1981a

"Three-Axis Attitude Determination from Vector Observations," M. D. Shuster and S. D. Oh, *Journal of Guidance and Control*, Vol. 4, No. 1, January–February 1981, pp. 70–77.

This was the first publication in the archival literature of the QUEST algorithm, previously presented at a conference as 1978b. This work was submitted as two articles, the first on the TRIAD algorithm by the two authors, the second on the QUEST algorithm by me alone. The journal insisted that the two articles be combined, hence, the footnote on page 72. I have always regarded this action by the AIAA as a breach of ethics, since it required me either to remove the name of my co-author from work to which she had contributed or to add her name to work to which she had made no communication whatsoever. Had I been braver, I would have simply withdrawn the QUEST part of the paper and submitted it someplace else or to the JGC (now the JGCD) at a much later date. This is one of my three very-frequently cited works and the only one of those three that consists mostly of original research. The other two, 1982c and 1993h, are both survey articles.

The colorful history of the development of the QUEST algorithm is retold in 2001c and 2006f.

The name "TRIAD" for Harold Black's algorithm originated in this article. Previously, it was best known as the "algebraic method," as in Wertz, *Spacecraft Attitude Determination and Control*, in opposition to the "geometric method." The earliest source I was able to find at the time was documentation for a ground-support system created by IBM Federal Systems, Inc., for NASA called "Tri-Axial Attitude Determination System," hence, the acronym TRIAD in capital letters for the ground-support system, which I took over as the name of the algorithm. ("QUEST" is an acronym for "Quaternion Estimator.") In the early 1980s, I became aware of Black's paper, which had appeared in the *AIAA Journal* in 1964 and which is probably the earliest published attitude estimation algorithm. "TRIAD" has now become the most commonly used name for the algorithm. I suggest that people call it "Black's TRIAD algorithm," at least in the first mention in a publication.

Besides the QUEST algorithm itself, the paper was important for: (1) the method of sequential rotations, which has wide application in attitude work; (2) the TASTE test, which greatly streamlines attitude data validation; (3) the QUEST measurement model, which has received wide application; (4) the introduction of the body-referenced attitude error covariance matrix as a general approach to attitude error-level characterization, which eliminated the diseases associated with inertially referenced attitude error covariance matrices in terms of the Euler angles; (5) the simple expression for the TRIAD and QUEST attitude-error covariance matrices when the QUEST measurement model is used, and (6) the computation of the Davenport overlap eigenvalue by Newton-Raphson iteration starting with an excellent starting value. Most of these results are components of more recent solutions to the Wahba problem. This was my first journal publication in Astronautics and probably the most innovative. After QUEST, it was all downhill.

There is no absolutely fastest solution to the Wahba problem. Depending on the platform, programming language, compiler, computer environment, and the inputs, either QUEST

or one of Daniele Mortari's ESOQ algorithms may be fastest. (See 2007a and 2007d for more on this.)

A number of improvements have been made to QUEST since its publication, which have not yet reached the literature. These improvements consist of a modified characteristic polynomial for the overlap eigenvalue (see 2007a), which is more robust than the previous one and a more efficient algorithm for detecting the need for a sequential rotation.

After the publication of this paper, many people began wrongly attributing Davenport's q-algorithm to me as part of QUEST. I am partly to blame for this. The conference article preceding the journal publication had cited Davenport 16 times. However, the JGC policy was not to cite private communications, and Davenport did not wish me to cite the CSC technical memorandum frequently, so there was little I could do except to mention the algorithm's origin in the Introduction. I had suggested to Davenport that he write an article on the q-Algorithm that could appear before or simultaneously with my article. I even offered to ghost-write it for him, but he would have none of it. In retrospect, I should have added the comment "this is Davenport's famous result" after the equation $K\bar{q} = \lambda_{\max}\,\bar{q}$, but this did not occur to me. In all later publications, I have done my best to make sure that Davenport is always acknowledged explicitly for the q-algorithm, and likewise Black for the TRIAD algorithm.

Superseded 1978b.

Succeeded by 1983d, 1989b, 1989c, 1990d, 1993j, 20004, 2005e, 2006b, 2007a, 2007d.