Departure from rigid co-rotation of plasma in Jupiter's dayside magnetosphere

R. L. McNutt, Jr, J. W. Belcher, J. D. Sullivan, F. Bagenal & H. S. Bridge

Center for Space Research, Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

The MIT plasma experiment on Voyager 1 shows that the plasma flow is not in strict co-rotation at distances greater than 10 jovian radii.

CO-ROTATION of the jovian magnetospheric plasma with the planet to some radial distance has been the basic assumption in all analyses of plasma dynamics in near Jupiter space[1]. Brice and Ioannidis[2] hypothesised that co-rotation should dominate convective motion in the entire magnetosphere. The MIT plasma experiment on the Voyager 1 spacecraft has made the first detailed *in situ* measurements of the low energy (10 eV to 5.95 keV) component of the jovian magnetospheric plasma[3]. The preliminary analysis of these measurements presented here shows departure of the plasma flow from strict co-rotation at radial distances greater than $\simeq 10$ jovian radii (R_J). Data used in this analysis were taken in the dayside jovian magnetosphere before the closest approach of the Voyager 1 spacecraft to the planet.

The experimental package consists of four modulated-grid Faraday cups[4]. Three of these form the main sensor cluster and the fourth, or side sensor, is mounted perpendicular to the symmetry axis of this cluster. During that part of the inbound leg of the Voyager 1 encounter which concerns us here, the cluster symmetry axis looks away from Jupiter and towards the Earth while the side sensor looks roughly into the direction of co-rotating plasma flow. In the positive ion mode, the experiment measures currents in both a low resolution mode (the L mode) with ~29% resolution in energy per charge and a high resolution mode (the M mode) with ~3.6% resolution in energy per charge. One L mode spectrum is obtained every 96 s and one full M mode spectrum every 192 s.

We have analysed low resolution mode spectra inbound from 12.00 UT, 4 March, 1979 (22.6 R_J) to 02.00 UT, 5 March, 1979 (11.4 R_J). By virtue of its wider energy-per-charge channels, the L mode has a higher signal-to-noise ratio than the *M* mode and gives better quality measurements for the protons in the data set considered. The L mode measurements in the side sensor frequently show good separation between the proton peak and that of the heavy ion constituents although the latter are, in general, unresolved (see Fig. 3 of ref. 3). As long as the plasma is cold (greater than mach 2) and flows directly into the side sensor, the response function[5] of the side sensor can be taken as unity to about 5% accuracy. Under this assumption, we have fit two convected, isotropic maxwellians to the side sensor L mode spectra, one to the protons and one to the heavy ions. In general, this provides a good representation of the data. The fit is poor if the mach number becomes so low that the two peaks strongly overlap or sufficiently high that the multi-component nature of the heavy ions begins to appear. Such fits are not presented here.

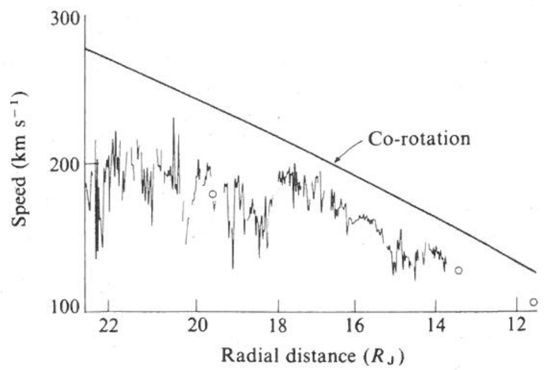

Fig. 1 Upper limit on the component of bulk plasma velocity into the side sensor versus radial distance.

A more realistic response function for the side sensor is (S. Olbert, personal communication)

$$\exp(-\alpha u_t^2/u_p^2)$$

where α is a constant of order unity, u_t is the ion velocity transverse to the cup normal and u_p is the ion velocity parallel to the cup normal. It can be shown by convolving this response function with a convected, isotropic maxwellian that maxwellian fits assuming unit response always overestimate the plasma bulk speed into the side sensor. The error increases with decreasing mach number of the flow and to a lesser extent with increasing component of plasma bulk velocity transverse to the cup normal. Thus, the speeds we derive from such fits should be taken only as upper limits on the component of plasma bulk velocity into the side sensor.

In Fig. 1, the solid line is the predicted component of rigid co-rotation velocity into the side sensor. The time period covered is that mentioned above with the radial distance of the spacecraft from Jupiter shown along the abscissa. We also plot the component of bulk velocity of the protons into the side sensor, as derived from the analysis described above. Gaps in the data trace appear where the fit is poor. The three circles represent proton measurements from three individual M mode spectra. During this time period, these M mode spectra are somewhat anomalous in that the protons exhibited a strong M mode signal. The spectra give proton and heavy ion bulk speeds consistent with the more numerous L mode measurements; they also show conclusively that the observed departure from co-rotation is not a spacecraft charging effect[6].

We stress that the plotted quantity is an upper limit. The present analysis is highly dependent on mach number which varies for these spectra between 1 and 4. Hence, structure in the curve should not be overinterpreted. The derived upper limits on the proton bulk speed into the side sensor lie consistently below the value expected for rigid co-rotation in the range from 11 to 22 R_J. We intend to do a more complete analysis of this data set, incorporating data from the main sensor and using the detailed response functions of all sensors. Construction of the full vector velocity of the plasma may then be possible for this magnetospheric region.

We thank S. Olbert and A. J. Lazarus for useful comments. This work was supported in part by NASA contract 953733.

Received 27 June; accepted 11 July 1979.

1. Kennel, C. F. & Coroniti, F. V. *A. Rev. astr. Astrophys.* **15,** 389–436 (1977).
2. Brice, N. M. & Ioannidis, G. A. *Icarus* **13,** 173–183 (1970).
3. Bridge, H. S. *et al. Science* **204,** 987–991 (1979).
4. Bridge, H. S. *et al. Space Sci. Rev.* **21,** 259–287 (1977).
5. Vasyliunas, V. M. in *Plasma Physics* (Lovbergs, R. H. ed.) Vol. 9B, 49–88 (Academic, New York, 1971).
6. Sullivan, J. D. & Bagenal, F. *Nature* **280,** 798–799 (1979).

0028–0836/79/350803—01$01.00