Technical Comments

Brief discussion of previous investigations in the aerospace sciences and technical comments on papers published in the Journal of Spacecraft and Rockets *are presented in this special department. Entries must be restricted to a maximum of 1000 words, or the equivalent of one* Journal *page including formulas and figures. A discussion will be published as quickly as possible after receipt of the manuscript. Neither the AIAA nor its editors are responsible for the opinions expressed by the correspondents. Authors will be invited to reply promptly.*

Comment on "Six-Degree-of-Freedom Entry Dispersion Analysis for the METEOR Recovery Module"

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THE paper by Desai et al.[1] leaves the reader with a misleading picture of previous analyses performed on the METEOR/COMET vehicle. Although the paper is well written and thorough in technical content, it contains inaccurate and inappropriate comments regarding the original AIAA paper on the subject by McCusker and Hill[2] and a Summerset et al. memorandum.[3] In the interest of fairness to the authors of those original works, they should be permitted an opportunity to comment.

The first of the aberrant comments presented in the Desai et al.[1] paper was that the original paper's landing dispersion results should be called into question because of the "incomplete" aerodynamic database utilized by Space Industries. The author later admits that the majority of the landing dispersions are due to exoatmospheric effects rather than to endoatmospheric effects. Indeed, the accuracy of the aerodynamics coefficients does not even rank as one of the top 20 dispersion contributors in the authors' Table 4. Furthermore, Space Industries' aerodynamics database was definitely not incomplete, as it was composed of all of the conventional static and dynamic stability coefficients and derivatives, in 5-deg-angle-of-attack increments, for 95 Mach numbers between 0 and 25. The accuracy of the aerodynamics coefficients is shown in both the original work and in the Desai et al. paper to not be a major factor, and neither paper should be considered suspect for its selection of aerodynamic coefficients.

The second issue with the paper is the omission of an important background fact, which sways the reader to improper conclusions regarding the original work. The root cause for the larger dispersion ellipse in the Desai et al. paper is that the assumed preflight preparations of the capsule were not as rigorous as those planned for the COMET mission. Thus, the newer METEOR work incorporated larger tolerances on most of the landing dispersions contributors, most notably the retro motor alignment, the looser pointing performance of the service module, and the capsule mass properties measurements. (Preflight measurements of the assembled METEOR vehicle showed that the motor-to-c.g. alignment tolerances of the original COMET paper had indeed been comfortably met and left adequate margin for the expected in-flight alignment dispersions.) The analysis technique and selection of dispersion contributors duplicated those in the original work and serve as a strong endorsement of the original paper. The Desai et al. paper states that its results are more conservative, implying that the original work by McCusker and Hill[2] and by Summerset[3] was not sufficiently conservative. The original dispersion analysis was realistic in the operational environment of the COMET program, where the rigorous preflight preparations were designed to ensure that those tolerances were met. The inputs of the original paper by McCusker and Hill would not be appropriate for the looser tolerances employed on the METEOR program several years later, and those of the new METEOR paper would not be appropriate for the original COMET mission. However, the same analysis method employed in the original paper is still appropriate, and it was indeed appropriate for the METEOR program to adopt it.

In summary, the original paper by McCusker and Hill[2] represented the most comprehensive re-entry dispersion analysis published in over 20 years, with a key innovation in the use of a Monte Carlo technique. Its analysis method and selection of variables were closely duplicated in the Desai et al.[1] paper. That paper increased tolerances on key dispersion contributors due to changes in preflight preparations and logically led to a larger dispersion ellipse. This fact should be much clearer in its Summary section.

The original COMET work presented by McCusker and Hill withstood rigorous scrutiny by numerous cognizant government organizations and their consultants over a two-year period. Most of this scrutiny was in the critical area of verifying that the tolerances on the dispersion contributors would be properly met, and the results presented in the original work are the product of that successful process.

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References

[1]Desai, P. N., Braun, R. D., Powell, R. W., Engelund, W. C., and Tartabini, P. V., "Six-Degree-of-Freedom Entry Dispersion Analysis for the METEOR Recovery Module," *Journal of Spacecraft and Rockets*, Vol. 34, No. 3, 1997, pp. 334–340.

[2]McCusker, T. J., and Hill, S. M., "Landing Dispersions for the Commercial Experiment Transporter Recovery System," AIAA Paper 93-3695, Aug. 1993.

[3]Summerset, T. K., McLain, M. G., and Sorge, M. E., "Comet Deorbit and Reentry Error Analysis," The Aerospace Corp., Contract F04701-88-C-0089, El Segundo, CA, Aug. 1992.

Reply by the Authors to T. McCusker

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IN response to the Technical Comment of McCusker regarding the findings of Ref. 1, the authors of the paper would like an opportunity to comment.

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No intent was made to degrade the results of the previous work of McCusker and Hill.[2] In fact, an attempt was made to avoid any statements that would imply such a viewpoint. However, where appropriate, comparisons are made to explain differences between the results of the two studies.

The first of these comparisons revolves around the aerodynamics of the recovery module. The results of the previous work by McCusker and Hill were called into question due to what was referred to as an "incomplete" aerodynamic database. The word incomplete was not meant so much to imply a lack of data points; indeed there were many. However, in fact, it was a reference to the lack of fidelity and benchmarking data by which to anchor the engineering and empirical models that were used to develop the McCusker and Hill database.

The METEOR program managers concluded the unsuitability of the McCusker and Hill aerodynamic database after comparisons were made with the aerodynamics generated by the current study. Large discrepancies in the aerodynamic coefficients were present. In some regions, the discrepancy between these two sets of nominal aerodynamics was significantly larger than the dispersions quoted for use in McCusker and Hill's Monte Carlo dispersion analyses. Because the aerodynamics of the current study were verified by extensive computational fluid dynamics calculations and wind-tunnel measurements, the fidelity of the previous program's aerodynamic database was questioned.

In the current study, the aerodynamic coefficients do play a small role in defining the landing footprint. However, this outcome is a direct result of having a high-fidelity aerodynamic database, so that small dispersions on the aerodynamic coefficients can be used with confidence in the Monte Carlo analysis. If the confidence in the aerodynamic database is low, much larger dispersions would be required, leading to larger contributions from the aerodynamics to the landing footprint. Additionally, without a credible aerodynamic database, the attitude behavior of the recovery module during the entry would be difficult to quantify at critical mission phases, e.g., atmospheric interface, peak heating, and parachute deployment, where program limits were prescribed. The previous work was concerned only with the landing footprint of the recovery module (no attitude information was presented), unlike the current study, where the knowledge of the recovery module's attitude at peak heating and parachute deployment was critical.

The current study states (in the Introduction) the reason for performing another analysis of the COMET/METEOR mission. This reason was solely the changes in the mission, i.e., orbit altitude, landing site, mass properties, etc., which occurred since the McCusker and Hill study. No statement questioning the validity of the Monte Carlo methodology employed in Ref. 2 is made. Again, only the results generated by McCusker and Hill were scrutinized after serious discrepancies were observed in their aerodynamic database. In addition, the current study goes on to state (at the end of the Results and Discussion section) the reasons for the larger landing footprint, as compared with the previous work. These reasons, as clearly stated, stem from a multitude of factors ranging from a change in the mission, to more uncertainties being considered, to larger dispersion tolerances being used on some of the mission parameters. These larger tolerances on some uncertainties, e.g., deorbit center-of-gravity offset, were selected after determining that previous program values were operationally unachievable.

Furthermore, the McCusker and Hill study only approximated the effects of some key uncertainties, such as recovery module deorbit center-of-gravity offset and parachute drift, both of which contribute considerably to the overall landing footprint. The results of the previous work were a good start, but in light of the issues concerning the aerodynamic database discrepancies, no attitude information, and approximating the effects of some key uncertainties, a statement of the current study being more conservative was and is entirely appropriate.

Finally, the Monte Carlo methodology employed by both studies has a long history of use inside and outside the aerospace community. Numerous programs predating the COMET/METEOR program have utilized this method. Therefore, the comments by McCusker and Hill suggesting that they were the innovators in the use of the Monte Carlo technique are not only presumptuous but inaccurate.

References

[1]Desai, P. N., Braun, R. D., Powell, R. W., Engelund, W. C., and Tartabini, P. V., "Six-Degree-of-freedom Entry Dispersion Analysis for the METEOR Recovery Module," *Journal of Spacecraft and Rockets*, Vol. 34, No. 3, 1997, pp. 334–340.

[2]McCusker, T., and Hill, S., "Landing Dispersions for the Commercial Experiment Transporter System," AIAA Paper 93-3695, 1993.