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Introduction

The purpose of this grant was first to develop solar wind shock models with tensor plasma pressure and then to compare some of the shock models with the satellite data from Pioneer 6 through Pioneer 9.

The results have been described in two renewal proposals, (May, 1971 and June, 1973) and in four semi-annual status reports. This final technical report is submitted in lieu of recent semi-annual status reports.

Theoretically we found difficulties with non-turbulent fluid shock models for tensor pressure plasmas. For microscopic shock theories nonlinear growth caused by plasma instabilities has frequently not clearly been demonstrated to lead to the formation of a shock. As a result no clear choice for a shock model for the bow shock or interplanetary tensor pressure shocks emerged. Hence, we decided to look at actual data across interplanetary shocks. We did find that further theoretical work on shock normals was necessary since the available procedures did not offer sufficient accuracy. In the course of our research we did look at Lepping and Argentino's method[1] for determination of more accurate shock normals but decided not to use their method. First we were interested in looking for a simpler procedure where hopefully the shock normal is given by a triple vector product. Second we could not use their subset of shock conditions for the tensor pressure case without a better knowledge of the electron and helium pressure than we expected to have.

When we looked at the plasma probe data and calculated plasma parameters, no calculation of the tensor pressure components had been done for our times of interest. Furthermore, none could be done for Pioneer 6 and 7 because of the expense at that time (June, 1971). Hence we found some shocks and analyzed them using MHD shock conditions. We showed that

(1) shocks were observed by the Ames plasma probe,

(2) the magnetic coplanarity shock normal is often inaccurate unless additional information is used,

(3) apparently some of the events identified by Taylor did not exhibit the classic shock structure where he used magnetic coplanarity as the criteria of choice,

(4) the agreement of the data with the MHD shock conditions can be greatly improved if certain vectors that appear in shock normals are selected to be perpendicular by varying the time span of the data,

(5) and the sensitivity of the shock normals and MHD jump conditions to the time span of the data chosen on both sides of the shock suggests that the method of averaging the fluctuations may be important.

The shock events identified on Pioneer 8 and 9 could not be checked for tensor pressure since the data analysis was not performed at Ames Research Center. Our inability to obtain this data has been very frustrating but we may be able to find some Vela data at Los Alamos suitable for analysis. Naturally we could not do part of the project proposed without this data.

Discussion of Research

Theoretical Analysis

We first tried to check existing theories for shocks with tensor or anisotropic pressure (temperature) that could apply to the earth's bow shock or to interplanetary shocks in the solar winds.

The theories were either fluid theories of which the Chew-Goldberger-Low[2] (CGL) model was the principal example or microscopic plasma models where certain instabilities were postulated for the dissipative mechanisms. The latter are of more recent origin and can only be shown to exhibit shocks by computer models with the present formalisms. The microscopic plasma models are useful if the dissipative mechanism is being studied and details of the shock structure (such as seen in bow shock crossings) are desired. The derivation of hyperbolic fluid equations in the conservation form from these theories whose solutions obey the evolutionary conditions has not been done rigorously for most of the microscopic mechanisms.

The fluid models we checked are variations of the CGL equations. These were Lynn's shock model[3], the Morioka and

Spreiter[4] calculations for perpendicular and parallel magnetic fields (direction is with respect to shock front normal) and the polytrope models. Lynn's model was intended to be valid only for very weak shocks and was therefore not applicable to the earth's bow shock or most interplanetary shocks. In addition his requirement of magnetic moment conservation through the shock was not consistent with the magnetic field parallel to the shock front for the CGL equations since the uncoupled energy equations gave a sufficient number of equations. The condition was consistent with the normal magnetic field case.

The Morioka and Spreiter shock model did not appear to agree with the bow shock results of December 16, 1965 as seen by Pioneer 6.[5] The parallel temperature ($T_{||}$) for the magnetic field perpendicular to the shock normal was not conserved as expected across the shock front according to the data. However, the determination of $T_{||}$ is difficult particularly behind the bow shock. Also the bow shock at this crossing was not exactly a perpendicular shock. Nevertheless, one expects that plasma turbulence coupled the parallel and perpendicular energy fluxes and hence changed $T_{||}$ across the shock.

The polytrope modifications of the CGL equations[6] were used for perpendicular shocks but $T_{||}$ across the shock.

The polytrope modifications of the CGL equations[6] were used for perpendicular shocks but $T_{||}$ decreased rather than increased across the shock as expected. All the above theoretical analysis led us to suspect that plasma turbulence must be considered for most interplanetary shocks and the probability of their being laminar shocks is small. However, we did not begin to calculate dissipative mechanisms for turbulent shocks because the list of possibilities seemed so large and would entail years of study. Gary[7] has done a number of calculations for perpendicular shocks which would be interesting to compare with interplanetary shock data.

We decided to check the satellite data for a hint of possible shock mechanisms. Since only isotropic pressure data was available we concentrated on comparing satellite data with the MHD shock jump conditions. The basic idea was to check the agreement of the data with the MHD shock conditions first and then explain any discrepancies.

However, the accurate determination of the shock surface normal turned out to be more difficult than expected. Mihalov et al.[5] had first pointed out the discrepancies in the shock normal results in the paper on the Pioneer 6, December 16, 1965 bow shock crossing. They attributed the errors in the magnetic coplanarity shock normal to errors in the magnetic field data behind the bow shock. Then we derived an expression for the shock normal of a stationary bow shock where only the magnetic field ahead of the shock was used. In addition, another source of error in the magnetic coplanarity shock normal is the small angle between the magnetic field ahead of and behind the shock. The error in the angle can frequently be as large as the angle itself or the shock direction is very inaccurate.

A general method for finding shock normals using plasma and magnetic field data for MHD shocks and triple vector products was found and a paper[8] published in the Journal of Geophysical Research on that subject. The advantage of some mixed data expressions is that the angles between the vectors are 90° or close to it theoretically. Hence, the effects of errors in the data are minimized. Also additional criteria for recognizing a good fit of the data to theory are available because certain vectors from plasma and magnetic field data must be mutually perpendicular.

Data Analysis

Laboratory Data

First we took some of Paul's[9] laboratory data on cylindrical, perpendicular shocks. They measured only isotropic temperatures but we tried to check possible values of γ, the gas constant as a possible hint for polytrope indices. For his data $\gamma = 5/3$ seemed the best fit though small errors caused large changes in the results. On the other hand Kornherr[10] found $\gamma = 2$ a better fit for ions in higher β shocks. There had been a long controversy about the proper choice of γ for the bow shock. This calculation was not published because the spread in the results was too great to give a definitive result for γ. However, since the laboratory data was more accurate than space data, a good guess for γ was more likely to be made from laboratory data.

Bow Shock

We already mentioned the Pioneer 6 bow shock data for the December 16, 1965 crossing. We calculated different shock normals and found improvement using some mixed data shock normals as compared to other shock normals used.

Interplanetary Shocks

Our main project was the detection and analysis of interplanetary shocks from Pioneer 6 and 7 satellite data. We used data from the Ames Research Center plasma probe of Dr. John Wolfe's group and the Goddard Space Flight Center magnetometer of Dr. Norman Ness. The events were identified by using a paper by Taylor[11] who identified shocks seen by IMP1 during this period using magnetometer data.
Dr. J. Feynman suggested we use Taylor's paper. Allowing for expected time lags, we checked the original NASA data books for computer runs of the 7-minute full flux mode scan. A hiatus in the plotted data frequently occurred because any sharp jump in current flux from one 50 second sector to the next caused the computer to reject the data because of a time aliasing criteria. Since shocks usually pass by in less than 50 seconds and the current jump is from 2 - 4 fold, only by looking at the current fluxes observed in the instrument could the shocks be identified. Later Dr. John Mihalov in Dr. John Wolfe's group did special 50 second computer calculations of the maximum flux mode through the shock.

Six events were originally identified and a seventh one on January 7, 1966 was later identified but not analyzed. Only fast shocks were searched for and it is dubious that slow shocks could be identified given the computer errors. The dates of the events were December 18, 1965 and January 21, 1966 for the Pioneer 6, August 29, 1966, August 30, 1966, September 19, 1966 and September 23, 1966 for the Pioneer 7 events. Most of the events appear to be the same event seen by Taylor using the time lags. Three of the six events do not exhibit the classic sharp jump in density and flow velocity expected. These may be nonlinear waves in the process of steepening as suggested by Chao[12]. The magnetic field magnitude for the August 30, 1966 event on Pioneer 7 resembles a solitary wave.

The method of analysis and results are discussed in a preprint[13]. These are given in summary form here. The events were assumed to be fast magnetohydrodynamic (MHD) shocks since only scalar pressure was measured. No electron data was available. Hence, the normal momentum and energy flux conservation equations for the Rankine-Hugoniot equations were not considered because the electron temperature must be known to determine the total pressure.

The events were tested by first calculating shock normals and then by fitting the proton and magnetic field data ahead and behind the shock to the Rankine-Hugoniot jump conditions. Six shock normals were used. The two spacecraft shock normal did not give very good agreement of data with theory for any of the events probably because the interplanetary shocks bent as they passed the earth's bow shock and magnetosphere. For the December 18, 1965 shock the two spacecraft were really too close together for good time resolution.

The velocity coplanarity shock normal is only approximate except for perpendicular shocks and as expected did not give results for the data that agreed well with the theory.

Three mixed data shock normals were used where both magnetic and proton data were used. These gave the best agreement between data and theory. The magnetic coplanarity shock normal was expected to be inaccurate because the angle between the magnetic field vectors ahead of and behind the shock was small leading to large errors in their vector product.

Median averages of all quantities except the density were taken on both sides of the shock. Medians rather means were used because they tend to give better statistical results. The usual period for averaging was 8-10 minutes where shorter periods of time gave worse results.

The results are given in tables I - VI in ref. 13. Two shocks are nearly perpendicular. Two events that did not appear to be classic shocks do not give the proper Mach number ahead and behind the discontinuity for a fast shock. One event is not included as it did not appear to be a shock at all. All events are quasi-perpendicular (that is the angle between the magnetic field and calculated shock normal is greater than 50°.

All the computer results are not given because they are lengthy. However, the August 29, 1966 shock normals (Table IV) are given because many others have calculated shock normals for this event. Our mixed data shock normal 3 differs by only 10° from the statistical result found by Lepping and Argentino.

For the December 18, 1965 low Mach number, nearly perpendicular, laminar shock the theoretical predictions for the angles between data vectors are quite closely obeyed for the vectors going into the mixed data shock normals.

Pioneer 8 and 9 Tensor Pressure Shocks

We obtained Ames proton bulk processor data from the National Data Center for Pioneer 8 and 9 satellites. Seven events of the classic shock form were identified. Plasma parameters with scalar pressure were calculated by Dr. John Mihalov for two of the most promising shocks.

We have not been able to complete the intended aim of the grant, especially that for the second renewal, because the data analysis for the shocks with tensor pressure was never done at Ames Research Center. Dr. John Wolfe finally said that it would be too expensive. Dr. Larry Kavanaugh and our interim technical advisor Dr. Frederick Berko both tried to obtain the analyzed data but they were unsuccessful. The lack of tensor pressure data has been very disappointing.

References

1. R.P. Lepping and P.D. Argentino, J. Geophys. Res. 76, 4349 (1971).
2. G.F. Chew, M.D. Goldberger and F.E. Low, Proc. Roy. Soc. 236, 112 (1956).
3. Y.M. Lynn, Phys. Fluids 10, 2278 (1967).
4. S. Morioka and J.R. Spreiter, J. Plasma Phys. 2, 449 (1968).
5. J.D. Mihalov, C.P. Sonett and J.H. Wolfe, J. Plasma Phys. 3, 449 (1969).
6. B. Abraham-Shrauner, Plasma Phys. 15, 375 (1973).
7. S.P. Gary, J. Plasma Phys. 4, 753 (1970); 6, 551 (1971); and 7, 417 (1972).
8. B. Abraham-Shrauner, J. Geophys. Res. 77, 730 (1972).
9. J.W.M. Paul, ERSIN Study Group on Collision-Free Shocks in Laboratory and Space, Frascati, (June, 1969).
10. M. Kornherr, Z. Physik 237, 37 (1970).
11. H.E. Taylor, Solar Phys. 6, 320 (1969).
12. J.K. Chao, J. Geophys. Res. 78, 5411 (1973).
13. B. Abraham-Shrauner and S.H. Yun, "Interplanetary shocks seen by Ames plasma probe on Pioneer 6 and 7", J. Geophys. Res. (submitted for publication)

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Papers

Barbara Abraham-Shrauner, "Determination of Magnetohydrodynamic Shock Normals", J. Geophys. Research, 77, 736 (1972).

Barbara Abraham-Shrauner, "Interplanetary Shocks observed on Pioneer 6 and 7 by Ames plasma probe", AGU annual Spring meeting, Supplementary program p. 42, June, 1975.

Barbara Abraham-Shrauner and Seh-Hoon Yun, "Interplanetary shocks seen by Ames plasma probe on Pioneer 6 and 7", J. Geophys. Res. (submitted for publication).