N85-22479

SPACECRAFT-ENVIRONMENT INTERACTION - THE ENVIRONMENTAL PLASMA ASPECT

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The knowledge and understanding of the interactions between an "obstacle" and a space plasma are fundamental to space plasma physics and are essential to space plasma diagnostics, in-situ data interpretation, and spacecraft charging. The obstacle can be a natural body moving in the solar system (i.e., a planet or a moon) or an artificial obstacle (i.e., a spacecraft orbiting the Earth or any other planet or moon). Artificial obstacles consist of rockets, satellites, space shuttle, space station, etc.

The effects involved in the interaction between an obstacle and a space plasma can be divided into

(1) Effects on the obstacle itself (i.e., its charging)

(2) Effects on the environmental plasma due to the motion of the obstacle (i.e., the creation of shocks ahead of the obstacle and complicated wakes behind the obstacle). In the wake (or antisolar direction), plasma oscillations are excited and instabilities, wave-particle interactions, turbulence, etc., are believed to take place.

The effects on the obstacle and on the environmental space plasma are coupled. Hence, simultaneous solutions to the Vlasov (or Boltzmann) and Poisson equations are sought. To obtain realistic solutions of practical use, three-dimensional and time-dependent models of the interaction are needed. Achieving the latter is indeed not simple.

The point should be made that experimental and theoretical work of practical interest (e.g., in low Earth orbit) can serve as model-experiments of a wider scope of interest and importance in space plasma physics and in astrophysics (e.g., Falthammar (1974), Samir and Stone (1980), and Podgorny and Andrijanov (1978)). This will, of course, require the use of qualitative scaling (Falthammar (1974) and Samir and Stone (1980)).

EXPERIMENTAL AND THEORETICAL THERMAL PLASMA RESULTS - STATUS REPORT

In-situ experimental results regarding the distribution of low-energy ions and electrons around ionospheric satellites in the altitude range $250<H<3000$ km are available in the open literature. For recent brief review papers on this

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subject we cite Samir (1981) and Samir and Stone (1980). Unfortunately, most of these results are limited to the very near vicinity of the satellite since most of the relevant measurements were made by probes flush mounted on the surface of the satellite. Although significant results were obtained which enhanced our knowledge and understanding of the interaction, more extensive spatial regions ahead and behind the satellite have to be researched.

In-situ results were compared with the theoretical models of Gurevich et al. (1970), Parker (1976), and Call (1969). Results of such comparisons are given in Samir and Fontheim (1981), Samir (1981), and Samir and Stone (1980). It is our understanding that studies along similar lines are now being performed by the S-CUBED group (Parks et al. (1983)). The main conclusion from these studies is that except for specific cases there is no quantitative agreement between theory and experiment for unmanned, low-altitude, small ionospheric satellites. The recent results from the space shuttle mission STS-3/Columbia known to the author have not, unfortunately, yielded thermal plasma information which can be used in a meaningful theory-experiment comparison. It is possible that the wave data (Shawhan and Murphy (1983)) may yield new relevant information.

More recently the distribution of H^+ and He^+ ions around the DE-A magnetospheric satellite at $H \approx (1, 4\text{-}3)R_E$ (R_E = radius of the Earth) have been examined (Samir, Comfort, and Chappell (1983)). This study extends the range of plasma parameters vis-a-vis earlier studies and is expected to be useful in magnetospheric physics and astrophysics. The wake of an auroral sounding rocket in the altitude range 120 to 320 km was studied by Bering (1983). The comments made in this paper should be of interest and direct relevance to the interpretation of parallel electric field measurements at low altitudes.

Effects involved in the charging aspect of the interaction were studied extensively in situ and in the laboratory. A large effort was also devoted to theoretical modeling. Recent review papers regarding this aspect of the interaction were published by Whipple (1981) and Garrett (1981) and will not be further discussed here. One point should, however, be made, namely, that in order to get realistic solutions for ϕ from $\Sigma I = 0$, the distribution of charge around a spacecraft has to be reliably known. This includes time-dependent effects, wave-particle interactions, instabilities, and turbulence.

To overcome the limitation mentioned above, where measurements are restricted to the very near vicinity of the spacecraft, multibody systems or multiprobe systems are needed. Mother-daughter concepts as well as shuttle-tether systems are applicable (Samir and Stone (1980) and Williamson et al. (1982)). The first time a multibody system was used to perform wake measurements was in the Gemini-Agena 10 mission (Troy et al. (1970)). The recent measurements of the thermal plasma environment of the STS-3/Columbia shuttle mission (Raitt et al. (1983)) yielded initial results some of which are in general accord with measurements and predictions obtained earlier from unmanned ionospheric satellites. Raitt et al. (1983) concludes that "thermal plasma probes mounted on the space shuttle orbiter are not a very good arrangement to obtain measurements of the ambient ionospheric thermal plasma." This conclusion is not surprising and indicates that, in order to study the interaction of a spacecraft with its environment, multibody systems are needed.

In addition to in-situ data, there are laboratory measurements which are directly relevant to spacecraft-environment interaction. In Stone (1981a,b) and Stone and Samir (1981), available results for thermal plasmas are reviewed. In Intriligator and Steele (1982, 1983), similar studies were performed for high-energy beams and an attempt was made to apply them to the Venusian wake. Other relevant comments are given in Eselevich (1983).

EXPANSION OF A PLASMA INTO A VACUUM

In a recent review paper (Samir et al. (1983)) the interaction between an obstacle and a rarefied space plasma was examined versus the phenomena and physical processes involved in the expansion of a plasma into a vacuum. This is a new approach based on theoretical and experimental work done in fusion research. Briefly, the basic processes involved in the expansion are (1) the propagation of a rarefaction wave into the unperturbed or ambient plasma and the existence of jump discontinuities (Gurevich and Meshcherkin (1981a)) at the front of the rarefaction wave, (2) the acceleration of ions to high velocities (i.e., to velocities reaching the order of the electron thermal speed in the ambient plasma) by the transfer of energy from the infinite reservoir of ambient thermal electrons, (3) the existence of an ion front, and (4) the excitation of plasma oscillations and instabilities over several spatial locations in the vacuum region. The intensity of these processes depends on the specific ionic constituents and their relative concentrations in the ambient plasma (Gurevich et al. (1973) and Singh and Schunk (1982, 1983)), as well as on the ambient electron temperature, the normalized characteristics length, and the nature of the density gradient at the plasma-vacuum interface. Theoretical results showing the distribution of ions, electrons, and electric fields in the vacuum region are given in Gurevich and Pitaevsky (1975), Gurevich and Meshcherkin (1981b)), and Singh and Schunk (1982, 1983).

The point to be made is that the wake behind an obstacle can be approximated by a vacuum region into which the ambient plasma expands. Intriligator (1983) suggests that structural patterns similar to those predicted in the plasma-expansion (Samir et al. (1983)) may exist in the Venusian wake.

REMARKS AND CONCLUSIONS

(1) Despite the fact that the interaction between a spacecraft and its environmental plasma is of fundamental interest and importance to science and technology alike, relatively few experimental results are available at the present time. This is particularly so for the angular distribution of charge and potential around a spacecraft orbiting the Earth.

(2) Reliable phenomenological knowledge and in-depth physical understanding of the structure of the close and far regions surrounding a spacecraft are needed in order to test models describing the entire interaction.

(3) To achieve the above objective, well-conceived in-situ and laboratory experiments are needed. Such experiments cannot be byproducts of geophysical measurements only.

(4) Future in-situ measurements can best be performed by using multibody and multiprobe systems. The space shuttle with its capability of ejecting and capturing small satellites is a suitable space platform for such investigations. Another facility adequate for performing relevant experiments is the shuttle-tether system. Numerous combinations exist by which very meaningful scientific and technological experiments can be performed by using the space shuttle (or any other large space platform) and ejectable multiprobe systems.

(5) By adopting a wider scientific viewpoint and considering the phenomena involved in the expansion of a plasma into a vacuum, an attempt can be made to preceed toward a UNIFIED perception of the interaction between an obstacle and a space plasma.

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