NGUYEN XUAN VINH – A LIFE IN HYPERSONIC FLIGHT

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Nguyễn Xuân Vinh (born January 1930 in Yên Bái, Vietnam) is a noted Vietnamese-American aerospace scientist and educator whose seminal work on the guidance, dynamics and optimal control of space vehicles and their interaction with the atmosphere has played a fundamental role in space exploration. Vinh is Professor Emeritus of Aerospace Engineering at the University of Michigan, where he taught for nearly thirty years. Among his many publications was "Hypersonic and Planetary Entry Flight Mechanics" (1980. Vinh, N. X.; Busemann, A.; Culp, R. D. University of Michigan Press) which contains equations for hypersonic flight that came to be known as "the Vinh equations".

INTRODUCTION

Professor Nguyễn Xuân Vinh was one of the first researchers to formulate a theoretical and rigorous approach to the problem of space vehicle dynamics and control in regimes where both orbital and atmospheric dynamics play crucial roles. His work laid the foundations of this field and continue to shape it in a fundamental way. His research has clearly established how this unique environment can be harnessed via maneuvers and strategies that take advantage of both flight regimes in an integrated, seamless, and elegant way. Extending far beyond theory, his contributions in this area cover the entire spectrum: he has written widely used textbooks on the subject, he has contributed seminal journal papers advancing the theoretical understanding of this field, he has developed practical implementations of his theoretical results in optimal flight controls, and he has trained students who continue to make new contributions to our understanding of flight mechanics in this regime.

Professor Vinh's achievements in space flight mechanics go beyond this particular area, however, and cover many other topics. His research has influenced the fields of theoretical optimal control, celestial mechanics, astrodynamics, guidance and navigation, and atmospheric flight mechanics among others. At the University of Michigan he trained students in all of these areas, including 30 doctoral candidates. These former students are now prominently involved in many aspects of space flight mechanics. Their ranks include professors at major research universities and

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senior researchers at national and international government and industry laboratories. Beyond leaving his own mark on the field, his legacy encompasses an entire class of researchers who are propagating his elegant style and unique approach to space flight mechanics.

Professor Vinh has been an inspiring leader in space flight mechanics and astrodynamics and had a broad influence both as a researcher and as a teacher. His three books and more than 100 technical papers cover a wide range of topics in the rigorous and systematic style that is his trademark. His style is clearly a product of his unique combination of experience and education: pilot, poet and novelist, Commander of the Vietnamese Air Force, holder of doctorates in both Aerospace Engineering, and Mathematics. In his books, he has brought together important results, including results of his own, that had previously been scattered throughout the literature and presented them from a unified perspective. His presentations are always carefully crafted, with a judicious choice of variables and elegant mathematical formulation of problems, insights into general characteristics of solutions, and a logical progression of topics. His books are valuable resources to the aerospace community: We personally use them and refer our students to them frequently.

He has received numerous awards for teaching and research, including the 2007 Dirk Brouwer Award from the American Astronautical Society and the 1994 Mechanics and Control of Flight Award from the American Institute of Aeronautics and Astronautics.

BIOGRAPHY AND EDUCATION

Nguyễn Xuân Vinh was born in 1930 in Yen Bay, Vietnam. As a historical footnote, his Vietnamese surname was actually Nguyễn, a common surname in Vietnam. In Asia people write their surnames first and given names last. But when he came to the United States in the early 1960s, people mistook "Vinh" as his last name routinely, and he simply adopted it as his new surname.

He attended the French Air Force Academy at Salon de Provence where he specialized in Aeronautical Engineering. In 1954, he graduated from the nearby Aix-Marseille University in Mathematics and was commissioned as an officer. The following year, he qualified as a multi-engine pilot in the French Air Force.

In early 1955, when the French Army officially handed over facilities and equipment to the Vietnamese National Army, he was ordered back to Vietnam. He was appointed Chief of Staff in the Air Force of the Republic of Vietnam in October 1957. In 1958, he became the Commander and first Air Marshal of the Vietnam Air Force at the age of 28. He served as Air Force Commander until 1962 when he was sent to study abroad in August 1962 by President Ngo Dinh Diem. He stayed in the U.S. after the assassination of President Diem fourteen months later, on November 1, 1963.

He studied at the University of Colorado, working closely with Adoph Busemann and C. Forbes Dewey. With a dissertation entitled, "Geometrical studies of orbital transfer problems," he was awarded a doctorate in 1965 --the first Ph.D. in aerospace engineering conferred by the University of Colorado. In 1972, he was awarded a national doctorate in Mathematics by the University of Paris, France. He joined the University of Michigan in 1968 as an associate professor of Aerospace Engineering and was promoted to the rank of professor in 1972. Vinh was named as Professor Emeritus of Aerospace Engineering upon his retirement from active faculty status on December 31, 1998.

TECHNICAL CONTRIBUTIONS

Professor Vinh has made fundamental contributions to the field of space flight mechanics. He was one of the first researchers to formulate a theoretical and rigorous approach to the problem of space vehicle dynamics and control in regimes where both orbital and atmospheric dynamics play crucial roles. His work laid the foundations of this field, drawing disparate elements together and presenting material in a cohesive and systematic way. He solved difficult technical problems with clever use of dimensionless variables, extending mathematical solutions to regimes where previous solutions could not apply. His research has clearly established how this unique environment can be harnessed via maneuvers and strategies that take advantage of both flight regimes in an integrated, seamless, and elegant way.

With more than 100 published research papers to his credit, Professor Vinh's contributions in mathematics, astrodynamics, and trajectory optimization are well known both nationally and internationally. In addition to publishing a large volume of his own work, he served as associate editor for Astrodynamics for Acta Astronautica, the archival journal for the International Academy of Astronautics, for 20 years (from 1979 until his retirement),

His papers are individually significant and penetrating, demonstrating creativity and mathematical sophistication of the highest order. They are complete works, often providing the most general solution to a problem. His research is rigorous, elegant, and visionary. His seminal work on the guidance, dynamics and optimal control of space vehicles and their interaction with the atmosphere continues to play a fundamental role in space exploration and technological development.

Professor Vinh was among the early researchers who investigated the control switching in optimal control problems frequently encountered in the bang-bang control and singular control problems. His work is unique in that it uses an elegant and illustrative geometric perspective to help the exposition of the theory. Professor Vinh's original work in optimal theory and its aerospace applications continues to be a source of inspiration and a model to follow.

Professor Vinh has written three books: Hypersonic and Planetary Entry Flight Mechanics (with A. Busemann and R.D. Culp), published by The University of Michigan Press in 1980; Optimal Trajectories in Atmospheric Flight, published by Elsevier Scientific Publishing Company in 1981; and Flight Mechanics of High Performance Aircraft, published by Cambridge University Press in 1993. In his letter recommending Prof. Vinh for the AAS Brouwer award in 2006, Prof. James Longuski writes, "In the past decade, virtually every paper I have examined in the fields of flight mechanics and optimal trajectories in the atmosphere has cited the first two books. The third book is a masterly work on aircraft performance. It is ideal for well-prepared seniors or graduate students, making a number of very sophisticated concepts highly accessible and paving the way for more advanced study. These three books are bound to become classics because of the seamless and elegant connection Professor Vinh makes between mathematical theory and engineering practice."

Professor Vinh has contributed to celestial mechanics, orbital transfer (aeroassisted, low-thrust, high-thrust), orbit contraction due to atmospheric drag, planetary entry dynamics, and missile guidance. Although he appreciated and utilized the capability to obtain numerical solutions to problems in flight mechanics and astrodynamics, his primary expertise, as well as his true passion, is in obtaining analytical solutions to astrodynamics problems. His strong mathematical training, innate cleverness, and diligence allowed him to discover changes of variables and ways of using perturbation methods to succeed where others had not. Analytic solutions are desirable for real-time guidance applications, wherever they are available and when numerical solutions are too slow or there is a lack of assurance of reliable convergence. Professor Vinh also recognized the importance of

analytical solutions in developing insight into the general characteristics of solutions, insight that is often difficult to obtain from numerical solutions.

Prof. Vinh's characteristically elegant analytical approach is evident in the following equations. These apply to atmospheric entry with or without lift and bank modulation, and also reduce to the equations for Keplerian motion for exoatmospheric flight with no atmospheric drag. Vinh's Unified Theory resolved deficiencies associated with Chapman's theory for planetary entry which restricted its application to planar entry trajectories with small entry flight path angles. Vinh defined the following dimensionless variable, which he used as the independent variable instead of time:

$$s = \int_0^t \left(\frac{V}{r}\right) \cos\gamma \, dt$$

Using this variable as the independent variable in place of time results in the following equations of motion for three-dimensional entry trajectories, first derived by Vinh and Brace and presented as Equations (13-13) in "Hypersonic and Planetary Entry Flight Mechanics":

$$\frac{dZ}{ds} = -\overline{\beta r} Z \tan\gamma$$

$$\frac{du}{ds} = -\frac{2Zu\sqrt{\beta r}}{\cos\gamma}\left(1 + \frac{C_L}{C_D}\cos\sigma \tan\gamma + \frac{\sin\gamma}{2Z\sqrt{\beta r}}\right)$$

$$\frac{d\theta}{ds} = \frac{\cos\psi}{\cos\phi}$$

$$\frac{d\phi}{ds} = \sin\psi$$

$$\frac{d\gamma}{ds} = \frac{Z\sqrt{\beta r}}{\cos\gamma}\left[\frac{C_L}{C_D}\cos\sigma - \frac{\cos\gamma}{Z\sqrt{\beta r}}\left(1 - \frac{\cos^2\gamma}{u}\right)\right]$$

$$\frac{d\psi}{ds} = \frac{Z\sqrt{\beta r}}{\cos^2\gamma}\left(\frac{C_L}{C_D}\sin\sigma - \frac{\cos^2\gamma}{Z\sqrt{\beta r}}\cos\psi \tan\phi\right)$$

These equations have been referred to as "Vinh's universal entry equations".

AN EDUCATOR AND MENTOR

Prof. Vinh trained many scholars and practitioners who are carrying on his tradition of elegant and rigorous inquiry. During his tenure at Michigan, Prof. Vinh chaired the doctoral committees for 30 students, many of them now professors at prestigious universities or leading engineers and scientists in the aerospace industry. It is estimated that over 1,000 aerospace engineers studied under him.

Many of his students, including the authors, cite his influence as critical to their careers. He is recalled as an exceptionally clear and well-organized communicator and presenter, despite his Vietnamese accent and an occasional penchant for slipping into French either in his lectures or on the blackboard. He used a dry sense of humor to lighten the classroom atmosphere, and taught exclusively from his own detailed notes, as available textbooks of the time did not cover much of the material he was teaching. His excellence in the classroom was recognized in 1984 at the University of Michigan with the Teaching Excellence Award.

Always a gentleman and scholar, Prof. Vinh was a caring and patient mentor to his students. He interacted with his students as an equal. Yet he would challenge students to reach their best in his own way. Sometimes he would pose a question to a student as an intellectual exercise. Professor Ping Lu recalled when he was a graduate student at Michigan, one evening on his way home, Prof. Vinh stopped by Ping's office (which was in a different building by the parking lot) and wrote on the blackboard a complex inequality. The expression was simplified to something akin to $2x \geq 5x$, where x is a negative quantity. After cancelling x from both sides, it left a ridiculous answer of $2 \geq 5$. Prof. Vinh then asked Ping to figure out what went wrong that night. The next morning on his way to his office, Prof. Vinh stopped by again. A man of few words, he turned around and left after getting Ping's explanation, without a single comment but with a smile on his face.

Prof. Vinh was a visiting professor at the Ecole Nationale Supérieure d'Etudes Aérospatiales in France from '74-'75, during which time he was able to return only occasionally to Michigan to work with his students. Former student Nikolas Bletsos recalls "the great rapport that was prevalent in our relationship, and even more importantly the almost amazingly easy flow and exchange of technical understanding of the subjects at hand that was communicated between us," during those visits which allowed him to make significant progress in his work during Prof. Vinh's year in Paris.

In 1982, Prof. Vinh served as a chair professor of applied mathematics at the National Tsing Hua University in Taiwan in 1982. He has been invited to lecture at universities and international conferences around the world including the United States, Canada, Britain, France, Austria, Germany, Italy, the Netherlands, Switzerland, Norway, Sweden, Hungary, Israel, Japan, China, Taiwan and Australia.

Prof. Longuski of Purdue writes, "As a doctoral student of Professor Vinh's, I was extremely impressed not only by his brilliant insights but also by his kindness and generosity in sharing his ideas. I owe a great deal of my success to having Professor Vinh as my advisor and I know many of his students who have expressed similar feelings."

LITERARY CONTRIBUTIONS

Vinh also has been a leader in the worldwide Vietnamese community, recognized for his literary contributions as a published poet and novelist. Most notably, in 1960, to promote a cadet recruitment program for the newly created Air Force Academy in Vietnam, he wrote a novel: *Pilot's Life*, which became a best-seller (now in its sixth printing). The novel is in the form of a series of letters written by a pilot to his sweetheart.

AWARDS

Professor Vinh has received several of the discipline's most prestigious awards.

Honorary Pilot: Republic of China Air Force, 1960; Royal Thai Air Force, 1962

Third American (after Neil Armstrong and Frank Borman) elected to membership in the prestigious French National Academy of Air and Space, elected 1984

Elected to membership in the International Academy of Astronautics, 1986

Professional Achievement Award, Michigan Governor's Advisory Commission for Asian American Affairs, 1987

University of Michigan Teaching Excellence Award, 1984

University of Michigan Research Excellence Award, 1991,

Mechanics and Control of Flight Award, American Institute of Aeronautics and Astronautics, 1994

Selected as an awardee for the Excellence 2000 Award presented by the United States Pan Asian American Chamber of Commerce in Washington, D.C.

Elected to the French Academy of Aeronautics and Astronautics, 2000.

Dirk Brouwer Award, American Astronautical Society, for outstanding lifetime achievement in the field of space flight mechanics and astrodynamics, 2006

In addition to the above, he has received awards from several outstanding universities for his research, teaching and humanitarian service. These universities include the University of Michigan, University of Massachusetts, University of Tokyo, University of Oklahoma, Universite de Paris, Taiwan National University, National Cheng Kung University (Taiwan), National Tsing Hua University (Taiwan), and Ecole Nationale Superieure de l' Aeronautique et de l'Espace (France).

The St Louis, MO School of Arts offers an annual award named the "Tradition of Nguyen Xuan Vinh" to encourage local students.

Marking his accomplishments outside the engineering world, he was awarded the Vietnam National Literature Prize in 1961 for his novel *Pilot's Life.*

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CONCLUSION

Professor Vinh has been widely honored for many different aspects of his work and his career. It is a strong testament to his intellect, ability, and character that he has won recognition in so many aspects of his life.

ACKNOWLEDGMENTS

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