THE COMMITTEE ON HONORS OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

and the

DYNAMIC SYSTEMS AND CONTROL DIVISION

have the honor of presenting the
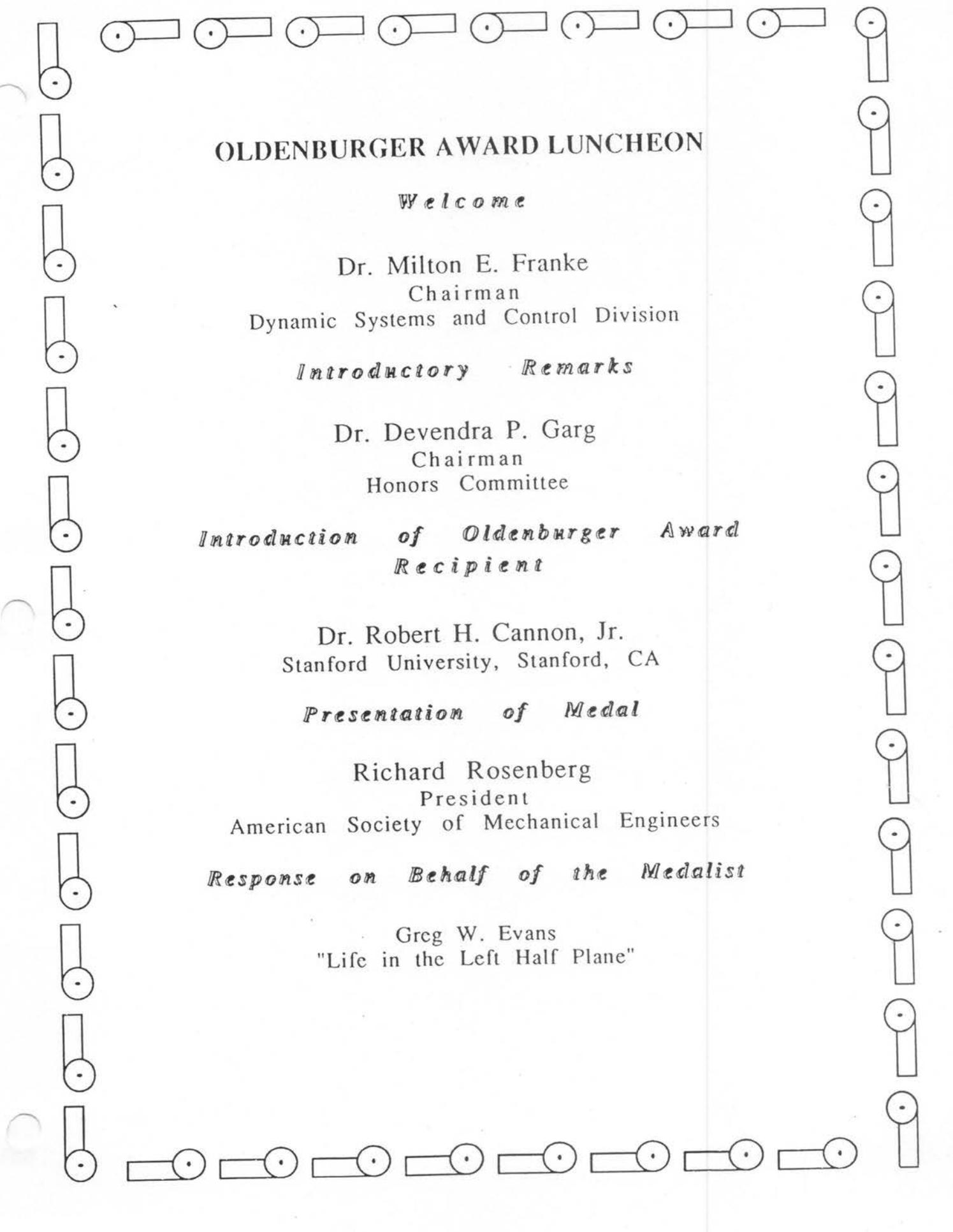
RUFUS OLDENBURGER MEDAL

to

WALTER R. EVANS

at the Twentieth Annual

OLDENBURGER AWARD LUNCHEON

December 15, 1987

OLDENBURGER AWARD LUNCHEON

Welcome

Dr. Milton E. Franke
Chairman
Dynamic Systems and Control Division

Introductory Remarks

Dr. Devendra P. Garg
Chairman
Honors Committee

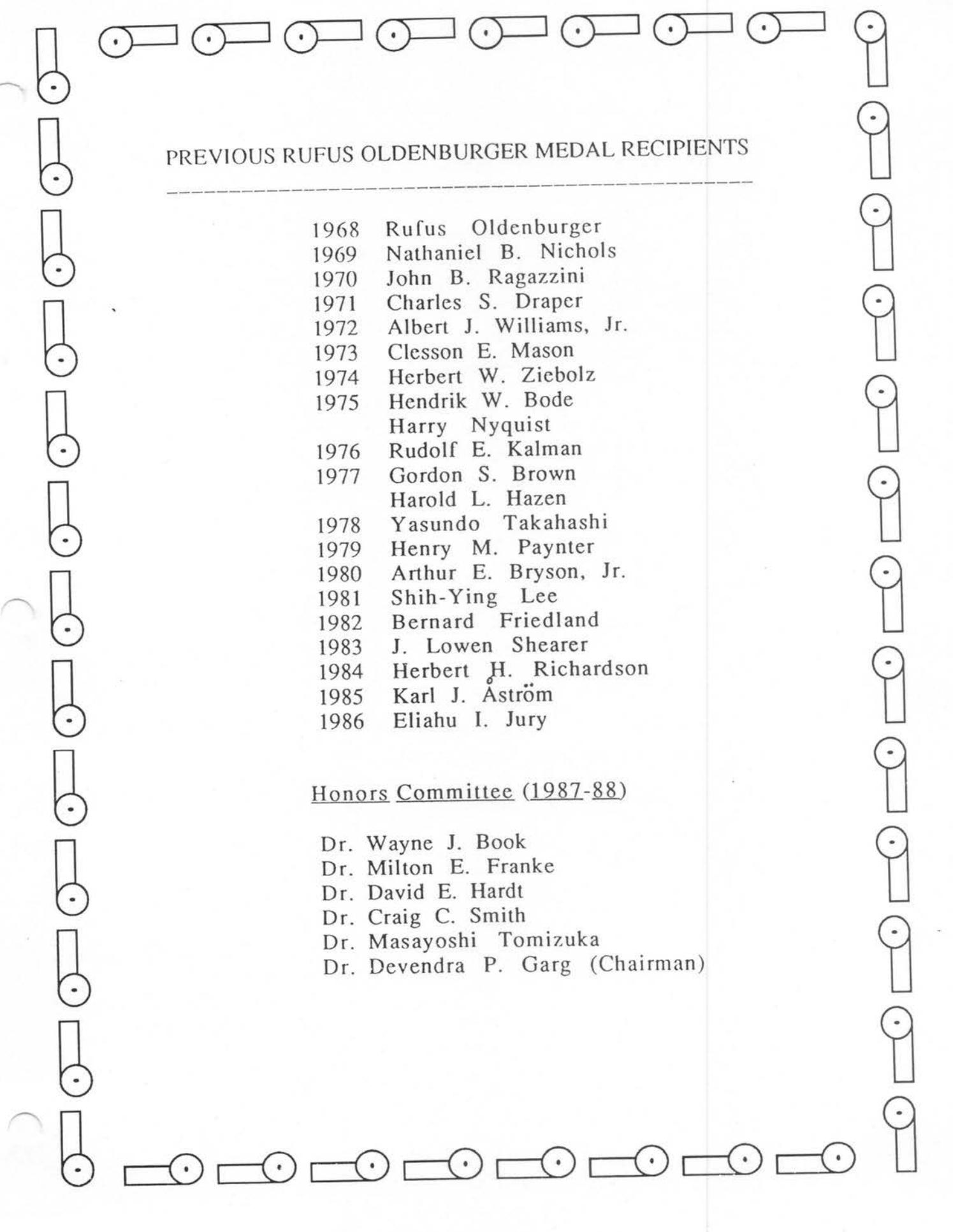*Introduction of Oldenburger Award Recipient*

Dr. Robert H. Cannon, Jr.
Stanford University, Stanford, CA

Presentation of Medal

Richard Rosenberg
President
American Society of Mechanical Engineers

Response on Behalf of the Medalist

Greg W. Evans
"Life in the Left Half Plane"

PREVIOUS RUFUS OLDENBURGER MEDAL RECIPIENTS

1968	Rufus Oldenburger
1969	Nathaniel B. Nichols
1970	John B. Ragazzini
1971	Charles S. Draper
1972	Albert J. Williams, Jr.
1973	Clesson E. Mason
1974	Herbert W. Ziebolz
1975	Hendrik W. Bode
	Harry Nyquist
1976	Rudolf E. Kalman
1977	Gordon S. Brown
	Harold L. Hazen
1978	Yasundo Takahashi
1979	Henry M. Paynter
1980	Arthur E. Bryson, Jr.
1981	Shih-Ying Lee
1982	Bernard Friedland
1983	J. Lowen Shearer
1984	Herbert H. Richardson
1985	Karl J. Áström
1986	Eliahu I. Jury

Honors Committee (1987-88)

Dr. Wayne J. Book
Dr. Milton E. Franke
Dr. David E. Hardt
Dr. Craig C. Smith
Dr. Masayoshi Tomizuka
Dr. Devendra P. Garg (Chairman)

Introductory Remarks

Remarks delivered by Dr. Devendra P. Garg, Chairman of the Honors Committee.

One of the most pleasant tasks that the Honors Committee has is to identify a deserving candidate for the Oldenburger Award. The members of the Awards Committee who helped in this task are listed on your program. I'm so pleased all of you could join us on this very happy occasion.

The award was established in 1968 and is given to recognize significant contributions made to the field of automatic control. This year's award recipient will be introduced by an exceptional engineer, who is Bob Cannon. I'm going to tell you little bit about him and then call upon him to help with that.

Bob Cannon is Charles Lee Powell Professor and Chairman of the Aeronautics and Astronautics Department at Stanford University. He received his Bachelors Degree at Rochester and Sc.D. degree from M.I.T. But that didn't keep him on the East Coast, he then moved to the West Coast, and has been at Caltech, and is, of course, at Stanford now. He has held the position of Assistant Secretary for the U.S. Department of Transportation and also Chief Scientist for the United States Air Force. Bob is a recognized leader in the field of navigation, inertial guidance, and control and is author of a very famous and popular book entitled <u>Dynamics of Physical Systems</u>. So it's a great pleasure for me to call upon Bob to introduce our recipient.

Introduction of Oldenburger Award Recipient

Remarks delivered by Dr. Robert H. Cannon, Jr. the Twentieth Annual Oldenburger Award Luncheon, December 15, 1987, in Boston, Massachusetts to the Dynamics and Control Division of the American Society of Mechanical Engineers (ASME).

Introduction of Dr. Cannon by Dr. Devendra P. Garg, Chairman of the Honors Committee.

I'm just very privileged to be able to be here this noon and take part in the festivities involved with the award of the Rufus Oldenburger Medal to Walter Evans. Getting to do this gives me the opportunity to do several things: to thank Evans for all of us who find the method he invented so helpful to us in designing feedback control systems, to thank him very personally for teaching me so much about engineering and making it so much fun, and to give you some glimpses into what a delightful guy he is.

Significance of Evans' Root-Locus Method

Evans invented the root-locus method in the 1940's and first published it in 1948. At North American Aviation's Aerophysics Laboratory where Evans worked, it had already become the primary method for designing automatic pilots for high performance aircraft and for the X10 pilotless missile, which was at the time the first operational supersonic aircraft -- either piloted or unpiloted.

The root-locus approach quickly became widely known and used and soon took its place as the central context for the preliminary study and design of feedback control systems. There are several reasons for that. The roots of a dynamic system's characteristic equation reveal directly and quantitatively the natural behavior it will have -- at what frequencies it will vibrate and how quickly the vibrations will damp out. By plotting the locus of these characteristic roots, as Evans' method does, versus the design parameter being chosen (control strength, for example) one can see precisely which values will give good behavior and which will not -- which values will make the the system unstable, for example.

It's of course true that the same information is available indirectly from other earlier approaches (from the frequency response plots of Nyquist and Bode, for example) and we make continual use of such methods also, both theoretically and especially experimentally. But it's the quick, direct display of behavior characteristics and the powerful, immediate dynamic insight this provides, that gives Evans' method its central role.

A Stable Platform's Root-Locus Plot

Moreover, root loci can be sketched quite accurately in seconds, by eye, using clever sketching rules that Evans developed, and I sketched one on the way up in the elevator to show how fast this can be done. Walt will recognize this. It's the root-locus for the control of a stable platform. It's a little Christmassy, of course, and that's intentional.

What you have is a characteristic equation at the top of the figure and what the characteristic equation has to do with is that the roots of that equation are the values "s" which will tell one how the system will behave. The roots of this are what go here to tell you what the motion will be like. And so by plotting those roots as a function in this case of the parameter "k", one can see for certain values near zero (marked "u"), the system will be unstable. Later on, for a fairly wide variety of choices of "k" it will be stable. But then as "k" gets too high (up in the upper right hand corner) it goes unstable again.

What we've plotted of course is the real part. If we plot it on a plane, the real part of "s" is horizontal and the imaginary part of "s" is vertical. And the object of the game is to stay in the left half plane. The green control logic was, in fact, designed by Evans to provide stability to this rather challenging plant. Enough of technology.

On S-Plane and Crunchy Spirule Uses

For getting things precise where it's critical to do so, Evans invented the Spirule, with which one can get almost three significant figure accuracy, again in seconds. And the two triangles and the diamond were done that way using a Spirule, which, of course, we all carry in our pockets (show one to all).

THE ROOT-LOCUS PLOT
FOR A STABLE PLATFORM

$$\frac{s^3 (s+\sigma)^3}{(s+6\sigma)^3} = -K$$

$$\theta = c\,e^{st}$$

stable

Imag. s

Real s →

stable
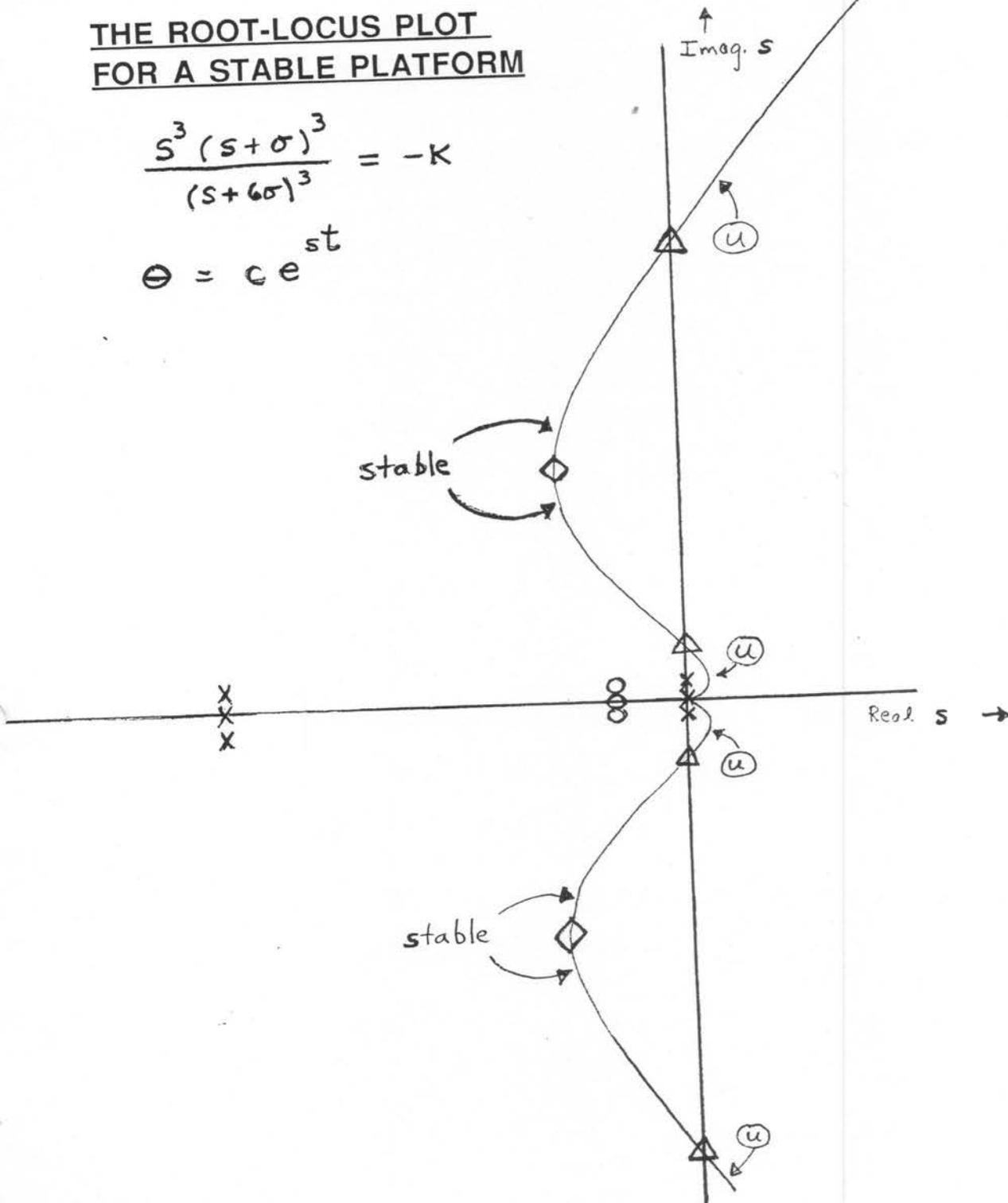
NOTE: THIS RENDITION OF THE ROOT-LOCUS PLOT
WAS DRAWN QUICKLY, BY EYE, BY GREG EVANS
FROM THE VIDEOTAPE OF DR. CANNON'S TALK.
THEREFORE, IT PROBABLY CONTAINS ERRORS.

Thus it is that even today, with great computing power all around us, we typically think about a new control system design in terms of the locus of its roots, which we can sketch in seconds. Then we let our computers work out the details and plot them for us.

To make the point about the connection between root-locus and frequency response methods -- on the Spirule, which is primarily for plotting these loci, there are also special scales for plotting Bode plots very quickly and very precisely. There are some other scales for multiplying things. It has many uses. One day I was walking by Walt's office and I heard a voice yell out, "Hey Bob! Got a new use for the Spirule!" and I looked in the door -- he was spreading peanut butter on his sandwich with it.

Evans' Mental Agility Won Admiration

Working with Walt was enormously stimulating and full of surprises. At no period in my life did I learn real engineering more rapidly, or more deeply, or with more enjoyment. Walt shared his small office with two of us, Bill Mullins and I. Bill was also one terrific engineer who made complex machines that worked, and that was one great office for a young, green freshout to be in.

It was in those days that Evans led the development and construction of the stable inertial platforms for the guidance systems for among others the X10 missile, the Minuteman ICBM, and two submarines called Nautilus and Skate, which used those systems to navigate for the first time under the polar icecap -- without any external reference.

For each system Evans saw the myriad new technical problems coming, and in problem after problem his agile mind made giant leaps over the details to the key to the good answer. A problem for us mortals was that, in his beguiling modesty, he just naturally assumed everybody else's mind worked as fast as his did. Typically after he'd left the office, Bill Mullins and I would sit there and we would scratch our heads and after about an hour we'd be able to figure out what it was he'd just told us in five minutes.

Evans' Seven Subject Stanford Seminar

Years later I invited Walt to come up and give a seminar at Stanford. So he wrote me a letter back and listed seven topics. So I wrote him back and I said, "They're all good topics, but either 2 or 5 would be particularly interesting to this group of people." Walt wrote back and he said, "You don't understand, I'm going to talk about all seven" . . . which he did . . . which blew us all away.

Evans' Physical Agility Won Arguments

Walt always loved a technical argument . . . and he loved to win. I can still here him as he points to a genius pad totally covered with scratches saying, "There's no chance for any error here!" For the center of discussion in our office would be a huge pad of blank paper called a genius pad in the center of the conference table, which was between our three desks, and there was also a fourth chair in the doorway for guests. One day Walt and a guest were going at it hot and heavy -- both talking at once, both furiously writing equations on the genius pad. Suddenly Walt reached over and broke the other guy's pencil. . . . And then he said, "Now! As I was saying."

On another occasion, when a good argument was going on in the next office, I saw Walt figgiting. He listened and he stood it as long as he could. Finally, he climbed up on his desk and went right over the partition and joined the argument.

Evans' Often Invoked Goddard's First Law

Evans was a wry observer of the political scene. When I'd first arrived there, and had been there about a week, he said "Now let me explain something to you. You'll find that it will be perfectly clear that if only two of our managers here would leave, everything would straighten right out. The interesting part is that for each of us it's a different two managers."

When pestered by the ever-present program manager's need for projections of what's going to happen in a program or, worse yet, reports on what has happened, Walt would always quote an axiom which he calls Goddard's First Law:

P.C.B.P.A.R.O.A.T.E.O.B.M.

Bill Goodard was a co-worker in the early days. This is his answer to the project manager: "Progress Can Be Planned And Reported Only At The Expense Of Being Made." We've all felt that one.

In those days we all worked for a fine manager named Fred Eyestone. When my wife one day bore us another son and I chose to name him Fred, Evans' response was . . . "Good move".

At Least I Tried, Walt

When, after a lot of years, my book about dynamics finally got to the galley stage, I sent a copy of the chapter on Evans' method to Walt, asking for his comments. Having changed the name from "root-locus" to "Evans' Method", and having introduced "Evans' Form" and the "Evans Function", I thought I might get a rise out of him. What I got back was letter saying, "I feel like a father who's just been asked for his daughter's hand in marriage. So much has already gone on it's not going to make any difference what I say."

Conclusion

Above all, Walt Evans was ever devoted to his four children, Randy, Greg, Nancy, and Gary, and to his wonderful wife, Arline, who has been his super-supportive and brilliant companion throughout his life and career. Arline, Greg, and Gary, as you know, are here with Walt today.

One last story. One day we in a discussion of a technical point, and it was getting kind of exciting, and Walt's voice was getting higher and higher as he began to see where it was taking us. Suddenly the phone rang. Walt picked up the phone. He said (using a very high-pitched voice), "Evans! Oh! Hi Arline!" . . . pause . . . (at very low pitch), "Evans!"

We're so glad that you guys are all here today. When I look at the list of very, very distinguished recipients of the Oldenburger Medal, I'm just so proud that I know so many of them and that the last one at this point is my very good friend, Walt Evans.

Presentation of the Medal

Remarks delivered by Richard Rosenberg, President, American Society of Mechanical Engineers.

On this special occasion we get together to honor one of our own fellow members, who has made outstanding contributions in dynamic systems and control, especially his development of the root-locus method of analysis. He has distinguished himself as an engineer, as a researcher, and as an educator. This is an accomplishment we all aspire to and strive for. It is a sincere pleasure for me, as president of ASME, to be able to present this year's prestigious Rufus Oldenburger Award to Walter R. Evans.

The American Society of
Mechanical Engineers
awards the
1987 Rufus Oldenburger Medal
to

Walter R. Evans

In recognition of his enduring contributions to methods for the analysis and design of control systems, in particular, his elucidation of the root locus as a means of visualizing control system performance and his work in developing methods for rapid graphical construction of root locus diagrams

Nancy D. Fitzroy
President

Executive Director

Life in the Left Half Plane

Delivered by W. R. Evans' son, Greg, at the Twentieth Annual Oldenburger Award Luncheon, December 15, 1987, in Boston, Massachusetts to the Dynamics and Control Division of the American Society of Mechanical Engineers (ASME).

Introduction of Walter R. Evans by Dr. Robert H. Cannon, Jr. of Stanford University.

Introduction

My mother, my younger brother, Gary, and I are very pleased to be with you this afternoon to witness my father's acceptance of your 1987 Rufus Oldenburger Award. Although Dad is unable to speak, I will endeavor to share with you in the course of my talk some of his views on a subject of lifelong interest to him -- the learning process.

Origins of the Root-Locus Method

As a student, my father's first love was geometry. In fact, the root-locus method began, in a way, in his Soldan High School geometry class. There he discovered a formal discipline matched to his pictorial way of thinking. Years later, he wrote about geometry's appeal in a letter to my high school math teacher:

"Math has always been a game for me and now is a good part of my livelihood. Geometry used to provide (me) a steady diet of looking for a pattern that would lead to a solution before settling down to the detail of writing down all the steps."

His next academic step was a degree in Electrical Engineering at Washington University in St. Louis. (By the way, he abandoned his initial major, Engineering Administration, when one of his professor's recommended he prove himself as an engineer first and prepare for the vice presidency later.) *[Post-speech note: His father, Gomer Evans, was an Engineering Vice President at the Wagner Electric Company.]*

Twenty years later, in a letter to its Engineering School's former Dean, Alexander S. Langsdorf, my father reflected on the how he learns best and how his Wash. U. teachers helped him:

"I personally learn most effectively by starting from simple examples and working up. Washington University was excellent in that professors such as yourself, Professor (Roy) Glasgow, Dr. (Frank) Bubb, and Dr. Middlemiss could and did take a student all the way back to the beginning if necessary, and work up to the question at hand."

His education continued at General Electric in Schnectady, New York, where he and his fellow students cooperated to survive the rigors of what was known simply as "The Advanced Course". Its particular appeal to him is evident in his later statement on the key to learning:

"The main key to learning in my opinion is to treat the problem as a game using all the simplifications possible to get the approximate answer. ... The General Electric Advanced Engineering Program put great emphasis on solving practical problems in approximate form starting from a few basic principles."

After completing the Advanced Course, my father returned to Washington University as an instructor. There, in one of his classes, a student asked him what would happen to a typical control system if a certain quadratic approximation broke down. My father credits this question as being the specific inspiration for root locus. Working from first principles, he obtained a graphical solution to what he referred to as the "slightly cubic system" envisioned by the student. It was the first root-locus plot. *[Post-speech correction: this question was asked in a class at North American Aviation in 1948]*

And so it's no accident that Dad's approaches to problem solving-- starting from the beginning, applying basic principles and geometric reasoning to achieve approximate answers before proceeding to the mathematical detail -- are at the heart of his rapid graphical analysis technique -- the root-locus method.

It was an unorthodox concept at the time, and as was true of many of his ideas, it did not catch on right away. Reflecting back thirty years later, as to why it eventually did, he wrote,

" ... I have had more than my share of luck in hitting it big with Root Locus. I mean luck because many other ideas, not directly

servo, have failed to arouse any interest. I think that the explanation is that I strive for a kind of understanding that most people don't seek. In the case of root locus, it provided a needed link to a complete solution of a system which many others did seek."

Ahead of His Time

Dad, I remember some of your ideas that didn't catch on at the time: spray painting tennis balls bright yellow and orange to improve their visibility, mounting wheels on luggage to enhance their transportability, and staggering work hours to ease traffic congestion. Let's face it, you often were ahead of the times.

The Teaching Machine

But getting back to the learning process, I'll never forget another of his ideas that's only now gaining acceptance -- using computers in the classroom. I won't forget it because it became my eighth grade science fair project. Together, we built an algebra teaching computer. Its opening message to the student reads as follows:

"This is no ordinary machine. It is a teaching machine. You ... can learn at (your) own individual pace. How? Depending upon the answer given, the machine advances to a more difficult question or to an explanation of why the answer given is wrong. (You) learn instantly whether you are right or wrong. Now push button A to begin."

The questions were written on a roll of shelf paper (toss it). Unique hole patterns under each answer provided the appropriate counts to a stepping relay and direction to a motor drive. The motor engaged when the student closed a sliding wooden panel that triggered a microswitch. Building logic circuits proved to be a lot of fun, and, 27 years later, I'm still at it.

To my disappointment, Dad was only secondarily interested in the details of the electrical and mechanical design. His primary interests were the contents and structure of its questions and answers -- how they could most effectively respond to any student -- whatever the state of his initial understanding of algebra.

Well, I learned more than algebra from the experience. I learned that punching holes, writing programs, and connecting switching relays together were one hell of a lot simpler than aligning and maintaining uniform tension on a roll of shelf paper wrapped around a couple of rotating wooden spindles, and I've stayed as far away as possible from mechanical engineering problems ever since.

On Teaching His Children

Dad's kind of problem solving, grounded in fundamental understanding, didn't always go down well with us kids. We were often content with a more superficial understanding. Perhaps he was referring to those resistive encounters with us when he wrote again to Dean Langsdorf:

" ... I find that working with my children is a good testing ground for teaching methods because the subject matter is simple, the opportunities frequent, and the reaction clear."

Well, our occasional reaction may have been resistant, but let me set the record straight. His four children went on to earn undergraduate degrees in physics, mathematics, computer science, and engineering. I think it's fair to say he was a role model to all four of us.

On Learning and the Role of the Teacher

My father's philosophy toward learning and teaching is, perhaps, best summarized in a 1965 letter he wrote to his favorite Wash. U. Professor, Roy Glasgow:

" ... it seems to me the real bulk of learning takes place in self study and problem solving with a lot of positive feedback around that loop. The function of the teacher is to pressure the lazy, inspire the bored, deflate the cocky, encourage the timid, detect and correct individual flaws, and broaden the viewpoint of all."

The Spirule Story

I'd like to shift gears now and pick up the root-locus story where we left off in St. Louis. John R. Moore offered my father a summer job in Downey,

California with North American Aviation. He accepted it and never turned back. There, with the support and encouragement of several auto-pilot designer colleagues (e.g., Jeff Schmidt, Bill Mullins, and others), another idea was born -- a plastic tool that became known as the Spirule. As the root-locus method provides a rapid means of plotting the roots of a servo-mechanism's characteristic equation, the Spirule simplifies the task of constructing accurate plots. Word of its utility spread more rapidly than he imagined. When the head of the University of Cincinnati's Electrical Engineering Department wrote him in 1950 to find out if any Spirules were available for instructional use, my father responded with the following note:

" ... none are available because of the following costs: $30 for a single machine shop model, or 50 cents each for a stamped version in a lot of 500. It's not worth $30 and the demand is far short of 500."

Soon thereafter, however, professors from UCLA and U.C. Berkeley placed orders for 150 and the Spirule Company was born. Mom was the shipping and receiving department, the executive secretary, and the accounting department. Later my older brother and I became the assembly line -- inserting eyelets and stuffing instruction sheets into envelopes. On one Sunday morning I answered the front doorbell while in my pajamas, only to confront a bewildered looking engineering undergraduate student who asked, "Is this the Spirule Company?" Since they were readily available in college bookstores, I can only surmise that a student desperate enough to drive to our house was cramming on the weekend before his final exam. At least one such student at UCLA, perhaps driven by his exasperation in mastering its use, was driven to rewrite the lyrics to Merle Travis's popular song, Sixteen Tons. I'll agree to read from just one of the stanzas, if you will agree to imagine Tennesee Ernie Ford singing it.

> I was born one mornin' as the root-locus flew.
> Buried neck-deep in snow and a-turnin dark blue.
> Raised in the Nyquist by an old zero--
> Get a grade in this course and I'll be a hero.
> You do sixteen tons, and what do you learn?
> Slide-rule's busted and the Spirule won't turn.
> Saint Peter, don't you call me, there's too much fuss--
> I owe my soul to the root-locus."

Well, you get the idea. Despite this student's travail, Spirule orders poured in. My father set prices over the years barely above his costs out of consideration for cash-pour students. Orders continue to this day, arriving at the same address that first appeared in the his 1954 <u>Control Systems Dynamics</u> book -- 9728 El Venado, Whittier, California. My parents still live there and that's where my roots are. Roots not in the reckless fast lane, but roots in the stable left half plane.

By now Mom has personally wrapped, packed, and delivered to Whittier's post office over 100,000 Spirules for shipment to universities and engineers around the world -- 65 countries in all.

Over the years she's received a lot of interesting correspondence, including two letters in 1973 from a Philippino -- Ho Hwa Hui. In the first, he simply asked what a Spirule cost. Mom took it as a typical order and sent him one the same day. He was delighted and included this note with his return payment:

"You have unknowingly given me a two-fold surprise package. First, you sent the Spirule to a complete stranger thousands of miles away without even a guarantee that you'll get paid! Secondly, you are Mrs. W. R. Evans, wife of one of the most respected and prestigious control engineers in the forefront of this highly technical field -- the W. R. Evans! Of course I don't have to tell you."

Conclusion

Yes, Ho Hwa, you're right. You didn't have to tell her, his colleagues, or the ASME. Today, by bestowing upon him the 1987 Rufus Oldenburger Medal, you recognize him for his method of plotting roots of characteristic equations. My brothers, sister, and I love him for planting in us the roots of character. Both you and we honor the same man, Walter Richard Evans, who today it can truly be said, takes his rightful place among the giants of Control Theory. Congratulations, Dad, and thank you all for coming today to acknowledge what many of us, even Ho Hwa Hui, have known for a long, long time.