existence of bands of very small magnetic shear on the dayside magnetopause (J. Geophys. Res. 103 (1998) 6703). The exact solution allows for a study of the change of the action of the velocity gradient with $\lambda$ from the long-$\lambda$ range where $dV/dy$ is KH destabilizing to the sort-$\lambda$ range where $dV/dy$ produces a stabilizing effect. Both, the WKB approximation and the well-known tangential discontinuity model ($\Delta \rightarrow 0$) are recovered as limiting cases of the exact solution. Properties of the KH and RT instabilities, for different density ratios on either side of the magnetopause, are described. For flute modes, at very small $\lambda$ the RT instability grows faster and becomes the dominant effect. However, it is shown that the growth rate remains bounded at a finite value as $\lambda \rightarrow 0$, when a theory with a finite $\delta$ model is considered. To study configurations with finite, arbitrary, $\delta/\Delta$ ratios, the MHD perturbation equations are solved numerically, using hyperbolic tangent functions for both the density and velocity transitions across the magnetopause. To examine the influence of different $\delta/\Delta$ ratios on the growth rates of KH and RT, calculations are performed for different $\delta/\Delta$, with and without acceleration, and for two different density ratios. It is found that the general features exhibited by the constant $dV/dy$ model are confirmed by these numerical solutions. The stability of pristine magnetopauses, and the possibility of observing some theoretical predictions during magnetopause crossing in ongoing missions, are discussed.