Malcolm D. Shuster

Professional Biography

Malcolm David Shuster was born in Boston, Massachusetts, on July 31, 1943, and lived his first year in the Brighton neighborhood of Boston. In 1944, his family moved to Revere, a suburb just north of Boston, where he attended public school.

His first taste of real science was his summer employment as a laboratory assistant at W. R. Grace & Company, Cambridge, Massachusetts, as part of a 1960 summer science program for gifted high-school students sponsored by the National Science Foundation. Here, he conducted experiments on water-vapor permittivities of thin films. In the summer of 1961 he was employed as a silk-screen printer.

From 1961 until 1965, he majored in Physics at the Massachusetts Institute of Technology (S.B. 1965). In his junior year he carried out experimental studies of Fermi surfaces via electron-positron annihilation. In the summer of 1964, he was a technical assistant at the Laboratory for Nuclear Science. This last activity developed into an undergraduate thesis on the experimental study of the Faraday rotation of gamma rays by nuclei using the Mössbauer Effect. During the summers of 1962 and 1963, he had worked as a grounds keeper at MIT.

From June to September 1965, he worked as a Physics laboratory assistant (wissenschaftlicher Hilfsassistent) at the Institut für Strahlen- und Kernphysik of the University of Bonn in West Germany, helping to prepare an experiment to detect a parity violation in nuclear beta-decay. He participated in the preparation of radioisotopes and in calculations of Compton scattering cross-sections needed for data analysis.

From Germany, he went to College Park, Maryland, where, from September 1965 until September 1970, he pursued graduate studies in Physics at the University of Maryland. He remained the entire five years in Maryland except for the summer of 1966, when he was a summer research fellow at the Imaging Research Laboratory of the 3M Company, in St. Paul, Minnesota. Here, he redesigned thermoluminescence experiments to measure the trapping-level spectra of variously doped ZnO semi-conductors, part of 3M's research program to develop a color copying machine. He was able to improve the signal-to-noise ratio of these experiments by five orders of magnitude.

At the University of Maryland, he was a graduate teaching assistant from September 1965 until June 1967. In this capacity, he was a laboratory instructor for the sophomore course on *Electricity and Magnetism* and a grader and recitation instructor for the graduate courses: *Classical Electrodynamics II* and *Quantum Mechanics I*. In June 1967, he became a research assistant in the Nuclear Theory group. His first year of research was spent in unproductive theoretical studies of higher resonance effects in nuclear vibration states. After abandoning this research topic he began a program to develop a field-theoretical approach to the description of threshold pion production from nuclear collisions, making use of dispersion relations and current-algebra techniques, then fashionable in Elementary-Particle Physics. Eventually, he was able to describe the production of pions from collisions of protons with nuclei from the pion-production threshold up to the (3, 3) resonance region without adjustable parameters. This became his doctoral dissertation, which he defended at the end of September 1970.

In September 1970, a week after defending his doctoral thesis, he began a two-year position at the Center for Nuclear Studies at Saclay, France, a facility of the French Atomic Energy Commission, just south of Paris. At Saclay, he refined the work on threshold pion production. In other research, he showed definitively, from the upper limit on the isotensor decay rates of muonic nuclei, that one of the popular lepton-number schemes was no longer tenable. He also showed that the ABC Effect, unexplained for the previous dozen years and thought by some to indicate the presence of a new elementary particle, resulted, in fact, from a combination of elementary-particle-resonance

and nuclear effects. During the spring semester 1972, he taught a 17-week (34-hour) graduate-level course *Physique nucléaire à moyennes énergies* at the Institut national des sciences et techniques nucléaires.

From August 1972 until September 1973, he was an instructor (wissenschaftlicher Assistent) at the Institut für Theoretische Kernphysik of the University of Karlsrule in West Germany. Here, he refined his research on the ABC Effect (current researches in this area still tend to be straightforward extensions of that work) and taught recitation sections of the Diplom-level courses: *Statistische Physik* and *Quantenmechanik*. He resigned this position in protest rather than sign a loyalty oath stipulated by a still active law of the Third Reich.

From October 1973 until July 1976, he was a lecturer (מרצה) in the Department of Physics and Astronomy of Tel-Aviv University in Israel. Here, he taught the graduate courses: *Theory of Nuclear Reactions*, *Weak and Electromagnetic Interactions of Nuclei*, *High-Energy Nuclear Physics*, and *Theory of Nuclear Matter* and carried out further research in the area of elementary-particle interactions with nuclei. One project sought to explain part of the discrepancy in the nuclear isobar mass equation as due to the presence of an intrinsic isotensor electromagnetic current; another explored relativistic rescattering effects in nucleon-nucleon scattering near the pion-production threshold. The ABC work was brought to a conclusion at Tel-Aviv University. He directed the Nuclear Seminar and was on the advisory board of the Library of Exact Sciences. In his second year at Tel-Aviv University he was a recipient of the Bat-Sheva de Rothschild Award.

He spent August 1976 as a visiting scientist at the Department of Physics and Astronomy of the University of Maryland before spending the academic year 1976-77 as a visiting assistant professor in the Physics Department of Carnegie-Mellon University in Pittsburgh, Pennsylvania. This was an important turning point in his life, in which many events (some personal) led him to abandon his academic career in Nuclear Physics and to strike out into industry. It was also an unproductive year for his research, which he simply abandoned at the close of the spring semester and never completed. He taught sections of the undergraduate courses in *Electricity and Magnetism* and *Mechanics II* as well as the graduate courses *Relativistic Quantum Mechanics* and *Current Algebra and Elementary Particles*. He took up Photography seriously, which led eventually to a popular magazine article on Photographic Densitometry.

In February 1977, he interviewed with the Attitude Systems Operation of the Computer Sciences Corporation in Silver Spring, Maryland, and joined the company in May 1977, after completing the academic year at CMU. At CSC, he supported eight different spacecraft, especially Magsat, two launches, and some non-mission-specific projects. In his very first year at CSC, he developed the QUEST algorithm, certainly his best known work and which was to have an important influence on much of the work he did afterward. For the Solar Maximum Mission, he modified the attitude-error computation part of the attitude-control algorithms to keep the spacecraft stable until a new gyro package, this time with properly-sized fuses, could be installed during the first Shuttle Repair Mission. Besides QUEST, his work on the attitude Kalman filter with F. Landis Markley and his earliest work on magnetometer bias determination date from this period.

In January 1981, after nearly four years at CSC, he joined Business and Technological Systems, Inc., a small engineering company in Seabrook, Maryland. Here his interests turned from spacecraft to submarine-launched ballistic-missile (SLBM) systems. His primary projects were: (1) to develop methods for the validation and verification of the Advance Weapon System (Trident) Simulation using real SLBM launch test data; and (2) to develop efficient and practical maximum-likelihood methods for the identification of realistic models for the Trident C4 and D5 systems, involving at times more than 200 bias and Markov parameters. He also carried out trajectory optimization studies of thermo-electrically propelled spacecraft from near-Earth to lunar orbit, gravity-gradiometry studies, and studies of geomagnetic field map generation from satellite data. Under contract to NASA, he developed general techniques for inflight spacecraft alignment estimation. His work on spin-axis attitude estimation was also performed at BTS, though based on ideas developed at CSC. During this period he completed a master's degree in Electrical Engineering at The Johns Hopkins University. While at BTS, he was frequently an adjunct graduate professor of Mechanical Engineering at

Howard University, where he taught his graduate-level course on *Spacecraft Attitude Determination* for the first time in 1983 (and later in 1985 and 1987) as well as the graduate course *Advanced Dynamics I*. In addition, he was the de facto advisor of a master's thesis at Howard University. He also gave his course on *Spacecraft Attitude Determination* at The Johns Hopkins University Applied Physics Laboratory and at NASA Goddard Space Flight Center.

In November 1987, he joined the Guidance and Control Group of the Space Department at The Johns Hopkins University Applied Physics Laboratory, where he supported nine NASA and DOD missions. His first task was to develop a working (and unconventional) attitude determination system for launch support of the SDIO Thrusted Vector Mission, which would take place in less than three months. For the Star-Tracker Mission (never launched) he developed an algorithm which used single-frame QUEST quaternions as effective measurements in a Kalman filter. This algorithm also became the center of the onboard attitude determination system of the SDIO MSX Mission, for which he also designed and developed the prototype attitude determination software. The algorithm also became central to the attitude determination systems of NASA's deep-space missions. In addition, he continued his basic research on attitude determination. His work on batch attitude sensor alignment estimation, begun at BTS, also came to final fruition at APL. The TWOSTEP algorithm for attitude-independent magnetometer calibration was developed with Roberto Alonso of the Argentine Space Agency (CONAE), then visiting NASA/GSFC. A method for eliminating parameter drift in the repeated inflight calibration of attitude sensors was developed with Roberto Lopes of the Brazilian National Space Research Institute (INPE), then visiting the University of Maryland. From this period also came his lengthy survey article on the attitude representations, and a lengthy introductory chapter on "Spacecraft Attitude Determination and Control" in the book *Fundamentals of Space Systems*, edited by Vincent L. Pisacane and Robert Moore and published by Oxford University Press. This chapter resulted from a course he taught conjointly with other APL staff at the G. C. Whiting School of Engineering of The Johns Hopkins University. (A second edition of the book, edited by Pisacane alone, appeared in 2005.) In the summer of 1989, he presented a two-week short course, *Restitution d'attitude des véhicules spatiaux*, at the French Space Agency (Centre national d'études spatiaux) in Toulouse, France.

In the fall of 1994, he joined the faculty of the University of Florida as professor of Aerospace Engineering, Mechanics and Engineering Science. His researches here included a new method of attitude determination from star-camera measurements, a hybrid approach to spacecraft sensor alignment estimation (with Ceília Zanardi of the University of Guarantinguetà, then a post-doctoral fellow at UF), autocollimator calibration, the focal-plane representation of attitude, and a generalization of the Euler angles (with F. Landis Markley of NASA/GSFC). In addition, he taught graduate courses in *Spacecraft Attitude Determination* and *Spacecraft Attitude Control* as well as the undergraduate courses in *Statics*, *Introduction to Space Systems*, *Control Theory*, and also *Introduction to Space* to non-technical starry-eyed UF undergraduates. He spent the summer of 1995 as a NASA/ASEE Fellow at the NASA/Jet Propulsion Laboratory in Pasadena, California. Throughout this period, he also gave many one-day short courses on *Spacecraft Attitude Determination and Control* at NASA Marshall Space Flight Center and at the Jet Propulsion Laboratory for the Applied Technology Institute.

In May 1999, he began work at the Orbital Sciences Corporation in Germantown, Maryland. Besides work on company projects, specifically the BSAT-1 and NSTAR missions, he also did some original research during this period, especially the elaboration of earlier unpublished work on the uniform attitude probability distributions, a Bayesian formulation of the Wahba problem (unpublished), and a simple derivation of the Gauss-Bonet theorem using the Euler angles. It was shortly after his arrival at Orbital that he began to experience serious health problems, which led to his being separated from the company in May 2001.

Since then, when not dealing with health problems, much of his time has been spent preparing his unpublished work for archival publication under the banner of the Acme Spacecraft Company, a company name which owes much to the animator Chuck Jones. From the standpoint of publications, his time at the Acme Spacecraft Company has been very productive including works on determin-

istic attitude determination, constraint in attitude estimation, the generalized Wahba problem, an examination of the TRIAD algorithm as a maximum-likelihood estimator, a generalization of the TRIAD algorithm which includes all variations, improvements to his spin-axis attitude estimation algorithms of 1983, and three works on effective direction measurements in attitude estimation. In addition, he is working, supposedly, on graduate-level books on The Attitude Representations and the Spacecraft Attitude Determination.

He is the author or coauthor of more than sixty journal articles in Physics and Astronautics, a like number of conference reports and more than eighty technical reports. He has been a general co-chairman, technical co-chairman, publications chairman, or local arrangements chairman for five AAS/AIAA and IEEE conferences and symposia and a member of the AAS Space Flight Mechanics Technical Committee from 1994 to 2001. In 1993 he was the guest editor (with John L. Junkins) of a special issue of the Journal of the Astronautical Sciences devoted to Attitude Representations, and for a short period, he was an associate editor of that journal, a task which he performed very poorly. Since its inception he has been a member of the advisory board of the Space Technology Library now published by Springer Scientific + Business Media (formerly Springer Verlag). He is member of the International Editorial Board of the Journal of Aerospace Engineering, Science and Applications, a new electronic journal to be published by the Associação Aeroespacial Brasileira. In November 2000, he received the Dirk Brouwer Award from the American Astronautical Society. He is a fellow of the American Astronautical Society, an associate fellow of the American Institute of Aeronautics and Astronautics, and a senior member of the Institute of Electrical and Electronics Engineers. He has been a fellow of the British Interplanetary Society and a member of the American Physical Society, SIAM, the TeX User's Group, Sigma Xi and Tau Beta Pi. On June 13-15, 2005, the American Astronautical Society held the Malcolm D. Shuster Astronautics Symposium in his honor. This was followed by a special double issue of The Journal of the Astronautical Sciences (volume 54, nos. 3 and 4, July–December 2006) dedicated to him.