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REPLY

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(NASA-TM-X-66041) [REPLY TO A PAPER ON THE USE OF TWO MAGNETOMETERS FOR MAGNETIC FIELD MEASUREMENTS ON A SPACECRAFT] N.F. Ness, et al (NASA) Sep. 1972 13 p CSCL 14B

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REPLY

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In the preceding discussion, Davis, Smith and Jones (DSJ) conduct a limited error analysis of the dual magnetometer method, attempting to justify the conclusion that a single magnetometer can meet almost all of the same goals: "... a continuous estimate of the spacecraft field and the unknown field in space". Certainly, philosophically, it must be stated that having data from two magnetometers can hardly be expected to lead to a less favorable position for data interpretation than with data from only one magnetometer. In this reply we will not re-derive or discuss the original paper by Ness et al. (1971) but only comment on the erroneous conclusions, inappropriate spacecraft field models, and improper error analysis which DSJ have made.

DSJ claim that the variance method has been demonstrated to be accurate to within 10% of the ambient field on the Pioneer 9 and Mariner 5 spacecraft. We are not able to fully assess these claims for the variance method, since no documentation has been published beyond the abstract by Davis and Smith (1968). In any event, DSJ reaffirm that it is necessary for the spacecraft field (or magnetometer zero level) to remain steady for a week or more for the variance method to be successful. Since the total fly-by time through the solar wind interaction region with Mercury is approximately 20 minutes, then it is clear that the variance method could not be used successfully during this planetary encounter, the most critical phase of the MVM '73 mission.

DSJ criticize our definition of the coupling matrix and claim that it does not have the characteristics we assume it to have. This is simply not true and apparently is due to their misunderstanding of our method and its definitions. We also suggested (not "claimed" as quoted by Davis et al.) that the method can be used on spin stabilized spacecraft. We are well aware of the advantage of spin stabilized spacecraft for accurately measuring the component of the magnetic field transverse to the spin axis (see review by Ness, 1970) and remark that our suggestion for its use on spin stabilized spacecraft was hardly a major feature of our initial suggestion. On the contrary, <u>the dual magnetometer concept was developed for those missions which are conducted with attitude stabilized spacecraft which have been constructed without an adequate magnetics control program</u>; <u>in fact, exactly the characteristics of the Mariner spacecraft series</u>.

DSJ then attempt to discuss the actual magnetic characteristics of spacecraft, considering only one spacecraft, Mariner 5, and present a diagram showing the magnitude of the equivalent dipole moments for each of the bay sections. They omit including or discussing the effects of the orientation of these magnetic moments and so their statement that a centered dipole model is a very poor approximation is not substantiated. It is necessary to know the orientation of the individual moments in order to compute the total spacecraft fields and to specify the radial distances at which the measurements (or predictions) are being made.

DSJ comment that solar panels are often significant magnetic sources. This is true on a few spacecraft, especially those with which they have experience. However, by properly designing and backwiring on solar array panels, it is possible to reduce the magnetic field from electrical currents to a minimum and by deperming the solar arrays (as is standardly done in many other spacecraft programs) the permanent magnetic field from the array can be effectively eliminated. Thus they do not always need to be considered as significant magnetic sources.

DSJ suggest that in those cases where the spacecraft field changes are of short duration, i.e., less than 1 week, special inflight tests should be conducted in which the change in the spacecraft field is obtained by averaging the observed changes over many test repetitions of the event. Again there is no documentation to substantiate this claim.

DSJ state that errors will occur in the use of roll maneuvers to check the spacecraft field and the coupling coefficient and these will be considerably larger than the uncertainty using the variance method. But this belief is not quantitatively substantiated.

DSJ claim that the coupling matrix is defined in several ways by Ness et al. (1971). Our definition of the coupling matrix is valid for the real MVM '73 spacecraft, even if the solar panels are taken into account, since the inboard magnetometer is at a greater distance from the center of the spacecraft than the outboard end of the solar panels. DSJ have problems in the diagonalization of the coupling matrix, but this is more apparent than real. They suggest that we have over formulated the problem but finally agree that the equation relating the spacecraft field at the two sensors is valid. The errors due to magnetometer zero offsets and incorrect coupling coefficients are adequately treated in the original publication by Ness et al. (1971).

The effect of high order monopoles is of prime interest and the claim by Davis et al. (1973) that the location of scientific and engineering subsystems near the periphery of the spacecraft (such as on Mariner 5) virtually assures significantly higher order magnetic moment fails to take into account the effect of the orientation of the magnetic moments or the radial distances involved.

Ness et al. (1971) proposed three methods for determining the coupling coefficients. DSJ fail to appreciate the value of multiple methods for determining the coupling coefficient: that is clearly to provide independent checks on the determination to obtain a realistic error estimate and hence a determination of the accuracy of the measurements of the ambient field.

DSJ then attempt to illustrate the adverse properties of the dual magnetometer method by conducting an error analysis based upon specific models of a spacecraft field, using dimensions relevant to the MVM '73 spacecraft. But no justification for the field sources utilized by them is given. They then show that for a limited range of their parameter S the dual magnetometer error is greater than the single magnetometer error. For a quantitative criterion they use the absolute value of the ratio of the errors of the dual magnetometer system to the single magnetometer.

This type of error analysis is a classic example of a problem which can arise in numerically evaluating mathematical formalae. The ratio of the errors becomes very large not because the dual magnetometer error increases without limit but because for certain unique combinations of the chosen parameters, the single magnetometer error goes to zero. Thus division by a very small quantity leads to a value of the ratio of the errors greater than unity.

Using the models presented by DSJ we show in Figure 1 the variation of the single (SM) and dual magnetometer (DM) errors separately, as a function of the parameter S, for the five models used by them. In all cases we also include an indication of the interval over which the absolute value of the ratio of the errors exceeds unity. The first feature evident from these individual error curves is that the slope of the dual magnetometer error is uniformly much smaller than that for the single magnetometer so that the errors are usually much less. Secondly, the fraction of the interval over which the ratio of errors exceeds unity is small and in some cases almost negligible (bottom right graph of Figure 1). Note that for those small intervals in which the SM errors exceed those of the DM, both errors are approaching zero, but at different rates and values of S depending upon the model chosen.

Thus, by presentation of an error analysis using a selection of special S/C models, limited parameter ranges and error ratios, a situation has been created which apparently casts the DM method in a less favorable light when compared with a SM.

It is not possible to correctly access the relative merits of the SM versus the DM by using the ratios of their errors only. What is important is the absolute magnitude of the error. Note that the error for the DM method is generally much smaller than that of the SM, except when both are approaching zero. Construction of pathological models with restricted parameter values which yield a smaller error for the SM is always possible. In contrast to DSJ we conclude that using the models they propose, the dual magnetometer method is clearly superior!

In their summary, DSJ note that we do not remark on the relation of the dual magnetometer technique to the conventional approach of using a magnetics control program and a long magnetometer boom to reduce the spacecraft field to tolerable levels. They ask the question "Do they intend to imply that under certain circumstances such magnetic requirements may be relaxed if dual magnetometers are used"?

We answer the question in the affirmative, Yes!. We developed the dual magnetometer method for specific application to spacecraft missions such as MVM '73, in which there would not be any magnetics control program nor a sufficiently long magnetometer boom to guaranteee reduction of the spacecraft field to an acceptable level. This concern was based upon the failure of both the experimenters and Project Offices at JPL for the Mariners 2, 4 and 5 spacecraft to negotiate, develop and implement a satisfactory magnetics control program. This is in contrast to all of our other flight experience in other spacecraft programs.

Indeed, we have pioneered the development of nonmagnetic fabrication methods and the methodology for effective realistic magnetics control programs working jointly with spacecraft engineers and project personnel in many spacecraft programs. We are sympathetic to the problems DSJ have had with the magnetic properties of the Mariner spacecraft and how that has restricted their ability to confidently analyze and interpret their data without an extensive program determining corrections to the data.

We have continued our analysis of the dual magnetometer method and its application to measurements on spacecraft. The studies of Neubauer (1972) and Neubauer and Schatten (1972) substantiate by detail study of models and measurements of spacecraft magnetic fields the gains obtained through use of the multiple magnetometer method on a spacecraft.

In summary our major points about the DSJ discussion are as follows:

1. The relative error (ratio of errors) is not sufficient to investigate properly the merits of the two magnetometer and the single magnetometer methods. It is too model dependent and one must investigate the errors of each method separately over a reasonable range of parameters in order to avoid the mathematical singularity of division by zero when computing the ratio.
2. There is no obvious correlation between the simplistic models of spacecraft fields presented by DSJ and the Mariner 5 spacecraft field. It is important to consider the orientation of individual subsystems magnetic moments, not only their magnitudes, and the radial distances at which the measurements (or predictions) are made.
3. Our studies (Neubuaer, 1972; Neubauer and Schatten, 1972) on spacecraft fields show that a centered dipole is in fact a good approximation at distances beyond two or three scale radii from the spacecraft.
4. The other comments in their discussion are in the nature of generalizations which do not hold up upon close inspection.

Some additional points which are relevant to future missions are:

1. The dual magnetometer system to be flown on MVM '73 is significantly less expensive in dollar cost than a number of other single magnetometer experiments which have flown on other missions.
2. Extremely long booms are not practical since alignment errors become unacceptably large and the impact on the dynamics of the S/C becomes considerable. Also the weight of a very long boom and associated cables becomes greater than that of a dual magnetometer system which requires only a modest length boom.

3. Beyond or closer to the sun than 1 AU, the physics of the interplanetary medium is not well enough understood to be highly confident in the variance method. This is especially important in outer planets missions.

4. Perming of the S/C during a close flyby of a planet with a strong magnetic field will present interpretive difficulties for a single magnetometer experiment using the variance method.

5. A dual magnetometer system also offers the valuable possibility of conducting cross-correlation analyses for signal detection enhancement (Ness, 1972).

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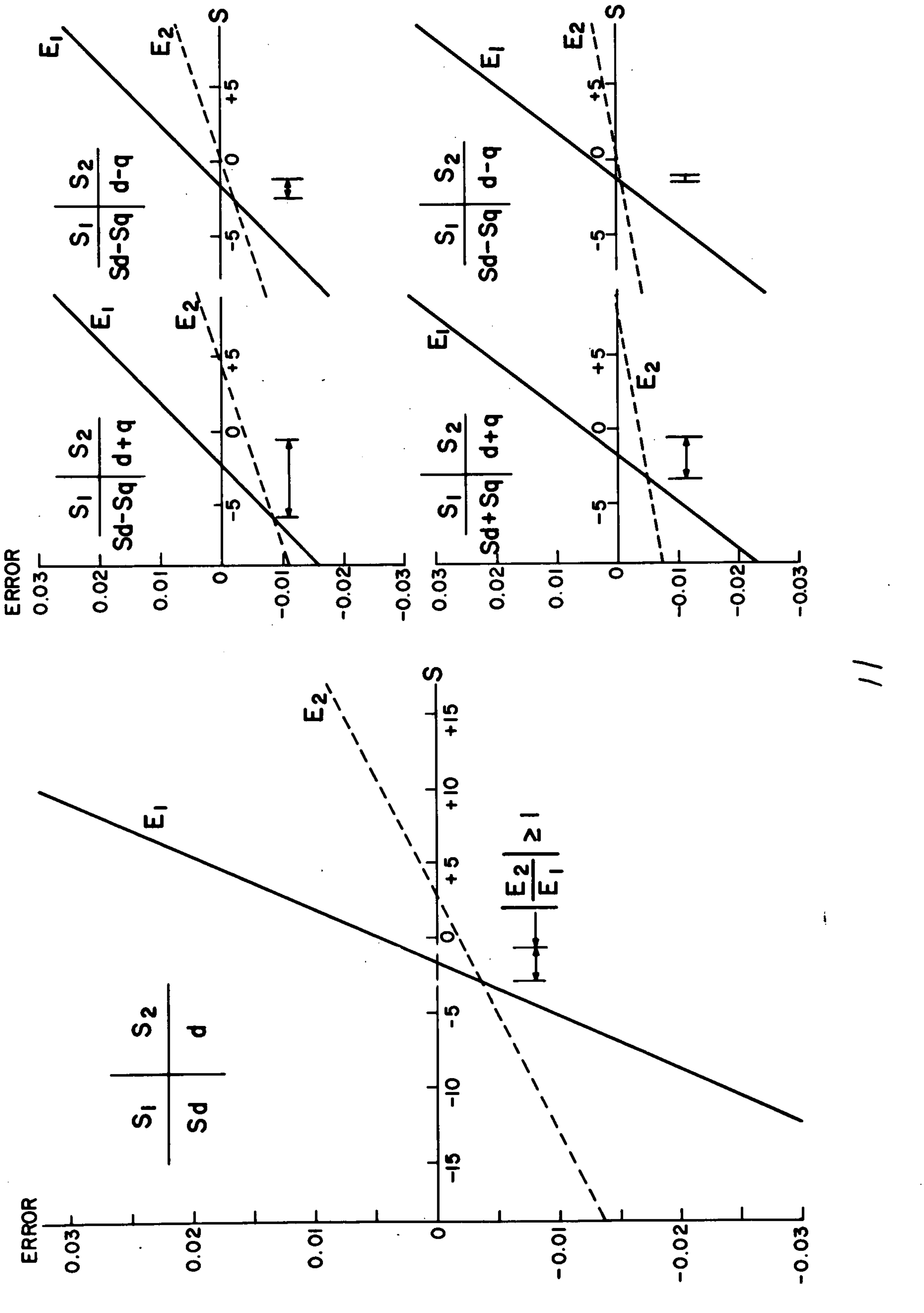
Figure Captions

1. Errors of measurements for DSJ spacecraft field models for single magnetometer (E_1) and dual magnetometer (E_2).



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