One Man's Corner

Part 1.A Lessons Learned from My Early FEA Career

 Henry H. Fong, Consultant, San Francisco, California, USA

henryhungfong@gmail.com


(Photo by Evelyn Y. Lee, 2002, in West Lake, China. This article is dedicated to her.)

Outline **-- Part 1**, in my series of "One Man's Corner" articles in *FEA Information*, describes some of my structural analysis, FEA (finite element analysis), and MCAE (mechanical computer-aided engineering) career highlights in the Southern California aerospace industry – in the 20-year period from 1966 to 1986. Four projects are discussed, each with: background, objective, structural analysis highlights, and lessons learned:

Part 1.A *Postbuckling Strength and Dynamic Response of Thin Shells*

Part 1.B *Evaluation of COSMIC/NASTRAN Program*

Part 1.C *Structural Analysis of Solar Energy Heliostats*

Part 1.D *Nonlinear FEA of Elastomeric Potting Materials in Traveling Wave Tubes.*

Part 2 will discuss my observations in the second half of my career, in the 20-year period, 1987-2007: FEA/MCAE market trends, computer hardware and processor advances; benchmarking; clustering in High Performance Computing (HPC); current MCAE market leaders – and why; and, cultural differences and recent HPC/MCAE achievements I saw in India and China.

Part 3 will be my crystal-ball gaze into the future – what may be in store for FEA and MCAE simulations in the future? I will attempt to hypothesize and speculate – using the frameworks posed by *New York Times* Foreign Affairs columnist Thomas L. Friedman in his provocative book, *The World is Flat – A Brief History of the 21st Century* (2005), and artificial intelligence expert, inventor, entrepreneur, and futurist Ray Kurzweil* in his profound book, *The Singularity is Near – When Humans Transcend Biology* (2005).

Disclaimer: The author would like to thank *FEA Information* for the kind invitation to write this series of articles on my career. These articles reflect my opinions and observations, and do not represent an endorsement or approval by the staff of *FEA Information,* or Livermore Software Technology Corporation. The content is based on my first-hand experiences on several structural analysis projects, lessons learned from each, observations on FEA/MCAE market trends, contact with many FEA/MCAE people in industry and academia around the world, and the very enjoyable experiences of having worked with some outstanding engineers, professors, and consultants. Any mistakes, or unintentional omissions, are strictly my own.

Introduction

If you want to understand today, you have to research yesterday – Pearl S. Buck

With a M.S. in structural engineering from the University of California at Berkeley (and mentored by Professor Robert L. Taylor*), I was all ready in January 1966 "to set the world on fire," and tackle big engineering challenges. But, I soon learned that we engineers and scientists should never forget their lives (and indeed, their careers) can often be impacted by the "big picture" around us: *socio-economic developments* (e.g., China, India, Russia), and *political upheavals* and other events around the world (e.g., 9/11, Iraq, Afghanistan, Pakistan), that are out of our control.

* *Member, U.S. National Academy of Engineering*

1.A Postbuckling Strength and Dynamic Response of Thin Shells

My first two jobs in the aerospace industry both involved the stress analyses of thin shells, at General Dynamics–Convair [1966-1968] and McDonnell Douglas Astronautics Company [1968-1978]. The GD work dealt with the stress analysis, and full-scale structural testing, of the *Centaur* upper-stage launch vehicle. The MDAC work involved the dynamic analysis of the *Spartan* ABM third stage's "nuclear warhead" shell structure, along with full-scale testing using contact explosives and underground nuclear tests. Both were performed under tremendous time constraints, involving intense competition with the Soviet and Chinese space and missiles programs. Along the way, I had met some very talented (and quite colorful) engineers and consultants.

Sidebar: In 1979, as a 37-year-old Chinese-American structural engineer (born in China but raised in the U.S.), I was fascinated by the seminal buckling work of thin shells by rocket scientists Theodore von Kármán and Hsue-shen Tsien (later known as *Qian Xue-sen*, in China), done at Caltech in 1939-1941. (von Kármán also later co-founded, with others like Frank Malina and Louis Dunn, Caltech's Jet Propulsion Laboratory and Aerojet Engineering Corporation.) I was also very intrigued by the subsequent

McCarthy-era, alleged spy controversy surrounding Qian's life in 1950-1955 – which led to his return to China in 1955. So, I decided to write a sincere, hand-written letter to Dr. Qian (then, aged 68), requesting his permission for me to go to China to interview him, and possibly, write a book about his memorable life and achievements. To my surprise, three months later, Dr. Qian replied – but he politely declined to be interviewed and to be biographied. [More on Dr. Qian's life later.]

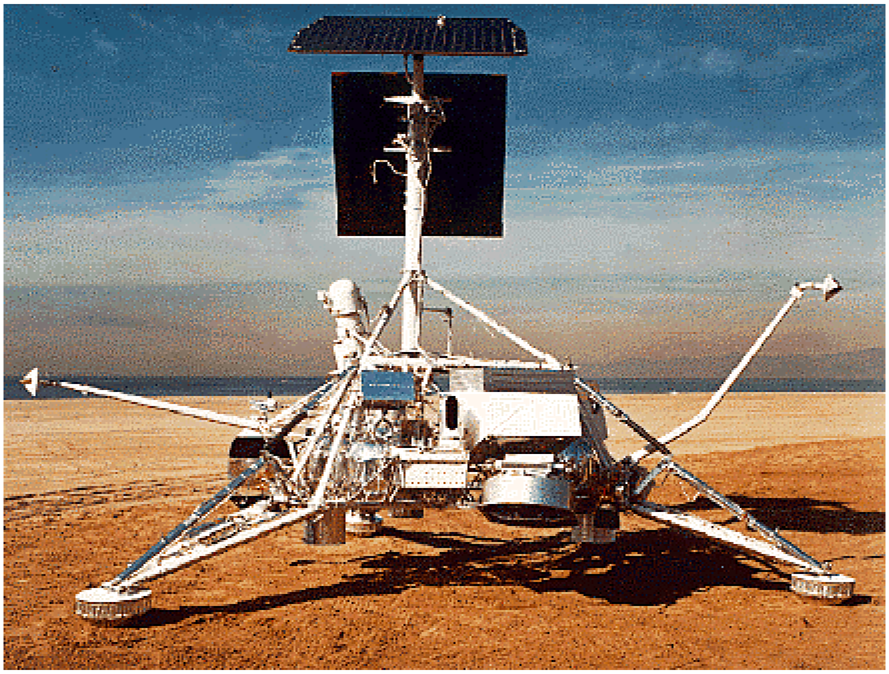
1.A.1 Postbuckling Strength of Centaur Launch Vehicle's Thin Shell [1966-1968]

Centaur upper-stage rocket

At UC Berkeley in 1965, while taking a "Flight Structures" course taught by Marc Trubert, we had used as text a 1950 book named *Aircraft Structures,* by David J. Peery at Penn State University. And, lo and behold, when I started working in January 1966 at GD in San Diego, I found out that Dr. Peery had retired from academia, and was now a structures consultant at GD. A short, rotund, good-humored, pipe-smoking man who very much looked the part of a structural analysis "guru," he led a GD structural analysis team that did the theoretical work to calculate the postbuckling strength of the highly unusual thin shell design for the *Centaur* rocket -- an internally-pressurized, balloon-like vessel made of 0.014 inch stainless steel. It contained the highly combustible liquid nitrogen and liquid hydrogen fuels. GD's *Centaur* upper stage rocket perched atop the reliable "workhorse" GD *Atlas* first-stage launch vehicle, and its primary mission (at that time) was to launch Hughes Aircraft's *Surveyor* spacecraft into space, with the aim of soft-landing it on the lunar surface. (*Surveyor*, of course, paved the way for the later *Mercury*, *Gemini* and *Apollo* U.S. manned spacecraft missions in the 1960s-1970s.)

As fate would have it, on February 3, 1966, the Russians beat the Americans to the moon, with the successful soft landing of their *Luna 9* spacecraft. This early Russian success really "took the air of the GD, Hughes, and NASA engineers' balloon" – it was my first, very dramatic exposure to the sight of utter despair amongst these engineers, and seeing tears running down the cheeks of grown men. (At that time, there was not a single woman engineer in our Stress Group.)

Nevertheless, the NASA/GD/Hughes team pushed on, and four months later, on June 2, 1966, *Atlas/Centaur* successfully launched the *Surveyor I* on its way to soft-land on the lunar surface.



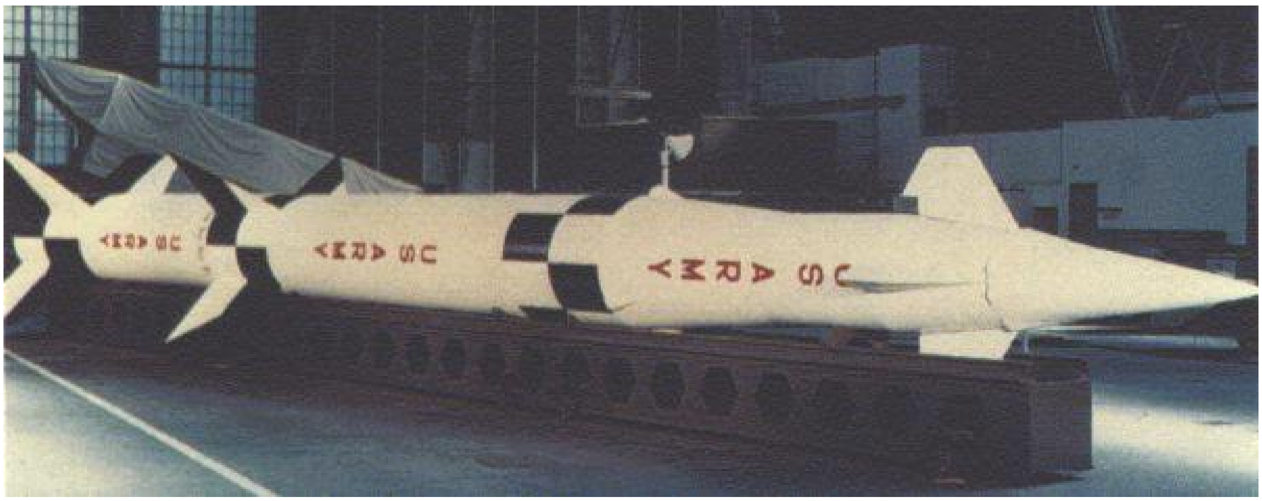
Surveyor 1 spacecraft

I recalled there was little finite element analysis work done at GD then. This was about four **years** before NASA sponsored the development of the *(COSMIC/)NASTRAN* general-purpose, structural and dynamic analysis program. Peery and his GD colleagues had developed a standardized “template” to perform the stress analysis of such internally pressurized thin shells, and also to determine the postbuckling strength of the shell after initial wrinkling of its skin.

Full-scale structural testing was conducted at Point Loma, San Diego. It was my first experience participating in such a large-scale, expensive, structural test. The strains, skin wrinkling, and postbuckling behavior (as measured by strain gauges and displacement gauges) correlated well with our analytical predictions. There were quite a few nervous engineers, GD and NASA executives who witnessed each test, as the shell’s internal pressure was gradually increased first to “flight loads,” and then, to “limit loads” (which, for the *Centaur* shell design, was 30 percent higher than the flight loads). Fortunately, although the thin shell wrinkled in a certain region as predicted, it never did burst. Since liquid nitrogen and liquid oxygen were highly flammable, the San Diego Fire Department stood by. I asked Jim Jenness, the senior engineer in charge of structural testing, if this type of precaution was standard procedure. He replied: “Safety, Henry, safety! It’s better to be safe than sorry.” Some time later, I remember seeing this advice appear in my fortune cookie at a Chinese restaurant in San Diego. **Lesson #1:** *The first responsibility of a structural engineer is to ensure that structures and components are properly designed to* safely *handle the anticipated operational loads, with an adequate margin of safety.*

I also quickly learned that all margins of safety in our stress analysis work were compared against material allowable strengths, as specified in that thick "granddaddy" of all material handbooks used in the U.S. aerospace industry – *MIL-HDBK-5C* (which I had never heard of at UC Berkeley – where we only used the *AISC Steel Design Manual* and the *Uniform Building Code*). My group leader, a tall lanky Texan with a flat-top crew-cut named John Buck, laughed at my naiveté, "Awww shucks, c'mon now, young man – you'll soon learn fast enough."

1.A.2 Dynamic Response of Spartan 3rd Stage Shell Structure Subjected to Impulsive Loads *[1968-1975]*



It was the early 1970s. President Richard Nixon had just made his 1972 groundbreaking trip to China to meet with Chairman Mao Zedong, Premier Zhou Enlai, and other top Chinese Communist officials. This was also during the very tense days of the Cold War – and U.S. defense officials were paranoid about an "accidental" launch of ICBMs (e.g., by a "rogue" Soviet, or Chinese, general) towards the U.S. To counter this potential missile threat, Nixon and the Department of Defense came up with the *Safeguard* anti-ballistic missile (ABM) system, which was deployed at twelve remote locations across the U.S., to shield major American cities and our own key launch sites. The two Safeguard ABM contractors were: McDonnell Douglas Astronautics Company – now part of Boeing Co. (*Spartan* long-range missile, shown above, whose third stage was nuclear-armed) and Martin-Marietta Aerospace (short-range, high-velocity, terminal interceptor named *Sprint*, also nuclear-tipped).

The Safeguard ABM system was managed by the U.S. Army, assisted by various defense contractors and U.S. Government labs, such as Kaman Nuclear, Kaman Aerospace, SRI International (SRI), Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratory-Livermore (SLL), and Defense Nuclear Agency (DNA). I attended some interesting Safeguard/Spartan "vulnerability working group" meetings – which were filled with top brass around the table, and PhDs in nuclear physics, chemistry, mathematics, material science, explosives, hydrodynamics, structural analysis, mechanics, underground testing, etc. – all in all, a very talented group of individuals (some of whom, as expected, were naturally quite outspoken). **Lesson #2:** *What President Dwight Eisenhower called in 1956 the "military-industrial complex" really existed!* Here it was, one stark example – sitting right there in that conference room!

I was likely the most junior person at these meetings (in terms of age and experience), and always sat quietly in the last row of the huge conference room. Some meetings had over seventy attendees. I could sometimes sense the electricity in the air. As a young Chinese-American engineer, who was still rather naïve, I remembered seeing, at one such meeting, a DOD transparency that I have never forgotten to this day – a detailed map of the targeted "first-strike" missile launch sites, key industrial complexes, and cities (with estimated casualties) in Mainland China – in case World War III ever broke out. (The map was undoubtedly derived from CIA's latest intelligence sources and U.S. spy satellites' hi-res photographs). Holy cow, I said to myself, this was serious shit – we were talking about the annihilation of hundreds of thousands – if not millions – of innocent lives. The somber conference room scene reminded me of the dreaded "doomsday scenario" in Stanley Kubrick' classic 1964 movie (shot in black-and-white, for special effect), *Dr. Strangelove*.

I soon discovered that, despite all the rigorous theoretical analyses presented by the defense contractors and by "experts" from LLNL, SLL, SRI, DOD, DOE, DNA, etc., the top brass still demanded *experimental verification.* **Lesson #3:** *If in doubt, test.*

My first assignment at MDAC (1968) was in the Spartan "Nuclear Effects" group led by Ken McClymonds. I had helped Ken to plan and instrument the CELT tests (contact explosive loading tests) at a remote site in Riverside County. (It was fun getting out of the office, basking in the warm sun, watching most of the hard work being done by the technicians.) Sheet explosives were carefully laid out in strips, on neoprene rubber sheets, and glued onto a mockup of the full-scale Spartan 3rd stage shell structure. *Boom* – and the whole test was over! These tests simulated (relatively inexpensively) the shock effects and impulsive loads caused by a nuclear explosion. Strain gauges and displacement gauges monitored the shell's structural response. Test data were correlated with predictions using an axisymmetric FEA shell code named *SABOR/DRASTIC III* (first developed by Stanley Klein, who had received his PhD at MIT under finite element pioneer Professor Theodore "Ted" H.H. Pian*, and then extended by Klein when he later worked at Aerospace Corporation). Ken also did simulations with something called the *PUFF* code. When I asked him what the code did, he explained that *PUFF* was a one-dimensional, wave propagation hydro-code widely used in the weapons community, to calculate material response (e.g., spallation effects) due to a shock load.

Two Outstanding Consultants – Herb Lindberg and Chuck Babcock

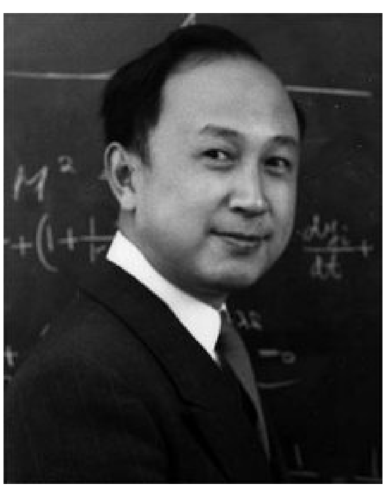
One of the most interesting experts I met during these Safeguard/Spartan vulnerability working group meetings was Dr. Herbert E. Lindberg of SRI International in Menlo Park, California.

Herb and his SRI colleagues had done a variety of dynamic buckling tests, and had published a series of technical articles and reports on the dynamic pulse buckling of thin shells (always with experimental verification). He was highly respected at these meetings. A modest, soft-spoken and technically superb professional, Herb's comments were eloquent, to-the-point, and always "right on." Herb helped us to design and instrument the later full-scale Spartan structural tests at the underground test site in Nevada, and then to interpret the material and structural response test data obtained. **Lesson #4:** *It's not* what *you know – it is* how *effectively you communicate it.*

The first structures consultant I got to know well was Professor Charles D. Babcock from Caltech. Everybody called him Chuck. He served as MDAC's shell and buckling expert consultant for much of the 1970s. Chuck had studied under famous mechanics professors at Caltech, such as Ernest E. Sechler and Yuan-cheng "Bert" Fung*. (Fung was first an outstanding aerodynamicist at Caltech, then switched to solid mechanics, and later, at UC San Diego, became a world-class pioneer in biomechanics and cardiovascular mechanics.) I remember when Chuck used to come to MDAC every other Friday, he never once carried a book. He told me: "Everything should be derived from scratch, from basic principles." I was really blown away by such raw intellect – it was all in his head. (Sadly, Chuck died in 1988 – he was only 53.)

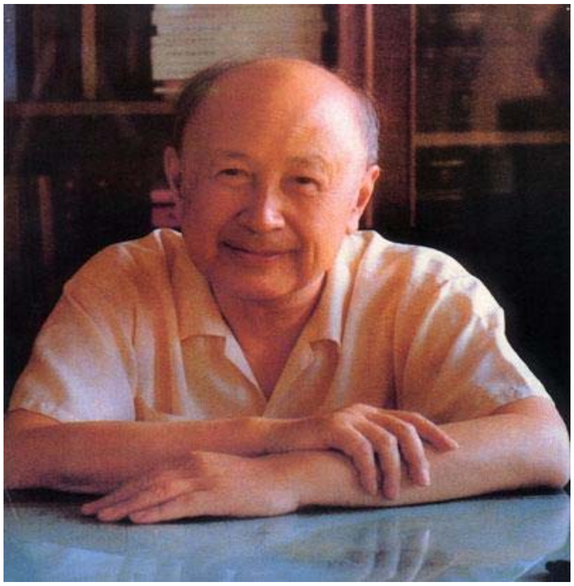
The Story of Qian Xue-sen – "the man who knew too much"

Reputedly Theodore von Kármán's top protégé, Dr. Qian Xue-sen (known as Hsue-shen Tsien, or Hsueh-shen Tsien, in his U.S. years, 1935-1955) was an eminent rocketry, jet propulsion, boundary layer, and shell buckling expert. Born in 1911, he graduated with honors from Jiaotong University in Shanghai, and came to the U.S. to study for his M.S. degree at MIT in 1935-1936. Then, Qian transferred to Caltech in October 1936 to study under the famed fluid dynamicist and rocket expert Theodore von Kármán, and received his doctorate in aviation and mathematics in 1939. He continued to teach and do outstanding research at Caltech in Pasadena, from 1939, through World War II, until 1955. [I heard recently from one source that Dr. Qian is still living today – he would now be almost 97.]



Professor Qian Xue-sen at Caltech (1949)

The photograph shown above is Professor Qian Xue-sen shown at Caltech in 1949 (38 years old). The second photo below shows a beaming Qian, when he was honored at his 90th birthday gala in Beijing, in January 2001. The third photo is the most recent photograph I found online of Qian Xue-sen, and was taken on January 19, 2008 – showing him warmly greeting China's President Hu Jintao (1st and 2nd photos are courtesy of *China Daily*; 3rd photo *courtesy of Xinhuanet* and *Splendid China*).

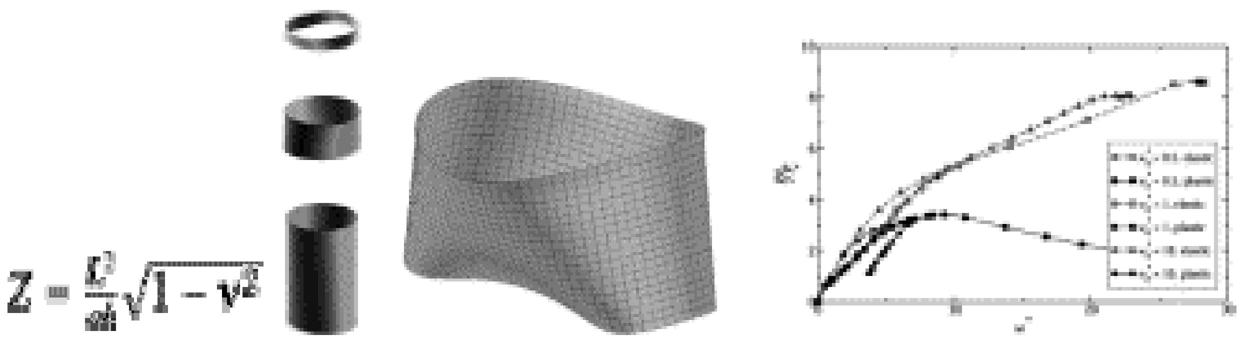


Dr. Qian Xue-sen at 90

Dr. Qian Xue-sen (96) greeting President Hu Jintao – Jan. 19, 2008

After Germany surrendered in World War II, the U.S. Army gave Qian the rank of Colonel, a security clearance, and then von Kármán and Qian were assigned to a specially picked team to debrief Dr. Wernher von Braun and his V-2 rocket team in Peenemunde, Germany – whose V-2 rockets had wreaked such havoc and caused over 5,000 deaths in Great Britain. (The U.S. Army later quietly moved the entire German V-2 team of over 125 scientists and engineers, plus their families, to Huntsville, Alabama – where they began their American rocketry research and development work at Redstone Arsenal. This effort eventually culminated in the launch of the huge *Saturn V* rocket that took the three *Apollo 11* astronauts to the moon in July 1969.)

Here are some shell buckling illustrations from Professor Qian's own files:



For those readers who may have not heard of Qian Xue-sen, suffice it to say that Qian has been regarded by many as *the* top man in charge of developing China's missile and space programs in the past half-century. (Qian was deported by the U.S. back to China in 1955. When interviewed by *TIME* magazine in a mid-1960s article after China launched her first ICBM, a top U.S. Army general, who was familiar with Qian's case, said that "Qian knew way too much; we should have never let him go. He was 'worth five Army divisions!' ")

The late Iris Chang, famed Chinese American journalist who later authored the sensational 1998 international bestseller *The Rape of Nanking*, earlier wrote an unauthorized biographical account of Qian's life, based on her research and interviews with people who knew him from his MIT and Caltech days. Chang's paperback is called *Thread of the Silkworm* (1995); it is the only book in English, which I am aware of, on Qian's life. **Lesson #5:** *A person should be keenly aware of the fact that sometimes in life, "big picture" events can affect his/her career, and make life take a different turn.*

A brilliant scientist and engineer, though widely known to be quite brash, Qian Xue-sen remains to this day an enigma, and a controversial figure in the U.S. The FBI lifted his security clearance in 1950, and later, placed him under "house arrest" in Pasadena (1950-1955)]. As part of secret negotiations conducted in Geneva between China and the U.S., which resulted in an exchange of

Dr. Qian for several American prisoners-of-war captured during the Korean conflict, Chairman Mao Zedong (who had specified Qian Xue-sen by name) and President Dwight D. Eisenhower personally arranged a deal that resulted in Qian's return to China.

I have some relatives who lived in Los Angeles or Pasadena during those years, who had known Qian socially during this turbulent 1950-1955 Korean War and McCarthyism period. They told me that Qian never even once discussed his politics with them, nor gave any indications he was a Communist sympathizer or spy. They thought he was a "regular guy" – just another super-smart young Chinese professor at Caltech. Their recollections about Qian were that, for all his tremendous rocketry and numerous other technical contributions to the United States before, during, and after World War II, Qian felt he was treated like a "common criminal" by the U.S. Government and the FBI in the 1950-1955 period, and unjustly accused of being a Communist and "spying" (a charge which was never proven in court). This insult then slowly resulted in Qian's "growing disillusionment with America," leading to his eventual return to China in September 1955.

As I mentioned, Dr. Qian had replied to me in August 1978, but declined my request to interview him. I then made another attempt to contact him. When I attended the first-ever international finite element conference in Shanghai in August 1982, I asked some Chinese finite element researchers (from Beijing) whom I had met there, whether they could help me arrange a meeting with Dr. Qian in Beijing. They were somewhat startled by my request, and politely informed me that Qian, as a general practice, "did not see foreign visitors."

Upon my return to the U.S., and since I possessed (at that time) a security clearance and was working at PDA Engineering (a defense contractor), it was standard procedure (for an American citizen who had traveled to a Communist bloc country) to be debriefed by the FBI upon return. The FBI asked me about the reasons for my China trip, what I saw there, and whether anybody tried to contact or recruit me while I was in China. After the FBI was satisfied with my answers, I then informed the local FBI agent that I still had, in my possession, the original letter written to me by Qian Xue-sen in 1978. The agent cordially asked if he could see and read Qian's short, 1-page, type-written letter to me, then made a copy for his files, and said he would research the matter further and get back to me. (The young man had no idea who Qian was – nor the murky circumstances that led to the FBI's accusations of his being a Chinese spy, and his deportation to China in 1955.) I politely suggested to him that FBI's headquarters probably still had, somewhere, an entire basement of classified files and boxes on the Qian investigation. The next time I saw the same FBI agent, a few months later, I noticed that (. . . much to my chagrin) his xeroxed copy of Qian's 1978 letter to me was now stamped *Top Secret.*

Acknowledgments: The author would like to thank Peter Marks and Stephen Perrenod for their careful reading of a draft of Part 1.A, and their excellent comments. In addition to those people already named, I would also like to thank these engineers for what I learned from them: Robert S. Shorey and Wellington T. Su (General Dynamics-Convair); Richard K. Wilson, Fino Calamaro, and John J. Dietrich (McDonnell Douglas Astronautics Company).

-*End of Part 1.A*-
