The Richard H. Battin Memorial Lecture delivered during *the Second Conference on Mathematical Sciences* (*CMS 2014*), Department of Mathematics, University of Karachi, Karachi, Pakistan, March 20, 2014 (Thursday, March 20, 2014; 1350h-1410h, Computer Laboratory, Room 336, Department of Mathematics), Technical Session on Astrodynamics and Climatology, CMS14-III, abstract#CMS14-12, p 3

The Extended-Q System

*Syed Arif Kamal**

Department of Mathematics, University of Karachi, Karachi 75270, Pakistan; profdrakamal@gmail.com

Astromathematics focuses on geometry to study orbits from a kinematical perspective. This branch of mathematics was introduced by the speaker on October 8, 2012 during the First National Conference on Space Sciences (NCSS 2012). In contrast to *astrodynamics*, the force expressions do not, explicitly, appear in the formulation of astromathamatics. Even if there appears a need to study force interactions, these are expressed as space-time-curvature equivalents. This formulation seems to be, generically, more suitable for accelerated frames governed by *geometrodynamics*. The speaker has worked in developing control laws (a control law is a relation, which is implemented on the original system to make it perform according to pre-decided standards), *viz.* the extended-cross-product steering, which was later adapted for the normal-component-cross-product steering, the dot-product steering, the normal-component-dot-product steering (if the components of velocity perpendicular and normal to the desired orbit are made to vanish, the spacecraft shall remain in that orbit unless there is a perturbation applied) and the ellipse-orientation steering as well as explicit guidance schemes (for a spacecraft approaching a destination, explicit guidance scheme draws a path containing the current position of spacecraft, destination and center of earth in order to compute velocity vectors required to achieve the destination during the remaining transfer time) for satellite-launch vehicles, *viz.* the Lambert scheme with cross-range error included, the multi-stage-Lambert scheme, the inverse-Lambert scheme, the multi-stage-Q system and the inverse-Q system. In *the extended-Q system*, both position and velocity vectors are managed, simultaneously, through extended-cross-product steering to put a satellite in the desired location with the recommended velocity. This lecture is dedicated to the loving memory of **Richard H. (Horace) Battin** (Tuesday, March 3, 1925, Atlantic City, New Jersey, United States – Saturday, February 8, 2014, Concord, Massachusetts, United States). The speaker got a chance to go through his classic "An Introduction to the Mathematics and (the) Methods of Astrodynamics" and write a review of this book, which is available at amazon as well as his homepage (Fig. 1). Some corrections and suggestions were communicated to Dr. Battin, who, very kindly, replied on October 25, 1993 (Fig. 2). Cross-product steering, put forward by Battin, was incomplete and needed an additional condition. This condition was added by the speaker and the new control law was termed as the extended-cross-product steering. Richard Battin received an SB (Bachelor of Science) degree in 1945 and a PhD in 1951 both from MIT. He began his career in 1951, serving as assistant director of MIT's Instrumentation Laboratory. He left this lab in 1956, becoming a staff member at Arthur Little Inc., but returned again to MIT in 1958. He, subsequently, assumed the role of technical director of the Apollo Mission Development Program as well as associate director of the MIT's Instrumentation Laboratory. In 1983, this laboratory was renamed as the Charles Stark Draper Laboratory Inc., where Battin served as the associate head of the NASA Program Department. After his retirement from Draper in 1987, Battin continued to teach as senior lecturer in Department of Aeronautics and Astronautics of MIT till 2010. In 1956, in collaboration with Dr. J. Halcombe Laning, he coauthored *Random Processes in Automatic Control* — a book which appeared in Russian, French and Chinese editions. His 1964 book *Astronautical Guidance* was, also, published in a Russian edition. He was an Honorary Fellow of the American Institute of Aeronautics and Astronautics, a Fellow the American Astronautical Society, a member of the National Academy of Engineering and the International Academy of Astronautics. Battin was noted for his teaching abilities, especially for his work in teaching, mentoring and inspiring many of the leaders in the world's guidance, navigation and control community. Three of the Apollo astronauts were his graduate students. To honor his teaching abilities, the students of MIT's Department of Aeronautics and Astronautics honored Battin with their first Undergraduate Teaching Award in 1981. Battin's many honors include the 1972 AIAA Louis W. Hill Space Transportation Award, the 1978 AIAA Mechanics and Control of Flight Award, the 1989 AIAA von Kármán Lectureship in Astronautics, the 2002 AIAA Aerospace Guidance, Navigation and Control Award, and the 1996 AAS Dirk Brouwer Award. Almighty give us the strength to continue his legacy. May his soul rest eternal peace!

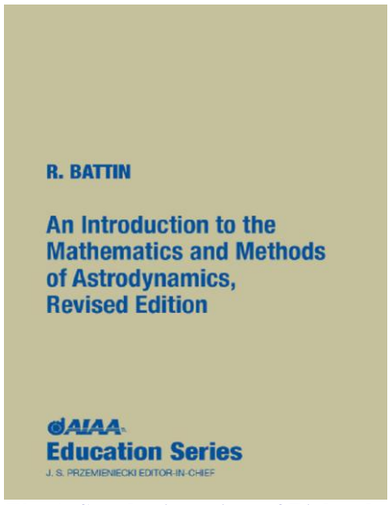
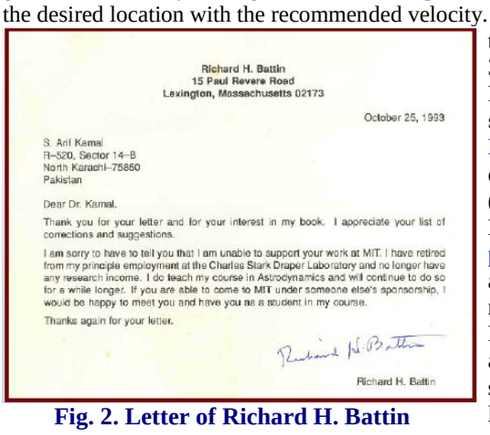


Fig. 1. Speaker's review of Richard H. Battin's classic, "An Introduction to the Mathematics and (the) Methods of Astrodynamics



Richard H. Battin
15 Paul Revere Road
Lexington, Massachusetts 02173

October 25, 1993

S. Arif Kamal
R–520, Sector 14–B
North Karachi–75850
Pakistan

Dear Dr. Kamal,

Thank you for your letter and for your interest in my book. I appreciate your list of corrections and suggestions.

I am sorry to have to tell you that I am unable to support your work at MIT. I have retired from my principle employment at the Charles Stark Draper Laboratory and no longer have any research income. I do teach my course in Astrodynamics and will continue to do so for a while longer. If you are able to come to MIT under someone else's sponsorship, I would be happy to meet you and have you as a student in my course.

Thanks again for your letter.

Richard H. Battin

Fig. 2. Letter of Richard H. Battin addressed to speaker

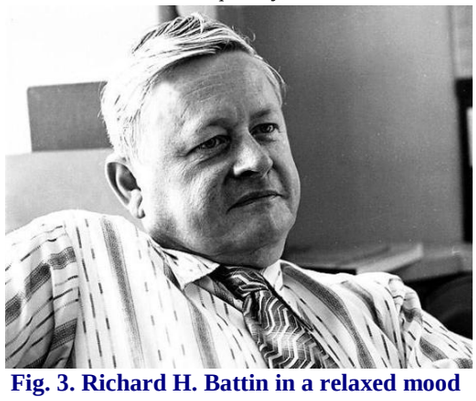


Fig. 3. Richard H. Battin in a relaxed mood

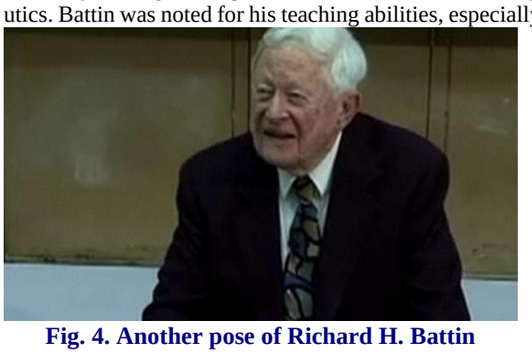


Fig. 4. Another pose of Richard H. Battin

Keywords: Astrodynamics • Astromathematics • Control laws • Explicit-guidance schemes • Q system • Richard H. Battin • Space-flight dynamics

Web address of this document: https://www.ngds-ku.org/Presentations/ExtendedQ.pdf

*PhD; MA (Astrophysics), Johns Hopkins, Baltimore, United States; MS (Gravitation Physics), Indiana, Bloomington, United States; MSc (Theoretical Physics with special courses in Space Physics), *summa cum laude*; BSc Honors (Physics, Mathematics and Statistics), *summa cum laude*, University of Karachi; Interdepartmental Faculty, Institute of Space and Planetary Astrophysics (ISPA), Departments of Physics and Computer Science, University of Karachi; Senior Scientific Officer, Control-Systems Laboratories (1992-1995) and Consultant, Guidance, Navigation and Control Laboratories (2005 to date), both at SUPARCO (Plant), Pakistan Space and Upper Atmosphere Research Commission; Visiting Faculty, Department of Aeronautics and Astronautics, Institute of Space Technology; Convener, NCRC (Mathematics), HEC (2004-2012); Convener, Subject Committee (Mathematics), NTS Pakistan (2009-2012) • *paper mail*: Professor and Chairman, Department of Mathematics, University of Karachi, PO Box 8423, Karachi 75270, Sindh, Pakistan • *telephone*: +92 21 9926 1300-15 ext. 2293 • *homepage* • *vita*