

The Contributions of Dr. Pei Chi Chou to Scientific Research, Especially Ballistics, and to Engineering Education

A tribute on the occasion of his seventieth birthday

by

W.J. Flis, Dyna East Corporation

S. Carmi, Drexel University

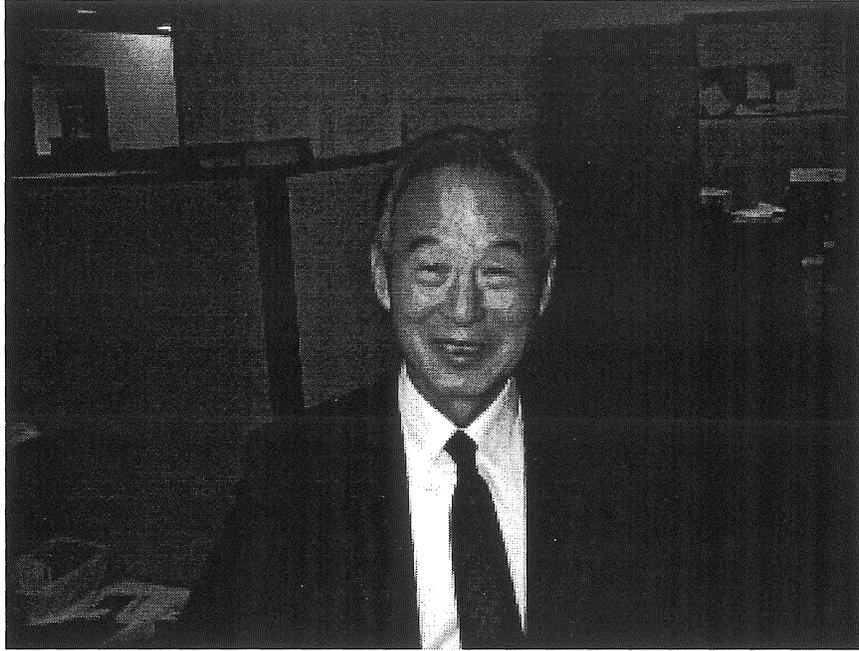
A. Wang, Drexel University

Introduction

Doctor Pei Chi Chou is a remarkable individual serving the engineering profession with distinction; an academician *par excellence*; a world-renowned researcher, who has made a long lasting contribution to the field of mechanics in general and to impact ballistics in particular; an outstanding educator who pioneered the research program that propelled Drexel Institute of Technology to University status following the granting of the first Ph.D. to one of his students; and a dedicated citizen with devoted service especially to the Chinese-American community. Pete impresses everyone with his deep sense of professionalism and dedication to engineering and at the same time with his free spirit of entrepreneurship, a great asset in today's global economic arena. Dr. Chou is well-known internationally, spanning the globe from the U.S. to China, to Europe, to Russia, to Israel. He is known as "Professor Chou" to hundreds of Drexel students, "Pete" to his friends and colleagues, and "Uncle Peter" to hundreds of Chinese student-campers.

This paper is a modest attempt to provide a perspective on some of Pete's work, as we celebrate his 70th birthday. A brief biography, his contributions to Drexel University, Dyna East Corporation, the ballistics community, and his service to the Chinese-American community are all included in this article, along with a list of his Ph.D. students, publications, tributes, and citations. Although Pete has decided to formally retire from his regular University position this coming year, we expect him to continue his productive research and guidance of students for many years to come. We wish him a long, healthy, and productive life along with his wife Rosalind and his sons and family.

Pei Chi Chou — A Brief Biography



Born on December 1, 1924 in Ichang, Hupei Province, China, Pei Chi was the third of five children of Hung Lieh Chou, M.D., and Shiu Lan Kao. When he was ten years old, his father, a director of Chiluh Hospital in Ching Tao, Shantung Province, sent him to the best boarding school in Peking. When Japan invaded China, he and his two brothers were sent to Chungking, the war-time capital of free China, where he finished high school, entered the National Central University and graduated in 1946 with a degree in aeronautical engineering. He qualified for further studies in the United States and in 1947 went to New York City, where his married sister lived, to attend New York University. He soon transferred to Harvard University, where he received a Master of Science in Aeronautical Engineering in 1949. The Communist takeover of China in that year interrupted the flow of funds from home, so Pei Chi returned to N.Y.U. to earn his Doctor of Engineering Science degree in 1951. However, the cash-poor summer of 1949 offered memorable experiences to Pei Chi as he supported himself delivering telephone books, picking potatoes, and working on an assembly line in a munitions factory.

Before joining Drexel as an assistant professor in 1953, Pei Chi worked at Republic Aviation. Later, he served as a consultant to the Budd Co., Philadelphia, 1955–57; Prewitt Aircraft Co., Clifton Heights, PA, 1957–8; Kellet Aircraft Corp., Willow Grove, PA, 1958–62; the Allegheny Ballistics Laboratory, Cumberland, MD, 1961–63; and the Air Force Materials Laboratory, Dayton, OH, 1966–70.

Pei Chi married Rosalind Chen in 1956. They now have four sons and, so far, four grandchildren. He is delighted that his third son is a mechanical/materials engineer, while the oldest and youngest are physicians and the second is a lawyer. As described later, in 1968, Pete co-founded the East Coast Chinese Family Camp, which nurtures and maintains heritage and family unity, and in 1972, he inaugurated the

Association of Chinese Schools, which recently established accreditation standards for teaching the Chinese language in high schools. Pei Chi has remained active in both.

In 1968, he started Dyna East Corporation with several Drexel students. Today, most of Dyna East's engineers are still Drexel graduates, and Pei Chi is proud and happy to have handed over the reins of management to his lawyer son.

Contributions through Drexel

Pete has made important contributions to research and education at Drexel University. He was the first professor at Drexel Institute of Technology (as it was then known) to be awarded research funding from external sources. Recognizing the strong connection between research and graduate education, Pete took the lead in encouraging and assisting Drexel to implement full-time advanced-degree programs in Engineering. First, full-time master's-degree programs in Mechanical and Electrical Engineering were instituted in September 1962; Pete led all professors in his level of research support and in number of student advisees during the initial years of this program. Subsequently, Pete was instrumental in developing Drexel's doctoral program. He helped prepare a formal plan for submission to the State of Pennsylvania, and after a critical review by a national blue-ribbon committee, Drexel was officially granted the right to bestow the Ph.D. in Applied Mechanics, effective September 1965. Pete directed the first Ph.D. student, Richard Mortimer, who got his degree in June 1967 and then went on to a distinguished career at Drexel, as a Professor, Department Head, and Associate V.P. for Academic Affairs, and outstanding service to the profession (ABET, ASEE, and ASME). Since then, Pete has supervised 22 more doctoral students, including eleven who remain active in ballistics, and ten who have contributed some fifteen papers (independent of Pete) to this very Symposium.

Pete founded and directed Drexel's Wave Propagation Research Center, a multidisciplinary group of faculty and students pursuing research in the broad area of wave propagation, including hypervelocity impact, explosive-metal interaction, blast, and the resulting dynamic structural and material response. This group, which included mechanics, materials scientists, mathematicians, and physicists, developed the MCDIT and MCDU series of method-of-characteristics computer codes, state-of-the-art and well-known at the time. The Explosives Laboratory established by this group, a unique feature among universities, is still in operation, under Pete's direction, for use in teaching and research. The WPRC produced a large number of doctoral degrees, including Drexel's first. In addition, this group directed research carried out by a much larger number of Master's-degree candidates.

With Nicholas J. Pagano, Pete wrote *Elasticity: Tensor, Dyadic, and Engineering Approaches*, published in 1967 by Van Nostrand's University Series in Basic Engineering, which was edited by William W. Hagerty, Drexel's President at the time. This long-time standard classroom text at many engineering schools has recently been republished by Dover Books. He also edited the book *Dynamic Response*, and served on the Editorial Advisory Board of the Journal of Composite Materials. Over the years, Pete has extensively collaborated with his faculty colleagues and co-authored papers with sixteen Drexel professors: Drake, Mortimer, Pagano, Koenig, Lorens, Tsou, Wang,

Rose, McNamee, Rogers, Tan, Lau, Meir, Tseng, Awerbuch, and Toland.

Pete was named J. Harland Billings Professor of Mechanical Engineering in 1973, one of the first named professorships at Drexel, a title he holds to this day.

During the period 1970-73, Drexel's College of Engineering was organized in an experimental "grid-structure," which consisted of vertical administrative lines across the traditional curricula and horizontal research lines grouping faculty studying in similar areas. Pete was chosen to head the Mechanics and Structures Advanced Studies Group, which included all Mechanics and Structures faculty. (In 1973, the experiment was concluded and the College reorganized back to the traditional structure of departments by disciplines, Mechanical Engineering, Civil Engineering, etc.)

As head of this group, Pete initiated in 1970 the establishment of Drexel's Composite Materials Laboratory by inviting Drs. Richard H. Toland (now Chief Engineer, United Engineers and Construction Co., Philadelphia) and R. Byron Pipes (now President, Rensselaer Polytechnic Institute) to join the faculty. At that time, Drexel was among only a handful of colleges that offered programs in composite materials at both the undergraduate and graduate levels, and engaged in active theoretical and experimental research in this field. Initially, Pete directed and participated in this research, in the areas of wave propagation, impact response, and fatigue-failure models; his leadership was instrumental in raising Drexel to preeminence in composite-materials research through the following 25 years.

Pete also contributed to the development of the rotary-forging manufacturing process, which has found an important application in the near-net-shape fabrication of EFP liners. Starting with an undergraduate student design project, Pete built this into a major study, which he led and coordinated between Dyna East and Drexel with the sponsorship of the National Science Foundation and the Advanced Technology Center of Southeastern Pennsylvania. This effort culminated in the construction of two operational machines, with numerical control and robotic material handling.

He has also been active in the American Institute of Aeronautics and Astronautics for many years, and recently received an award for 40 years' service. He also received the "Division Flag Award" of the Aerospace Division, American Society of Mechanical Engineers, in February 1991.

All in all, Pete's contributions to Drexel University have helped make it an important international center for research and education.

Dyna East Corporation

It is through Dyna East Corporation that Dr. Chou has made his most important contributions to the ballistics field. This venture originated in 1968, when it was incorporated by Pete as a vehicle for his personal consulting. Then, in 1973, it became a "real company" with the hiring of two of Pete's recently graduated Ph.D.'s (Joseph Carleone and Donald Tuckmantel) and a few undergraduate students (notably Robert Ciccarelli, now Vice President), who occupied a fondly remembered one-room office above Cavanaugh's Restaurant and Jailhouse Bar, Drexel's unofficial "recreation

center.” Dyna East’s first ballistics projects were undertaken through the sponsorship of the Ballistic Research Laboratory (shaped-charge research), the Frankford Arsenal (shaped-charge design), and the Watertown Arsenal (modeling of interior ballistics).

Over the years, under Pete’s leadership, Dyna East has gradually expanded into a full-service company for warhead research and development, including fabrication of prototypes and their testing. In 1986, Dyna East moved to its present location, also adjacent to Drexel’s campus, occupying some 10,000 square feet of office space, plus a manufacturing shop and ballistic test range at other locations.

Meanwhile, the range of Dyna East’s technical fields has evolved and expanded. In the late 1970’s and early 1980’s, important contributions were made on the design of EFP’s, in several programs with Honeywell’s Defense Systems Division (now Alliant Techsystems), including the development of the first demonstrated aerodynamically stable EFP. In the early 1980’s, research expanded into the mechanics of jet penetration, especially against modern armors. Several projects addressed the development of tandem warheads for defeat of armor and of underwater targets. From the mid-1980’s to the present, work has continued on the design and development of advanced armors for defeat of shaped charges and projectiles. All along, Pete has guided and materially contributed to all of these efforts.

On a local note, through Pete’s efforts, Dyna East, in association with Drexel, has hosted long-term (one- or two-year) visits by a number of eminent ballistics researchers from Israel, including Eitan Hirsch, Simcha Miller, Reuven Granot, Eliahu Racah, and Dan Tsur. These stimulating collaborations yielded important innovations in shaped-charge theory, computational methods, and experimental techniques.

Today, Pete remains President of this flourishing company of twenty full-time employees, still active in research and participating in the day-to-day business affairs.

Contributions to ballistics research

Pete has made many important contributions to ballistics, especially in the mechanics of shaped charges, in particular:

- Shaped-charge liner collapse. With Carleone, he modified and calibrated Richter and Defourneaux’s projection-angle formula, and later contributed to the development of a Gurney-type formula for hollow cylindrical charges; with Eitan Hirsch, he formulated the unsteady liner-projection theory which yielded a more general form of the Taylor formula for liners having non-uniform accelerations.
- Shaped-charge jet position related to initial position within the liner, thus giving a description of the jet’s velocity versus its position at any time, allowing the computation of the jet strain rate and radius.
- Well-known studies, with Carleone, of shaped-charge jet breakup, including one-dimensional models of jet instability (neck formation) and a semi-empirical breakup time formula, which is still widely used.

The success of these three studies culminated in the development, in 1975, of one of the first complete one-dimensional computer codes for shaped-charge design, DESC (Dyna East Shaped Charge).

He has also made numerous other contributions to ballistics, including: hemispherical shaped-charge jet formation; examination of the approximation involved in the virtual-origin assumption; aerodynamic drag on the jet tip; the effect of charge rotation (spinning) on jet formation, including insights into the mechanisms of spin-compensation through liner fluting and anisotropy; the effect of anisotropy on jet breakup and EFP formation; techniques of hydrocode analysis, including rezoning, shear bands, and metalforming; modeling of reactive armor; and many contributions to warhead design, especially EFP's, tandem warheads, and underwater warheads.

His recent work has focused on the study of the response and initiation of explosives due to mechanical stimuli, including shock and impact. This has included work on shear bands in explosives, reaction-rate modeling, and, most recently, the solid-mechanics properties and constitutive modeling of explosives.

In 1988, Pete was instrumental in founding Drexel's Center for Ballistics, under the co-sponsorship of the ADPA. Pete, as the Center's Director, has contributed to curriculum and course development as well as teaching. The Center offers graduate courses leading to a Master of Science degree in Ballistics. Courses have included Physics of Explosives, Impact and Wave Propagation, Numerical Methods in Ballistics, Interior Ballistics, and Exterior Ballistics. Many students have graduated with M.S. degrees from the Center since its inception. From 1989 to 1993, the Center also offered short Continuing-Education courses, such as Fundamentals of Shaped Charges, Warheads and Terminal Ballistics, and Interior Ballistics. Many of the courses were taught by experts from the Ballistic Research Laboratory, including Drs. R. Eichelberger, R. Frey, B. Burns, S. Segletes, W. Walters, and Mr. A. Host. Starting in 1991, several of the graduate courses were taught also at Aberdeen Proving Ground to better serve students from BRL, and later general engineering courses were added to establish a permanent off-campus M.S. program there.

Pete has long been active in the International Symposia on Ballistics, as a member of the sponsoring ADPA Ballistics Steering Committee, and continuing now on the International Ballistics Committee. In addition, he has presented some eighteen papers through this Fifteenth Symposium. Pete's contributions to ballistics were formally recognized in 1990 when he received the ADPA's John Ulrich Award for Outstanding Leadership.

Contributions to the Chinese-American Community

Dr. Chou's university teaching and research career has spanned from 1953 to 1995. Much more can be written about his significant contributions as a foremost engineering educator and world-renowned research scientist over a career of almost half a century. It is less widely known, outside his professional circle, that Pete has contributed just as significantly to the Chinese-American communities in which he and his family lived during the same period of time.

About 1960, the Chous and six other families organized a Chinese Language School in suburban Philadelphia with only 12 young children; the purpose of this

school was to teach Chinese language, heritage, and culture. In this endeavor, Pete was to remain an ever-present force over the next 30 years. The school founded by Pete in 1961 has grown into the Main Line Chinese School in Radnor, PA, which celebrated its 30th Anniversary in 1991 with more than 80 families and 200 students. Today, about 10% of the School's students are non-Chinese, and some of its advanced courses have been integrated into the curricula of Radnor High School.

With the influx of Chinese immigrants, Chinese schools have sprouted all over the United States, especially on the East and West Coasts. With this phenomenal growth in numbers, there arose pressing issues to be dealt with and demands to be met in every school; a well-coordinated effort among all the schools was needed to address these problems. Thus, in 1968, Pete single-handedly founded the Association of Chinese Schools (ACS). Starting from just seven schools, ACS today comprises nearly 100 schools from Boston to Washington alone. Annual conferences have been held uninterrupted since the group's founding, and recently, ACS established accreditation standards for teaching Chinese in high schools. Pete continues his involvement in this organization to this date.

By the late 1960's, the Chou's children were in their early teens. As parents, they must plan well ahead what to do with the children during their long summer recess from school. In 1968, with only a few Chinese families sharing his vision, Pete was instrumental in starting a Chinese family camp for the children and their parents in a mountain retreat for a week during the summer. But, unlike the usual children's summer camp, this Chinese family camp is unique unto itself; Chinese arts, history, and culture are blended with sports, recreation, and cooking in an extended-family atmosphere. For more than 25 years in succession, the East Coast Chinese Family Camp has held its annual sessions, sometimes with more than 500 attending.

The effects of the Camp experience on the children are immeasurable; and, to some extent, the effects on the parents are even greater. A youngster who attended the Camp during 1985-91 wrote recently: "I view Camp as a lifetime experience, not a mere one-week event. . . Camp spirit is caring. It is big cousins giving little cousins piggy-back rides. It is eating fifty *jiaozi* [Chinese dumplings] and not feeling sick. . . . It is our love and need of our own heritage that binds us together." A parent attending Camp during 1972-85 expressed another viewpoint: "Those of us who participated for ten or more years had the pleasure of seeing nearly all the children grow up to have a sense of humor, and be confident, happier, and better citizens than their parents. As parents, we also hope that the children marry right. That, to us, will be an extra bonus."

The existence and continued success of the Chinese Family Camp is due to a handful of individuals who carefully and diligently guided the organization through some 20-plus years. And, Pete has been the central pillar of this support.

Peter was, is, and will be an educator. Retirement from Drexel University will likely close the chapter of his formal teaching career; but his involvement as an educator inside and outside the University will definitely continue. This has long and deeply been ingrained in his person.

Tributes

Over the last eighteen years, I have had the distinct pleasure of collaborating with Pete Chou on several technical reports and journal articles. These publications represent only a small fraction of his achievements in the fields of mechanics and engineering. Our joint efforts involved shaped charge studies but Dr. Chou also contributed extensively in many other areas including wave propagation, elasticity, and the behavior of high explosives. We also taught several short courses and university courses together.

I found Pete to be an excellent teacher and a dedicated, conscientious researcher with tremendous insight into the basic mechanics of material behavior. Working with him has been a great learning experience for me. I wish him all the best for the future.

William Walters
Research Engineer, U.S. Army Research Laboratory
Aberdeen Proving Ground, Maryland

It is a pleasure to offer my congratulations to Dr. Pei Chi Chou on his seventieth birthday and his retirement from Drexel University. I first met Pete at Drexel before he started Dyna East. At that time I was a research physicist at the Ballistic Research Laboratory. The small blast chamber in the basement of one of the University buildings is still fresh in my mind! I was used to sturdier stuff. From that time I have seen Dr. Chou make major contributions to the theory of shaped charges and penetration mechanics. Many of the researchers in this field received their training from Dr. Chou. His cooperation with government laboratories and their staffs established a firm theoretical support to their experimental work. All of us in the field of high-velocity impact owe a debt to Pete. My colleagues and I at Battelle wish him well on his retirement.

Robert L. Jameson
Research Leader, Battelle
Edgewood, Maryland

As a colleague and a schoolmate back in the 1940's, I would like to congratulate Pete on his retirement this year and welcome him to our Club of Evergreen in Philadelphia, Drexel's Alumni Club in Taiwan, and the Alumni Club of National Central University in Chung-Li, Taiwan. Over the years, Pete's hard work and contributions to the mechanics area, including compressible flow, ballistics, and composite materials, have been widely recognized and gained him world renown as a scholar. I enjoyed and participated in his early research and development work, which influenced my later work in the fluid mechanics and cooling technology areas.

At this milestone of Pete's life, I wish him health and happiness for many, many golden years to come. Shall we both plan a world-wide trip together and enjoy fine food and visiting old friends?

Fu-Kang Tsou
Professor Emeritus, Mech. Engrg. and Mechanics, Drexel University
Visiting Professor, Mech. Engrg. Dept., National Central University
Chung-Li, Taiwan

I am always amazed how many different activities that Dr. Pei Chi Chou has touched and contributed to through the years. When he decides to take on a subject, his effort is always done correctly and sets the stage for others to follow. It was in the late 1960's that he and I discussed composite materials as an up-and-coming field for serious mechanics analysis. Then in late 1972, he and his student J. Carleone wrote "Elastic Constants' of Layered Media" for the Journal of Composite Materials. This work was later followed by N.J. Pagano in 1974, C.T. Sun and S. Li in 1988, H.J. Chen and myself in 1995, and possibly by others also. In the statistical analysis of fatigue data and life predictions of composite materials, Dr. Chou again put the house in order. We all wish him well in his impending retirement. We also know that he is not going to sit in a rocking chair. Instead we expect him to continue to challenge the younger and not-so-young generations as he always has.

Stephen W. Tsai
Department of Aeronautics and Astronautics
Stanford University

I have known Dr. Chou for almost twenty years. I believe we first met at the Third International Symposium on Ballistics in Karlsruhe, Germany. I remember him at that first meeting to be very friendly and approachable, even though he was a distinguished member of the ballistics community and I was just a newcomer. As I recall, he even presented part of his paper in German at the Symposium.

During the past years I have had the opportunity to work with Dr. Chou on several occasions. I always enjoyed going to Dyna East because the people were good technically, the problems were interesting and challenging, and the working atmosphere was pleasant. Dr. Chou has always had the ability to quickly get to the heart of the problem, and then to understand it with a range of approaches, from simplified models to sophisticated computations.

I wish him well in the future and hope that we will have more opportunities to work together.

Gordon R. Johnson
Chief Engineering Fellow, Alliant Techsystems
Hopkins, Minnesota

As a life-long denizen of the West Coast, my relationship with Pete Chou has been necessarily limited to our contacts at technical meetings of the ADPA Bomb and Warhead Section, International Ballistics Symposia, and occasional special technical meetings where we both participated. The many excellent reports and technical presentations by Dr. Chou and his colleagues attest to Dr. Chou's expertise as both a teacher and scientist. Through these and my relationships with several of his former students, I developed a deep respect and an admiration for Pete Chou as a force to be reckoned with in our mutual areas of interest. I am impressed by his novel solutions to difficult problems and his development of novel manufacturing methods to fabricate critical hardware elements. I regard Dr. Chou as one of the very few true innovators in shaped charge, and cannot think of a higher praise. I confess to being somewhat envious of his ability to develop and demonstrate his ideas through both his associations

with Drexel University where he trained the minds of his students, and his corporate enterprise, Dyna East Corporation, which provided a means to introduce and implement his ideas into practice in the field of ballistics. The high regard of both the academic and ballistics community for Dr. Chou is demonstrated by his many awards and recognitions. It was my honor to participate in the ADPA Bomb and Warhead Section's recognition of Pete Chou's major contributions to ballistics technology. I am honored to have this opportunity to provide this tribute, to congratulate Pete for making it to 70, and to wish to my dear friend a long and happy retirement!

Donald R. Kennedy
President, D.R. Kennedy and Associates, Inc.
Los Altos, California

When I became interested in studying shaped charges in the late '70's, I learned a lot from Dr. Chou's description of DESC, which was the first analytical computer code written for shaped charges. At that time I was writing a code of my own and was lucky to publish my first paper in this field. For my sabbatical year of 1980-81, I naturally applied to Dr. Chou to work with him, enclosing my paper as a self-recommendation.

Since Dyna East was in those days a very small company, Dr. Chou wanted to make sure to find a good subject for me to work on. Thus, we met during the 5th Symposium on Ballistics in Toulouse, where Dr. Chou suggested that I work on "explosive-metal interaction." I had no idea what he meant by that!

So I came to Philadelphia and received excellent hospitality and great help in finding accommodations at Wynnewood House. Within two weeks, I found myself deep in the study of the projection-angle problem, while attempting to solve the relevant differential equation either using a computer or analytically. Two months later, when the first stage of the problem was finally cracked, the work really became most fruitful and interesting. We met almost every day, discussing all sides of the problem. We took up the additional subject of the virtual origin, while writing drafts of a paper on our obtained results for the 6th Symposium on Ballistics.

It was not just a very interesting year for my family and myself but also a period of the most fruitful work I ever had with any scientist. Under Dr. Chou's leadership, in the numerous intensive discussions we held, fundamental basic results were produced which led to many later excellent works. Perhaps the best indication of the significance of that time is the number of papers at this current Symposium that are directly or indirectly based on the work done then.

Following my stay, several of my Israeli colleagues were invited by Dr. Chou to work at Dyna East during their sabbaticals. All of them enjoyed their experience there, learned a lot, and came home with achievements in their fields of interest which helped them greatly and gave them a good push of progress. We all feel the deepest gratitude to Dr. Chou for his excellent teaching of conduct in research practice and for his good friendship and scientific leadership.

Eitan Hirsch
Netanya, Israel

Over the many years in which I have known Pete, I have been impressed not only with his own contributions to a better understanding of shaped charge phenomena, but also with the contributions made by his students, who carry on the tradition of quantitative creative thinking which he has instilled in them.

I am pleased to recognize Pete's attainment of age 70, and to express the hope that he remains active after his retirement from Drexel, so that we can continue to benefit from his insights. Good luck, Pete!

Louis Zernow
President, Zernow Technical Services, Inc.
San Dimas, California

As a friend, a student, and later a research associate, I have known Dr. Chou for more than thirty years. I would like to express my deepest appreciation for his tireless encouragement, guidance, and inspiration during the time of my dissertation work at Drexel University. I obtained my Ph.D. from the University of Pennsylvania, but my dissertation was completed under the tutelage of Dr. Chou prior to the establishment of a doctoral program at Drexel.

During his tenure at Drexel, Dr. Chou has spearheaded numerous research programs. He possesses the rare quality of profound theoretical understanding. In addition, he knows how to develop a theoretical concept into practical applications. Students working in his laboratories not only gain experience in theory, but also in other areas. Many of his students have gone on to become valuable employees for government agencies and industry.

Dr. Chou has made significant contributions to all three services in the Defense Department. Specifically, I would like to acknowledge his efforts that have made the Navy's advanced composite wing structures more impact-resistant.

Besides his academic and engineering achievements, he has worked to benefit the community. He is a founding member of the East Coast Chinese Family Camp, an activity that has benefited thousands of American youth of Chinese heritage.

On his retirement, I wish him good health and happiness for many, many years to come.

Dr. Shih L. Huang
Superintendent, Aero Structures Div. (retired), Naval Air Development Center
Southampton, Pennsylvania

It is a personal privilege and honor on this momentous occasion to extend to Dr. Chou my heartfelt thanks for the impact he had on my career. As a married undergraduate with children, my goal in life was to earn my B.S. in Mechanical Engineering as soon as possible and then earn money to support my family. During my junior year, I accepted a co-operative job with a professor who had the reputation for being demanding but fair, a disciplined teacher, an excellent researcher, and a straightforward person—Dr. Chou.

Working with Dr. Chou proved to be a godsend. Through him I became aware of the excitement and challenges of research and the rewards of teaching. Needless to say, by the time I was awarded the B.S. degree, my goals had drastically changed and I commenced full-time graduate studies. Subsequently, Drexel was granted the authority to award Ph.D.'s, so I returned to Drexel from the University of Pennsylvania and had the privilege and honor of having Dr. Chou as my Ph.D. thesis advisor.

My subsequent career of teaching, research, and administration would not have occurred without the guidance, support, and friendship of Dr. Chou—for this I am extremely grateful.

Richard W. Mortimer
Professor, Mechanical Engineering, Drexel University

It is my honor to offer Professor Pei Chi Chou congratulations and best wishes upon his retirement from Drexel University, and a happy seventieth birthday. Pete was my doctoral adviser, teacher, and friend while I attended Drexel Institute of Technology in the sixties. I want to thank him for the help, encouragement, and motivation he provided to me and his other students over the past 35 years. We truly appreciate it.

Pete's many significant contributions to the general field of engineering mechanics, including wave propagation, hypervelocity impact, composite materials, and warhead mechanics, are internationally recognized and appreciated. Over the years, he has consulted with NASA, the military services, and other governmental and private organizations and authored many excellent papers and textbooks. He has been a technical resource for Drexel University, Dyna East Corporation, and the country. While his contributions as a researcher are well-known, I consider his excellence in teaching to be his greatest attribute. Pete, enjoy your retirement from Drexel; it will allow you time to pursue your other interests.

Robert R. Karpp
Los Alamos National Laboratory (retired)
Valrico, Florida

Pete Chou has been many things to me during my career: teacher, advisor, mentor, and expert assistant to assemble cribs during my early stages of my engineering career. He sought and rewarded near-perfection. What student could forget the red marks on the first few pages of a draft paper, thesis, or report. He had insight into dynamic phenomena that hasn't been rivaled by many. I recall Dick Schaller spending several months hard at work to obtain a solution to a particular problem; he presented the results to Dr. Chou (I still want to call him that after all these years)—who then pulled out a slide rule and pronounced that he had a mistake in the third decimal place!

After I completed graduate school, I didn't have a lot of contact with Pete, until I became involved with the international series of ballistics symposia. I can tell you that he is widely esteemed by colleagues all over the world, especially through his technical work in shaped charges, and through his participation in the organization of such affairs. He is also a strong member of the ADPA Ballistics Division which hosts half of these well-known symposia.

His interest in education has clearly been a major factor in his life ... who else would have the energy to organize a graduate program in ballistics ... and then get me involved in it. To me, he will always be the major factor in my professional life, and I can relate to you that the research I completed under his tutelage has stood me in good stead throughout my career. I can honestly say that I feel that I have an unfair advantage in dealing with others due to my education in the Pete Chou school of professional life.

Bruce P. Burns
Army Research Laboratory
Aberdeen Proving Ground, Maryland

It is a pleasure to extend my congratulations on an excellent career and continued best wishes for a healthy, long, and exciting retirement to P.C. Chou. My special thanks also go out for his encouragement and introduction of me to graduate school in pursuit of a Ph.D. I received my Ph.D. under the guidance of P.C. Chou on December 12, 1969. Having produced some twenty-four Ph.D. students so far in my own career at Drexel and Penn State Universities, I've continued to carry forward his teaching of life to all of them as well as his technical contributions in wave propagation applied to my work in ultrasonic analysis. In recruitment, I'll never forget, "Joe, you must obtain a Ph.D., you owe it to yourself, your family, society, and your country. You must make the best of your capabilities." I still tell this to new students in my recruitment efforts. Another famous expression of his was, "It's part of the training, Joe," referring to social activities as well as professional and technical activities. Another expression on learning was "Joe, read it again," for various questions that I presented to him. He was right; each reading was clearer in pointing out specific points all leading to independent work activity and creativity. P.C. Chou has always been a master of simplicity in presentation. He could make complex lengthy material appear straightforward and simple. He taught me a great deal about writing with various elements of style and presentation. I've tried to follow his example in most of my own work to date.

Again, best wishes to Pete for continued success and a fulfilling retirement.

Joseph L. Rose
Paul Morrow Professor of Engineering Science and Mechanics
Pennsylvania State University, University Park, Pennsylvania

I was one of Dr. Chou's first students in the new Ph.D. program at Drexel University. The backbone of the program was Dr. Chou. Without his reputation in the technical community and his exceptional ability to attract research funding, the program never would have succeeded.

One of the things that I remember most about Dr. Chou was that he was very demanding, but at the same time, he would stand by you when you faltered. After doing more poorly in a test than I should have, he assured others that I indeed knew the subject. He then made sure that I would never falter again by having me teach a graduate course in that subject. His words of wisdom, which I haven't forgotten to this day, were that one does not truly learn a subject until one teaches it. While I was at Drexel and afterward managing Dyna East for Dr. Chou, he was continuously breaking new

ground in the fields of wave propagation and composite materials. Not so coincidentally, he would enter a new field by personally teaching a course in that subject.

Dr. Chou ingrained in me the merit of being precise when communicating with others. His demanding voice is still vivid in my mind today after more than 20 years, sounding "Say what you mean." He was a perfectionist when it came to expressing one's thoughts clearly. To this day, I can hear his voice when I am speaking and have become as demanding as he was when dealing with others.

I thank Dr. Chou for all he has given me, the technical training, the fatherly advice, and the fun and challenge of starting Dyna East Corporation. I remember one of the "smartest" things he did was to appoint his wife, Rosalind, as security officer for the new Dyna East. Rosalind and I spent many hours setting up the program, getting the proper safe, and securing the firm's security clearance. I'm sure he had a smile through all of this.

To Dr. Chou, good luck in the future, and may you and your family have many happy years of retirement.

Donald L. Tuckmantel
Project Engineering Manager, Raytheon Engineers and Constructors, Inc.
Philadelphia, Pennsylvania

Researcher, teacher, engineer, mentor, entrepreneur, businessman, jogger, skier ... these titles help to describe one of the most dedicated persons in the fields of ballistics, solid mechanics, explosives, and wave propagation, Pei Chi Chou. My deepest congratulations on your seventieth year and my best regards to Rosalind and your family.

It is with particular pleasure that I have the opportunity to thank you for the many years of support and guidance, first as my major professor at Drexel then as the leader of Dyna East Corporation, where many of the modern foundations of warhead design mechanics were developed. Your vision, foresight, and energy continue to be an inspiration to me.

Who of your former students can forget your ability to immediately get to the crux of the problem, your direction to always return to the fundamentals, your admonishment to make our presentations concise and to the point, and your challenge to "say it in one sentence"?

In closing, I wish you health and happiness, a long life, and continued fruitful research.

Joseph Carleone
V.P. Tactical, Defense, and Armament Programs, Aerojet
Rancho Cordova, California

I started working in Dr. Chou's group in the summer of 1967 as a co-op student with the assignment of assisting his graduate students in their research. Back then the group was called the Wave Propagation Research Center and included several of his earliest doctoral students; I was actually hired by Dr. Chou's first doctoral student, Dr. Richard Mortimer. In this environment I learned applications for the math and physics-

ics I studied as an undergraduate by solving impact and wave problems by the Method of Characteristics. I also vastly improved my skills in Fortran, working with large codes consisting of several boxes of cards. Later, in the early 1970's I decided to become one of Dr. Chou's graduate students and was involved in a transition of work from wave propagation to the reliability of material systems, especially composites. During this period I worked side by side with Dr. Chou in learning the basics of statistics as a tool for our research. This work led to several new courses in Mechanical Engineering, to projects of several doctoral students working in the reliability of materials (of which I was the first) and to yet another area of expertise for Dr. Chou.

Congratulations to you for an extremely productive career at Drexel and best wishes for a long and happy retirement. Ironically, after 14 years of industrial research at DuPont, I am following in your footsteps with a career change to a high-school algebra teacher, which I remember was one of your first endeavors after undergraduate training. Hopefully, I can make as much of an impact on my inner-city students as you have made in the lives of your students.

Robert B. Croman, Mathematics Teacher
John Bartram High School for Human Services
Philadelphia, PA

Remembering my formative years of Dr. P.C. Chou's tutelage in ordnance technology is analogous to looking back at the evolution of personal computers. One wonders how we made do with the equipment that was available at the time.

Since I was a veteran of military service with "hands-on" experience with conventional munitions, Dr. Chou decided that responsibility for the experimental aspects of shaped-charge research would rest with me. I recall our first tests of full-calibre shaped charges to verify our liner manufacturing methods. Several liners and cases were delivered to an explosive-casting company near Allentown, PA, where the charges were cast with Pentolite. Stacked steel targets were prepared and trucked to a remote site in the Pennsylvania woods. I recall testing these charges, which were Dyna East's first, with cap and fuze detonator/booster assemblies. The fuze was lit and we drove off several hundred yards to await the resultant explosion. It was then my task to go find the target plates tossed about in the underbrush to enable reconstruction of the target stack back in the lab. Smaller charges, about 50 grams each, were tested in a small bunker in Drexel's Mechanical Engineering Laboratories in West Philadelphia. Our neighbors probably wondered what was going on in the unmarked building on Lancaster Avenue in a very urban area.

It is most pleasant to recall how much was accomplished with so little in resources. It brings to mind the saying that "great ideas do not necessarily originate in large rooms." I owe much to the wisdom of Dr. P.C. Chou. I clearly remember that as busy as he was, he always had time to talk with his students and would stop what he was doing to answer a question or clarify a point. I am deeply in his debt.

David J. Leidel
Director of Systems Engineering, BEI Defense Systems Co.
Euleless, Texas

It is my great pleasure to express my heartiest congratulations to Professor Pei Chi Chou on his 70th birthday. On this occasion, I would like to thank Professor Chou for his guidance and full support during the period of my Ph.D. work at Drexel University.

Professor Chou is not only a well-known scholar in Mechanics and Shaped Charges, but also a tireless research worker. His great achievements and contributions in the scientific field provide an example for all of us to respect.

On this occasion, I would also like to wish him good health and further fruitful research achievements.

Sheng-Chih Hung
Technology Superintendent, Chung-Shan Institute of Science and Technology
Lung-Tan, Taiwan, R.O.C.

My association with Dr. Pei Chi Chou spans the last twenty-three years and constitutes my entire career as a professional. Contrary to popular opinion, I did not arrive with Dr. Chou from China on his first trip to the U.S., but we have worked together for so long that I can see how people can make this mistake. It would require at least an entire volume of text to properly present all I have learned from Dr. Chou. Most important of these lessons, in my estimation, is that no task is insurmountable and that any task is achievable through proper preparation and hard work. One of his most famous and often-used expressions is "You can't say you can't do it." He has taught me to stay focused and I owe so much to his guidance.

Pei Chi Chou's contributions, especially in shaped-charge research, have established him as one of the most recognized and respected names in the field of ballistics. It is, however, his other career endeavor that makes Professor Chou special. His work at Drexel University has led to numerous doctoral dissertations. People such as Bob Karpp, Bruce Burns, Joe Carleone, Bill Flis, Dave Leidel, Sheng-Chih Hung, Chris Weickert, and Steve Segletes have gone on to successful careers in ballistics. These men have contributed greatly to our professional community, and they owe their start and, more specifically, their important early education to Dr. Chou. It is through these men that Pete Chou will continue to contribute long after his retirement.

It is therefore a pleasure and an honor to extend my gratitude for his help, and my congratulations for his accomplishments to Dr. Pei Chi Chou on this celebration of his seventieth birthday and retirement from Drexel University.

Robert Ciccarelli
Vice President, Dyna East Corporation
Philadelphia, Pennsylvania

It is my great pleasure to congratulate my former mentor, Professor Pei Chi Chou, on the occasions of his 70th birthday and the publication of this special paper in honor of his excellent contributions to the ballistics research community. I came to Drexel University in 1980 for graduate study from China which had just started to open its doors. Because of historical reasons, I knew little about U.S. tradition, culture, and schools, and had many special difficulties in my early times of study at Drexel. It was Prof. Chou's encouragement and assistance that helped me go through the usually difficult

time. Working with Prof. Chou at Drexel for nearly ten years was a very memorable experience that I benefited from tremendously for my career. I wish Prof. Chou continued well-being and many more fruitful years to come.

Longwu Wu
Senior Applications Analyst, Cray Research Inc.
Eagan, Minnesota

On this occasion, I would like to express my deepest appreciation to Professor Chou for his support and guidance during my dissertation work at Drexel University. I entered the graduate program at Drexel after eight years of research experience with the defense R&D organization in India. My expectations were high. On the recommendations of several faculty, I elected to meet with Professor Chou as a possible doctoral advisor. Even during our first meeting I was impressed with his depth of knowledge and ability to identify goals at the outset. I learned a lot from Professor Chou during our four-year association, specifically the following: (a) How to focus with single-minded devotion on a research issue? (b) How to organize a research team? and (c) How to handle several tasks simultaneously? Though small errors sometimes taxed his patience, he was always encouraging. His mentoring has had significant influence on my academic and professional career. I wish him the best of luck and continued intellectual vigor.

Rajiv Shivpuri
Department of Industrial, Welding, and Systems Engineering
and the Engineering Research Center for Net Shape Manufacturing
The Ohio State University, Columbus, Ohio

It is my honor and greatest pleasure to offer Professor Pei Chi Chou, advisor, mentor, and friend, my sincere congratulations on achieving this retirement milestone after an illustrious career in academia. It is humbling for a starting Assistant Professor to examine the impact that Dr. Chou has had on my life and career. I am at the point where I can appreciate his educational and pioneering research contributions to the scientific community, but at the same time I can see the long, hard road that needs to be traveled to get there. In short I am at the point in my career where I can better appreciate my admiration for him and stand in awe at his accomplishments.

Through my years of interaction with Dr. Chou I have found him to be, at the same time, a simple and a complicated man. I am sure that he has received countless commendations for his various outstanding contributions, becoming somewhat used to such accolades. At the same time I can recall that one of his biggest joys came when he was selected as one of the top ten engineers in the United States. This joy of his, at this unique accomplishment, was one more example, which I try very hard to emulate, that being an engineer before anything else is what makes him most proud and what defines him as a man and human being. It is in this spirit of joy, of his national and international recognition at being an accomplished engineer, that I would like to wish him and his lovely wife Rosalind many more years of happiness and good health.

Javad Hashemi
Department of Mechanical Engineering, Texas Technical University
Lubbock, Texas

It is a pleasure and honor to extend my congratulations to Dr. Pei Chi Chou on the occasion of his retirement from Drexel, after a long and prolific career. His is one of the most widely recognized and respected names in terminal ballistics. As a Drexel co-op at BRL, I cut my teeth on the early Chou and Carleone jet instability work. Later, back at Drexel, I would have the privilege of having Dr. Chou as my undergraduate Senior Design advisor and eventually my thesis advisor. With true clarity of purpose, Dr. Chou always kept focused on "the question" to be answered, and with a firm guiding hand, saw to it that the research stayed directed to that end. To work with a colleague of Dr. Chou's caliber is an honor for anyone, but to have had the opportunity to study under him is a privilege for which I will always be grateful. I'm sure I join many others in wishing Dr. Chou many prolific years of retirement to come.

Steven B. Segletes
U.S. Army Research Laboratory
Aberdeen Proving Ground, Maryland

It is my honor to congratulate my teacher Prof. P.C. Chou on this milestone of his life. On this occasion I would like to express publicly my deepest appreciation and gratitude for his guidance, encouragement, and example of hard work during the period I spent at Drexel University pursuing my third degree in the area of ballistics. Thanks to him, this period of time was most exciting, stimulating, and rewarding for me.

I would like to join my colleagues in Israel in wishing him many more years of health and productive work.

Ze'ev Ritman
Head of Explosive Systems Department, Rafael
Haifa, Israel

Doctoral Students of Pei Chi Chou

Richard W. Mortimer, '67
Richard F. Perry, '69
Donald L. Tuckmantel, '71
Arthur S. Warnock, '75
Robert B. Croman, '78
Harry R. Miller, '80
Rajiv Shivpuri, '87
Yar-Fine Liu, '91*

Robert R. Karpp, '68*
Alan D. Benson, '70
Joseph F. Carleone, '72*
David K.-K. Chou, '75
David J. Leidel, '78*
Longwu Wu, '85
Javad Hashemi, '88*
Ze'ev Ritman, '93*

Bruce P. Burns, '69*
Joseph L. Rose, '70
James C. Mao, '72
William J. Flis, '77*
Sheng-Chih Hung, '80*
Chris A. Weickert, '86*
Steven B. Segletes, '88*

** active in ballistics*

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Pei Chi Chou — Scientific Citations

Dr. Chou's major contributions, as evident from the above, are in the ballistics field. His publications in ballistics are referenced and cited frequently by authors of the International Ballistics Symposia. In other fields, he pioneered the application of the method of characteristics to wave propagation problems in the 1960's, while in the 1970's, he made contributions in composite materials, including elastic properties, wave propagation, and statistical aspects of fatigue and failure.

A review of the Science Citation Index, which does not include papers in the Ballistics Symposia, shows that his works on the method of characteristics have been cited the most frequently: *J. Appl. Mech.*, 1966, 28 times; *AIAA J.*, 1967, 9 times; *J. Appl. Mech.*, 1967, 14 times, and *AIAA J.*, 1968, 18 times. Citations of his publications on composite materials include: *J. Comp. Matl.*, 1970, 10 times; *J. Comp. Matl.*, 1972, 11 times; *AIAA J.*, 1973, 14 times; and *J. Comp. Matl.*, 1979, 19 times. It is interesting to note that his paper of 1958 on helicopter rotor stability is still being referenced in 1994.