THE NATURE OF STREAM-STREAM INTERACTION IN THE LARGE-SCALE STRUCTURE OF THE SOLAR WIND

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ABSTRACT The stream-stream interaction between a slow solar wind and its leading faster solar wind is considered. A hydrodynamic model comprising double-layered rarefactions and recompressions is proposed toward understanding the observed large-scale structure near the trailing portion of a high-speed stream.

This paper considers the problem of solar wind stream-stream interaction, and introduces additional discussions concerning the interpretation of the quasistatic large-scale solar wind structure.

It is now well inferred from near-earth direct monitoring measurements that, over several consecutive rotations of the sun the solar wind, at times, may possess a near-stable corotating structure. Longitudinal and, to a much lesser extent, latitudinal variations in the solar wind strength appear to be the basic cause. Geomagnetic disturbances often exhibit periodicities, some of which implicate a clear association with solar rotation. Long sequences of the stronger among these—the recurrent storms—were first attributed to the so-called *M* regions on the solar surface by *Bartels* [1932]. His view, which incorporates quasipermanent narrow beams of corpuscular radiation, was long held although observational identifications of these regions were lacking. *Dessler and Fejer* [1963] reconsidered this view and proposed that these storms are generated by corotating nonuniformities resulting from the interaction between a slow-wind region and an overtaking-wind region. *Razdan et al.* [1965] examined their model hypothesis and showed that the basic idea is hydrodynamically viable with respect to the expected implications at 1 AU.

The general premise of regarding longitudinal gradients in solar wind strength near the sun responsible for the corotating wind variations in the interplanetary region is very reasonable. In addition, the particular picture of one steady wind overtaking another appears to provide useful clues to the dynamical complexities near the leading portion of a high speed stream. Here, the key ideas of a solar wind interface (tangential discontinuity) and accompanying compressions, bounded by perhaps two shock waves, go far toward giving overall interpretations to many observations, as discussed by Dr. Davis in his presentation yesterday.

Phenomena related to the trailing portion of a strong wind have not received adequate considerations in the literature. *Sarabhai* [1963] thought that the decrease in velocity results in the formation of a cavity, or region of reduced density, behind the *M* region beam. Although the suggestion is inherently interesting, it is actually difficult to see how the model is arrived at through his given hydrodynamic arguments. We would like to reopen the discussion and try to indicate a different model concept for limited considerations in the following.

The question is raised: what appropriate hydrodynamic structures may connect two steady solar winds, departing from each other? If we allow ourselves the luxury of disregarding the secondary nonradial motions generated in the context of corotating interactions viewed in the solar equatorial plane, then the problem is grossly similar to its sister problem in the context of spherical flow in which a fast steady expanding flow pulls away from a trailing slow steady expanding flow. Here, one is easily tempted to argue that a more or less simple and smooth rarefaction region would be created, a conclusion generally associated with experiences with laboratory planar flows. However, the conditions of the

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solar wind are sufficiently different to warrant separate considerations for this type of stream-stream interaction. It is interesting to point out that there exist classes of hydrodynamic solutions to the spherical problem mentioned above [*Lee,* to be published]. They correspond to specific model assumptions made on the solar winds: invariant mass flow rate per steradian and invariant streaming and sound velocities. Not all of these have been scrutinized and cataloged, but one has sufficient bearing on our present consideration that a qualitative description of its main features may shed some light on the original problem.

When a fast wind moves ahead, leaving a trailing slow wind behind, it tends to expand inward on account of its inherent specific thermal energy density. At the same time, the slower wind left behind tends to expand outward. Thus rarefaction waves of respectively decelerative and accelerative nature are generated. First consider the drastic case where the separation of the two steady winds takes place at a sufficiently high relative velocity. Since the specific thermal energy densities for the two winds are both finite, the edges of the two expansion waves cannot meet, thus creating a vacuum. This sequence of wind-rarefaction-vacuum-rarefaction-wind would characterize the structure of the basic stream-stream "noninteraction." [The reader will find it interesting to compare this picture with *Sarabhai's,* 1963, picture.] Consider next the probably more realistic case where the relative separating velocity is less drastic so that the two rarefaction waves begin to interfere with each other. In figure 1, we have sketched the configuration of the total interaction as projected on the solar equitorial plane. Here, we consider the interference to be only moderate such that it is confined spatially to the regions to the two sides of the interface discontinuity (tangential discontinuity as shown). We note that the interference interaction is basically analogous to the leading edge interaction discussed earlier, except that the double-layered recompression here results from a collision between the expanded extensions of the two winds which, if it were not for compressibility, would depart from each other permanently. It follows that respectively inward-looking and outward-looking shock waves are expected in the flow. Thus the trailing-edge interaction may have a structure composed of regions of fast wind region-rarefied region (fast wind)-recompressed region (fast wind)-recompressed region (slow wind)-rarefied region (slow wind)-slow wind region. In this model picture, five flow discontinuities—two rarefaction fronts, two shock waves and an interface discontinuity—combine to give demarcations to the flow field.

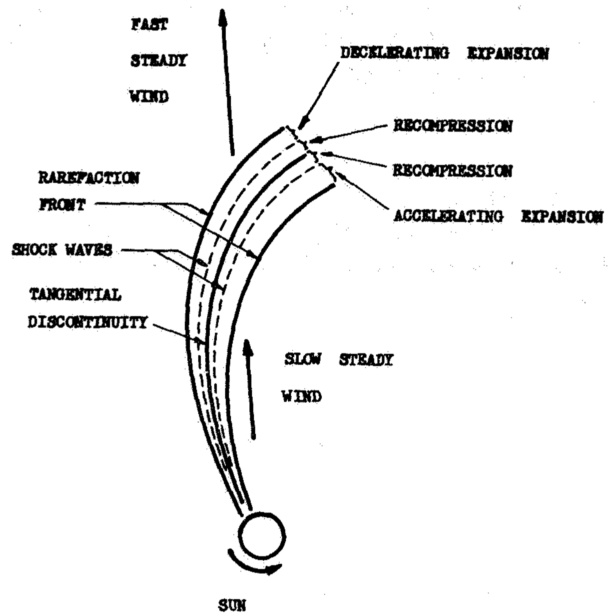

Figure 1. *Configuration of stream-stream interaction at the trailing portion of a fast steady wind. This wind and its following slow steady wind are joined through an assemblage of unsteady wave regions encompassing double-layered expansions and recompressions. The discontinuities comprise the sequence of rarefaction front – shock wave – tangential discontinuity – shock wave – rarefaction front.*

In the above, we have outlined the essential physical arguments for a specific class of stream-stream interaction. Depending on quantitative specifications on the two interacting solar winds, other possible modes of flow connections may be predicted. We refrain from discussing them here.

If the more complete view is taken that close to the sun the longitudinal strength of the solar wind varies alternately from strong to weak, to strong, and so forth, we should see, of course, leading-edge and trailing-edge types of stream-stream interaction. According to our discussions, plasma compression can be expected at both the leading and trailing portions of a stream. Thus, the mere presence of locally high density does not necessarily imply the arrival of any new enhanced "stream" or "beam." Here, we are being reminded that the occasional detections of density enhancement occur near the minimum of the corresponding time-profiles of the velocity, an interesting fact already observed by Dr. Smith in a comment following Dr. Wolfe's paper yesterday. Finally, the durations of density enhancements of both leading-edge and trailing-edge interactions are expected from our model considerations to be followed by high (by local comparisons) velocities in the solar wind, in good agreement with the usual observations.

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