ATTITUDE
CHARACTER
SCHOLARSHIP

THE BRIDGE
HIGHLIGHTS

IEEE

IEEE-Eta Kappa Nu

2013-2014 Vol. 109 / No. 4

IEEE-HKN BOARD OF GOVERNORS

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IEEE-Eta Kappa Nu (IEEE-HKN)

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Catching up with IEEE-Eta Kappa Nu

Eta Kappa Nu merged with IEEE in September of 2010. The merger meant all kinds of adjustments, both for HKN and for IEEE. Fast forward to 2014. What is the status of IEEE-HKN?

Operationally, IEEE-HKN is part of the IEEE Educational Activities Department. The IEEE-HKN Board of Governors consists of 12 volunteers:

President
President-Elect
Past President
Five Governors representing the IEEE Regions
Two at-large Governors
One Governor appointed by the IEEE Member and Geographic Activities Board
One Student Representative

These, and other changes, were made to the IEEE-HKN Operations Manual, and approved in June of 2013. The regions now align with IEEE regions. The addition of a Student Representative to the Board will prove to be a valuable addition, serving a one year term starting on 1 January of each year.

The IEEE-HKN Operations manual can be found on the IEEE-HKN website: www.hkn.org

"The stability of working with IEEE has improved service back to our Chapters and members."

As of the date of this publication, 181 of our chapters are active. We are inducting more than 2,500 students each year. We have installed chapters in Canada, Mexico, Singapore, Hong Kong, India, and Qatar. Our organization continues to grow in terms of chapters reinstating, welcoming new chapters, and working with our dedicated faculty advisors and the officers of each chapter. Our LA Alumni Chapter continues to administer the Outstanding Student Award, and work closely with chapters in southern California.

Members of the HKN 1947 Jury of Award: L-R: R.W.Wilbrahamr, Chairman, J H. Foote, C. A.Powell, N. S. Hibshman, W. B.Kauwenrhoven.

IEEE-HKN Chapter and IEEE Student branches co-exist at many Universities. There are cases where the two cooperate on almost all matters (except invitation, induction, and other rituals specific to IEEE-HKN), in some cases they work together on certain projects or even compete (at flag football), and some where they simply co-exist. All models work and the model most suited is the one encouraged.

What the merger has done is include all of the additional opportunities of IEEE student membership to those invited to join IEEE-HKN. The stability of working with IEEE has improved service back to our chapters and members. Processes have been streamlined, and the professional staff supporting IEEE-HKN have been able to work with our Board of Governors, Faculty Advisors, Department Heads, IEEE student program staff, officers, and alumni to envision a future for IEEE-HKN that will allow us to continue the tradition established by our founders, to recognize the scholastic achievements, character, and attitude. Eta Kappa Nu is, as it was founded to be, "A Worthwhile Goal."

Leadership Letters

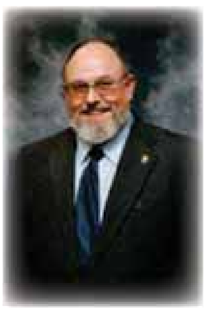
The IEEE-HKN "Highlights" issue of THE BRIDGE is comprehensive of the original articles written for THE BRIDGE in 2013 and a review of the impact and accomplishments of our Chapters and organization in recent years.

THE BRIDGE has been published since 1909, and under the editorship of Steve Watkins, this publication has reached new heights of quality. We have moved to electronic distribution which enables us to reach many more readers with timely content, but for some purposes a paper publication still meets a real need. We hope that you will enjoy reading this digest of some of our most significant articles from 2013.

As the academic honor society within IEEE, Eta Kappa Nu (IEEE-HKN) fulfills a very important need. We strive to develop complete, well-rounded students who transition to leadership in professional practice and benefit society over the span of their careers in IEEE's technical fields of interest. Our first step is to recognize students who are performing exceptionally well academically and then to engage in two activities: first, to help those students grow professionally into the global leaders of our technological society, and second, to enable them to assist all of their fellow students to develop their own professional and technical skills. So service to others is a key component of IEEE-HKN. This service continues after graduation through mentorship of student chapters, and professional recognition continues via our young professional awards. All of this culminates with recognition of the most accomplished technical and professional contributors as Eminent Members of IEEE-HKN.

I hope that through this publication your understanding of the value of IEEE-HKN, not just to its members, but to society at large, will grow.

John Orr
President, IEEE-HKN
Alpha Chapter



Steve E. Watkins
Editor-in-Chief,
THE BRIDGE
Gamma Theta
Chapter

This publication "Highlights" is the latest volume of THE BRIDGE magazine. The goals of the editorial board have been to report on happenings within our organization, to celebrate excellent among our members and chapters, and to provide articles that further the technical and professional knowledge of our readers. The articles have been a mix of original content and selected reprints from accomplished authors (most of whom are HKN members!). Our issue themes were "Engineering for Space Applications" (March 2013), "Engineering Ethics" (June 2013), and "Celebrating Engineering Accomplishment" (November 2013).
A particular emphasis has been on the history of technology and the profession.

The magazine is a collaborative effort of Dr. Catherine Slater (Editorial Board), Dr. Stephen M. Williams (Editorial Board), and Joanne Van Voorhis (IEEE-HKN Production Manager and Features Editor) with the valuable support of Nancy M. Ostin (IEEE-HKN Director) and Amy Recine (IEEE-HKN Activities Program Manager). The efforts of the article authors, the IEEE History Center, and other contributors are greatly appreciated. We are proud of the quality displayed within these issues and will strive to make further improvements as we go into 2014.

We hope that the readers of the "Highlights" issue of THE BRIDGE and its rich content of the magazine and gain insights into the Eta Kappa Nu organization. HKN began in 1904 with ten electrical engineering students who saw the need for a national organization which would promote excellence and develop leadership within the profession. Their membership ideal is summarized in the initiation ritual: "This is what we strive for as members of Eta Kappa Nu: to lead a balanced life, a life in which scholarship, character, and attitude are jointly developed." They chose the Wheatstone Bridge circuit as an emblem to be a reminder of this balanced life ideal. They acknowledged the importance of the past through the name, using the first, fourth, and last letters of the Greek word for amber or electron HΛEKTPON. As the organization continues into its second century, the magazine is dedicated to this early vision.

IEEE-HKN is experiencing a renaissance. In the past two years we have seen renewed interest from our Chapters, potential Chapters, Universities from around the world and industry in IEEE-HKN. What we are hearing from members and interested parties is a return to the core values that define Eta Kappa Nu; Scholarship, Attitude and Character. The commitment to service and the value that an IEEE-HKN Chapter brings to its university, department, the student body and the community is evident in the hours dedicated to tutoring, exam prep, peer-peer counseling, lab sessions, tech talks and more. Learn about IEEE-HKN and the difference it can make, email us at info@hkn.org.

Nancy M.Ostin
Director, IEEE-HKN

What's New with Our Chapters? | CHARACTER

IEEE-HKN Chapters are as vibrant and active as ever. The Annual Outstanding Chapter Award, once given to a single Chapter, is now presented to mulitple Chapters who distinguish themselves.

In bestowing an award, the standing committee attaches less importance to the number of a Chapter's activities than to their nature and quality. Of critical concern to the committee in judging a Chapter are activities to improve professional development, to raise instructional and institutional standards, to encourage scholarship and creativity, to provide a public service, and generally to further the established goals of IEEE-HKN.

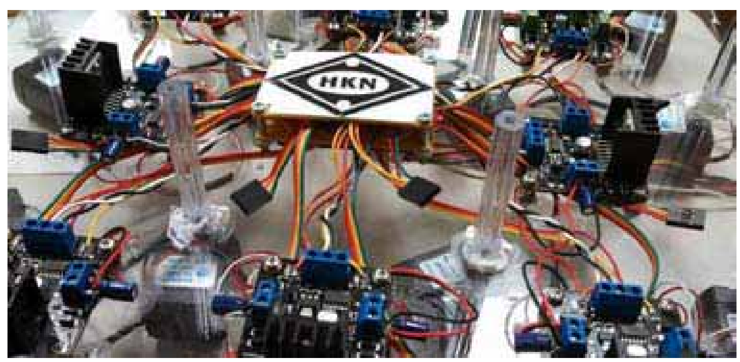
girl scouts

The Zeta Nu Chapter (University of Tulsa) volunteered during an on-campus "Brownie Day" for young girls in the local community.

For example, for the academic year 2011-2012, twenty three (23) Chapters were recognized and presented the Outstanding Chapter Award. In just those twenty-three Chapters, over 50,000 hours of community service were performed.

That equals almost fifty (50) hours per student for the academic year. That is 50 hours of tutoring, exam prep, peer counseling, service, tech talks, career development, workshops, STEM outreach to high school students, robotics competitions, teaching, community projects, department tours and so much more.

People often ask, how is an IEEE-Eta Kappa Nu student or Chapter different from an IEEE student branch or other organization? The key is SERVICE. One of the central ideals of IEEE-Eta Kappa Nu is character. How is your character developed? Our induction ritual states, *"do not make false assumption that the world owes you a living. On the contrary by virtue of your superior talents and extensive training, you owe to your community to aid and assist them in whenever they need something that is in your power to give."* Community service is a critical element of the IEEE-HKN Chapter and individual.



Iota Gamma Chapter

This development of character is the guiding principal to the goal of developing the individual as the complete engineer or professional.

Award	Nomination Deadline	Committee Chair
Outstanding Teaching Award	30 April	Dave Soldan John Orr
Outstanding Student Award	30 June	John DeGraw
Outstanding Chapter Award	15 October	Stephen Goodnick
Outstanding Young Professional Award	31 May	Jon Bredeson
Karapetoff Award	31 May	Jim D'Arcy
Eminent Member	Rolling	Richard Gowen
Distinguished Service Award	31 May	Evelyn Hirt

1. Ashkay Gupta accepts the Outstanding Chapter Award from John Orr on behalf of Georgia Tech.
2. Eminent Member Ceremony for Dr. Faquir Kohli at MIT, October 2013
3. IEEE-HKN students from Rutgers, NJIT and Stevens at the Eminent Member Ceremony with Martin Cooper (inventor of the first hand held cell phone) November 2013.
4. Eminent Member Ceremony 2013 L-R seated: Jeremy Chang and Sharud Agarwal (University of Texas Psi Chapter) Dr. John Orr, Nancy M. Ostin, Dr. Jung Uck Seo, Mrs. Seo L-R standing: Dr. Stephen Goodnick, Cecelia Jankowski, Dr. Marcian Hoff, Mrs. Hoff
5. Plaques for the Outstanding Chapter Award.
6. Alan Lefkow, 2013 Chair of the Outstanding Chapter Award Committee.
7. Larry Martin (L), 2013 Outstanding Student Award recipient with his Faculty Advisor Wayne Shiroma, University of Hawaii at Manoa, Delta Omega Chapter.

Student Leadership Conference

The event includes professional and Chapter development sessions, networking and mini-competitions, technical workshops and career fairs.

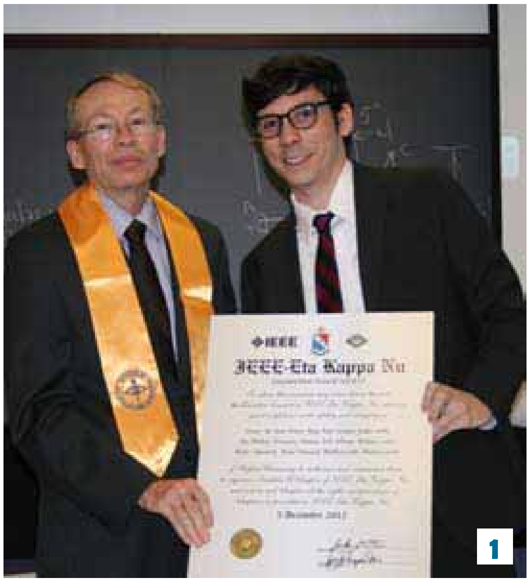
In 2013 the Student Leadership Conference went to Arizona State University with the Epsilon Beta Chapter as host. From 15-17 March, over 112 students pre-registered for the event and 102 attended over the three day program. Total conference attendance was 138 including speakers, VIP guests, and staff. The keynote address was presented by Past IEEE President Moshe Kam; the lunch speaker was David Alan Grier of the IEEE-Computer Society. James Bates, IEEE-HKN member (inducted Kappa Epsilon – Brigham Young University) and Senior Vice President and General Manager of Freescale was our featured dinner speaker. The program included a panel discussion hosted by Dr. Stephen Goodnick of three of the "Dream Jobs" professionals highlighted in the February 2013 issue of IEEE's Spectrum Magazine.

1. Dr. Moshe Kam, Past IEEE President, gave the keynote address. 2. Students engaged in Q & A with David Alan Grier, President, IEEE Computer Society. 3. Dr. Stephen Goodnick and the "Dream Jobs" Panel.

The 2014 Student Leadership Conference will be held in Ames, Iowa, by the Nu Chapter (Iowa State University) from 14-16 March. The event will focus on a "Do It Yourself" theme and is expected to attract up to 150 student members. Due to a special funding source for 2014, IEEE-HKN will offer an additional travel stipend to attending Faculty Advisors. The Faculty Advisors at the meeting will not only assist in officer training and planning for future Chapter programs and activities, but will also participate in a round table discussion of the future of IEEE-HKN.

In 2015, the Conference will be held in California by the Mu Chapter (University of California, Berkeley). Due to the proximity of Silicon Valley and access to many of the IEEE-HKN alumni who work, teach, own and/or funded their company in the area, combined with the Chapter's 100th anniversary occurring at the same time, the event will continue the legacy of serving as an outstanding experience for all who participate.

In 2015, the Student Leadership Conference will be held in California by the Mu Chapter (University of California, Berkeley), which will also be the 100th anniversary of the Chapter.



1. President John Orr presents the Chapter Charter to Steve Prince, President Lambda Xi Chapter 2. Signing the official Chapter Signature Book is a tradition of IEEE-HKN 3. Lambda Eta Chapter Installation Ceremony Chapter 4. Lambda Zeta Chapter 5. Board member Mark Lar presides over the re-installation of the Delta Phi Chapter 6. Former President Stephen Goodnick at the Lambda Eta Chapter 7. Lambda Omicron Chapter

Installation & Induction Ceremonies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1. Lambda Theta Chapter 2. Lambda Omega Chapter 3. Lambda Eta Chapter 4. Lambda Omicron Chapter 5. Lambda Mu Chapter 6. Lambda Theta Chapter 7. Lambda Xi Chapter 8. Lambda Nu Chapter 9. Lambda Omicron Chapter

Our Chapters on IEEE-HKN Founders Day

IEEE-HKN
Founders Day
2013


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1. Delta Xi Chapter 2. IEEE-HKN fist bump 3. Kappa Theta Chapter 4. Delta Omega Chapter 5. Lambda Rho Chapter 6. Gamma Zeta Chapter 7. Beta Chapter 8. Lambda Zeta Chapter 9. Lambda Zeta Founder's Day Cake

SCHOLARSHIP

IEEE-HKN celebrated our first FOUNDERS DAY on 28 October, the 109th anniversary of the founding of Eta Kappa Nu. We invited all Chapters to join in fun, and celebrate locally to raise the visibility of IEEE-HKN on their campus, to demonstrate the cohesiveness of our mission around the world, to pay tribute to our history, rich in tradition and success, as well as to promote the IEEE-HKN of today and the benefits to each individual who is invited to join.

To honor our past, we digitized the two films created by HKN to encourage student to consider careers in engineering. These films, Engineering: A Career for Tomorrow (1954), and Engineering: A Challenge for the Future (1968), can be found on our website: www.hkn.org. If you recognize yourself or anyone in the films, please let us know.

Collectively, 22 Chapters hosted celebrations which impacted on hundreds of people. From barbecues to introducing a troop of Girl Scouts to engineering, the activities were as different as our Chapters. This celebration did exactly as intended, bring our Chapters together to spread our message and communicate our value, while honoring our past and celebrating our future.

"Thank you for the Founder Day kit and ideas for holding IEEE-HKN founders day event. HKN has a strong brand is an easily recognizable logo. Branding ourselves will provide us with the means to orchestrate larger events than ever before, increase the recognition of IEEE-HKN on our campus, and strongly encourage personal and professional development on a greater scale than was previously possible."

Jing Chen
Vice President
Beta Pi Chapter at City College of New York

"Thanks for the Founders Day kit and ideas. We held a BBQ, it was great. Our Chapter has about 50 candidates this quarter, which must be a UCLA record."

Bill Goodin
Faculty Adviser Zeta Omega Chapter at
University of California, Los Angeles

"The Founders Day celebration went extremely well. We had 77 students and faculty attend."

Andrew Saunders,
President
Lambda Zeta Chapter at University of North Texas

Gamma Delta Chapter Founder's Day BBQ

"We received the Founders Day materials on last Friday and decided to participate in this wonderful event to share our Chapter's experience and stories. Thank you."

Yuko Huang,
Treasurer
Iota Upsilon
University of Washington

Iota Upsilon Chapter

Founders Monument at the Alpha Chapter at the University of Illinois, Urbana-Champaign

The Strategic Vision

Strategic Goals 2014

Core Purpose

To realize IEEE-HKN's potential as a recognized leader in encouraging excellence in scholarship, technical achievement, leadership, and service in the IEEE's technical fields of interest.
IEEE-HKN Core Values

- Recognize and promote distinguished scholarship.
- Recognize students and professionals for their scholarship and professional achievement, and instill an appreciation of excellence.
- Promote the use of technology to benefit humanity- An emphasis on the development of technology which positively impacts on society, past and future.
- Inspire and develop leadership. Attract and develop tomorrow's leaders through leadership training and opportunities.
- Recognize and promote technical innovation. Recognize and promote excellence in technical innovation, from early career through lifelong achievement.
- Build character. Provide opportunities for professional development with an emphasis on ethical behavior, positive attitude, tolerance, and hard work.
- Encourage and recognize service to the profession and to society. Develop a lifelong appreciation and commitment to service and volunteerism to the profession and to society as a whole.

L to R: Dick Gowen, Chair Eminent Member Committee. John Vig, former President IEEE. Bruce Einstein, former President IEEE-HKN

2013 Graduation at ASU, Epsilon Beta Chapter, Niki Troyer (Vice President), Breana Branham, Kaitlyn Beaudet (Treasurer)

Big, Audacious GOAL

To be recognized as the premier global honor society that helps to develop well-rounded students through excellence in scholarship, technical achievement, leadership and service, and transitioning to professional practice, benefitting society over the span of their careers in the IEEE's technical fields of interest.

What is next for IEEE-HKN?

For those of you who have been touched by Eta Kappa Nu, and for all the students and professionals to come, we invite you to be part of the envisioned future of IEEE-HKN.
We invite all alumni to consider how they might like to contribute. There are opportunities to serve on a committee or the Board of Governors, Advisory Board, or Chapter Professional Advisor. In addition, there are opportunities to speak, both at the chapter and organization programs. We invite alumni to consider becoming a mentor to a student on a capstone or senior design project.

Kyle Everly at graduation at Florida Institute of Technology, Zeta Epsilon Chapter

You can decide on how much to be involved, but please be involved.

The PLEDGE

"I sincerely promise that I will live up to. . . In word and in deed. . . the principles for which IEEE-Eta Kappa Nu stands. . . To the members now and to those to come after . . . I bind myself to the faithful observance of these promises. . . I give my solemn word of honor."

To sign up and learn more about volunteer opportunities for IEEE-HKN, visit us at www.hkn.org

IEEE

IEEE-Eta Kappa Nu

March Reprint

123 Million Miles in Space and 12 Miles in LA Traffic

Engineering the Final Journey of the Space Shuttle Endeavour

(Image Credit: NASA/Bill Ingalls)

By Burton Dicht

THE FINAL JOURNEY

In the mid 1970's, engineers at Rockwell International's Space Transportation Systems Division in Downey, California, were tasked with developing the Space Shuttle Orbiters as part of NASA's new Space Transportation System. They confronted many technical challenges and overcame them with creativity and innovation as they pushed the boundaries of technology to design the world's first reusable spacecraft.

Today, more than thirty years later, those same engineers would have been impressed with the engineering effort and ingenuity that was required to complete the final mission of one of their creations, the Space Shuttle Orbiter Endeavour. On October 14, 2012, Endeavour arrived at its final home, the California Science Center, after a twelve mile journey that started at the Los Angeles International Airport (LAX) and wound through the streets of Inglewood and Los Angeles.

In planning, preparation and execution, Endeavour's final journey, which was labeled, "Mission 26: The Big Endeavour," rivaled any of its twenty-five space missions. Endeavour is about the size of a DC-9 jetliner, with a length of 122 feet, a wingspan of 78 feet, a vertical height of 58 feet and a weight of 145,000 pounds. On Endeavour's arrival at the Science Center, Los Angeles Mayor Antonio Villaraigosa commented, "Nothing like this has ever been attempted before, and nothing like this will ever be attempted again. This was not just a once in a lifetime event, this was a once event."

PRESERVING THE SPACE SHUTTLE LEGACY

Endeavour's journey to the Science Center had its origins in a December 2008 announcement that NASA was seeking ideas from science and aerospace museums on how to preserve the legacy of the space shuttle orbiters at the conclusion of the Space Shuttle Program in 2010 or 2011. The Science Center joined 20 other museums and submitted proposals to acquire one of the three retiring orbiters: Discovery, Atlantis or Endeavour. The prototype orbiter Enterprise, which never flew in space, was also available for display. (Five orbiters were constructed with Columbia and Challenger lost in accidents.)

In an April 12, 2011 announcement that coincided with the thirtieth anniversary of the shuttle program's first flight, NASA administrator Charles Bolden announced that Endeavour would be displayed at the Science Center. Of the other orbiters, Discovery would go to the Smithsonian's National Air and Space Museum Steven F. Udvar-Hazy Center in Virginia, Atlantis to the Kennedy Space Center Visitors Complex in Florida, and Enterprise to the Intrepid Sea, Air and Space Museum in New York City.

TAKE THE FREEWAY OR SIDE STREETS: DETERMINING THE BEST ROUTE

In making the award, NASA assumed the responsibility for transporting the orbiter to an airport near the host museums. Each museum was then responsible for the final delivery of the orbiter to its own facility. Kenneth Phillips, the Science Center's curator for aerospace science, indicated that questions for delivery of the orbiters were not addressed in the proposal to NASA. Phillips added, "In fact, we didn't even know whether NASA would fly the orbiter into LAX or Edwards Air Force Base. So, it was not possible at that time to develop a plan."

LAX to Science Center Route.
(Photo Credit: Google Map Created by the California Science Center)

Located south of downtown Los Angeles in Exposition Park, the Science Center had experience in transporting aircraft and spacecraft through urban areas to the facility. The Lockheed A-12 Blackbird, the Gemini 11 Capsule, the Apollo-Soyuz Command Module and a United Airlines DC-8 passenger jet are several examples. The DC-8, with a 150 foot length, 143 foot wingspan and a 43 foot vertical tail was towed along city streets to the Science Center from Long Beach in June 1984. With the wings and tail removed, the DC-8's journey took about 6 hours. However, the challenges to the Science Center staff in transporting Endeavour would be far more daunting.

Following the April 2011 award, the Science Center was required to submit a report to NASA within 45 days detailing the logistics of transporting Endeavour from LAX to the Exposition Park facility. Knowing that cars are king in L.A., using the freeways seemed a logical first option. The freeways were wide enough to accommodate the orbiter's wingspan and weight.

The showstopper for the freeway option was the overpasses. The orbiter's height and 58 foot vertical tail made it impossible for it to pass through the average 16.5 foot overpass vertical clearance. Phillips noted, an option that they discussed was lifting the orbiter at each overpass and translating it horizontally across the road and then lowering the orbiter back to the transport trailer. The problem was, no system existed that was capable of carrying out those movements. NASA's orbiter lift system only provided for vertical lift, so this option was never considered.

Many also asked why the orbiter's wings and tail were not removed, which is typically done when transporting aircraft in order to make the transportation simpler. Displaying the orbiters as intact as possible to their flying configurations was a priority. Removing the wings and tail would mean cutting and permanently damaging the Thermal Protection System (TPS) tiles. Plus, removing and re-attaching the wings and tail required a complicated infrastructure that was only available in the Orbiter Processing Facility (OPF) located at the Kennedy Space Center. Once disassembled, it would have been impossible to reassemble Endeavour to its original state.

The best options were surface streets. Phillips noted, "The great thing about Los Angeles is that it has very wide boulevards." To assist in the planning and logistics of the move, Science Center officials brought in Parsons, an engineering and construction firm headquartered in Pasadena. Working as a subcontractor to Parsons and donating their engineering services, Psomas, a California based consulting and engineering company that specializes in transportation challenges, was tasked with identifying potential routes. Using satellite technology and onsite surveying, the Psomas engineers reviewed seven possible routes that were later analyzed to determine the optimal path. "We were looking for grades that did not exceed 5% and the minimum number of other obstacles like power lines, trees and traffic and street lights," says Phillips. The route that was chosen would start at LAX and travel over several major thoroughfares including La Tijera Boulevard, Manchester Avenue, over the 405 Freeway, Crenshaw Boulevard and Martin Luther King Boulevard before ending at the Science Center.

An artist rendering of the Space Shuttle Orbiter on the Overland Transporter with the Self-propelled Modular Transporters (SPMT). (Photo Credit: California Science Center)

THE OVERLAND TRANSPORTER, SPMTs AND ASSORTED ITEMS

With the route selected, the question was how to actually move Endeavour? Following their assembly at Air Force Plant 42 in Palmdale, California, the orbiters had to be transported 35 miles on surface roads to Edwards Air Force Base (EAFB) for the ferry flight to the Kennedy Space Center (KSC). NASA developed a specially fabricated frame called the Overland Transporter (OT) to perform this task. The OT had one forward and two aft fittings that mirrored the connections used to attach the orbiter to the external tank for launch and the Shuttle Carrier Aircraft (SCA) for the orbiter ferry flights.

The OT had last been used in April 1985 to transport Atlantis to EAFB. As the final orbiter to be assembled, Endeavour was flown directly from Plant 42 to the KSC and never used the OT. Luckily, the OT had been kept in storage in an EAFB hangar. After a thorough inspection by NASA for corrosion and structural integrity, it was determined to be in good shape to carry Endeavour from LAX to the Science Center. Because of the tight spaces along the route, the OT and Endeavour could not be towed and instead they would rest on top of Self-propelled Modular Transporters (SPMT) supplied by the Sarens Group.

The Sarens Group is a Belgian company that specializes in heavy lifting and engineered transport. The SPMTs, manufactured by KAMAG, were comprised of four independent, multi-axle, computer-controlled wheeled vehicles. The configuration chosen for Endeavour consisted of two 4-axle units at the front and two 6-axle units at the rear that were coupled together side-by-side respectively. In total, there would be 80 wheels on the vehicle that would be synchronously steered using only one remote control. The electronic multi-mode steering together with a steering angle of +130°/-100° enables the SPMTs to be extremely flexible and maneuverable, making them particularly suited for the tight bends that would be encountered on Endeavour's urban journey.

A single operator, using the remote joystick and walking alongside the orbiter controlled the movements. The operator was assisted by spotters positioned near the nose, tail and wingtips to enable precision maneuverability. Voicing the importance of their company's contribution, Jim Hennessy, Sarens North America's marketing manager said, "This may not be the largest or heaviest object we have transported, but it is certainly one of the most important in our company's history. The Endeavour is a national treasure and we are honored to play a key role in its final mission in route to the California Science Center where it will be put on display for all to see."

Having identified the route and transport plan, the Science Center submitted the logistics report to NASA in late May. In July 2011, a NASA team arrived to review the plans, scout the route and to meet with officials from the Science Center. NASA also met with the Los Angeles World Airports, the managers of LAX, to alleviate concerns about the space required to demate the orbiter from the SCA and for the storage and security of Endeavour. After six weeks of negotiations, the details were finalized. United Airlines donated the use of one of its hangars to store Endeavour while the final preparations for the move were completed. The decision was also made to conduct the demating of Endeavour immediately after the conclusion of the arrival ceremony in hopes of lessoning the disruption to the airport.

ORBITER TRANSITION AND RETIREMENT

Concurrent with the planning and preparations for Endeavour's ground move, engineers and technicians from NASA and the United Space Alliance (USA), the consortium of companies that maintained and processed the shuttles, began the Transition and Retirement (T&R) phase for the three orbiters. The main objectives were to make the orbiters safe and ready for public display and to remove selected hardware for possible use in future NASA programs.

All of the orbiters had their Space Shuttle Main Engines (SSME) removed. The SSMEs are the first reusable rocket engines and remain the most advanced engines ever designed. NASA plans to use the SSMEs as part of the new Space Launch System heavy-lift rocket. In place of the SSMEs, technicians installed actual engine nozzles that had been flown or tested. The nozzles were then cosmetically treated to look weathered in order to simulate normal flight wear and tear. Also removed were the Orbital Maneuvering System (OMS) pods and the Forward Reaction Control System (FRCS).

The OMS pods and the FRCSs used hypergolic propellants for orbital insertion and maneuvering. Hypergols, as they are called, are also very toxic. Exposure to humans would be very dangerous. To ensure the orbiters were safe for public display, the OMS pods and the FRCSs were sent to the White Sands Test Facility in Las Cruces, N.M. for cleaning and servicing. The FRCSs were returned to the KSC to be reinstalled into the orbiters. The OMS Pod nozzles were replaced with real-life replicas to be reinstalled after the orbiters arrived at their display sites.

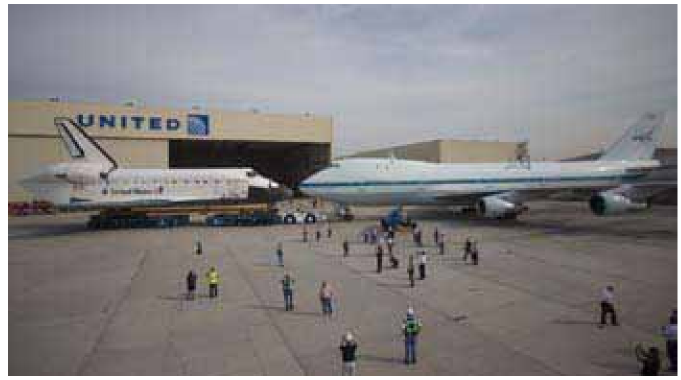
Specifically for Endeavour, technicians removed some additional equipment that would be on display to provide the public with a better understanding of the space experience. They included: 1) One of Endeavour's three fuel cell power plants, which generated electricity from chemical reactions using hydrogen and oxygen; 2) The Galley, which gave astronauts the tools they needed to rehydrate and heat food; and 3) The Waste Collection System (or zero-g toilet) that used air flow to pull waste away from the astronauts' bodies and into the collection chamber.

As the sun rises at the Shuttle Landing Facility at NASA's Kennedy Space Center in Florida, preparations are under way to back NASA's Shuttle Carrier Aircraft, or SCA, away from the Mate -**Demate device. Space shuttle Endeavour has been fitted with an aerodynamic tailcone and secured atop the aircraft for its ferry flight. (Photo credit: NASA/Frankie Martin)**

The work to de-service and de-commission Endeavour was completed in August 2012, more than a year following its 25th mission, which landed at the KSC on June 1, 2011. "Endeavour's preparations have gone extremely well. Since its last flight, we have been de-servicing the vehicle instead of servicing it," said Stephanie Stilson, NASA's flow director for orbiter transition and retirement. The final step was to close out the crew module. This was handled as carefully as it would have been for any space mission. "For flight we had to carefully make sure everything was in place for a mission. We are making sure everything is secured for Endeavour's flight to the museum in California," said Bobby Wright, a senior aerospace technician with USA.

The preparations for the ferry flight began on September 14, 2012, as Endeavour was towed to the Shuttle Landing Facility (SLF) to be mated to the SCA. The SCA is a modified 747 that has three attach fittings on the top of the fuselage that connect and secure the orbiter. NASA used a device called the Mate-Demate Device (MDD) to lift the orbiter onto the SCA. The MDD is a structure that has a self-contained crane, which lifted the orbiter vertically from a sling that was attached to the fuselage. The SCA would then be towed into position under the orbiter, which was then lowered and attached to the support assemblies on the SCA fuselage. This was typically a two day process.

PREPARING THE ROUTE



Space shuttle Endeavour secured to the Overland Transporter (OLT) meets nose to nose with the Shuttle Carrier Aircraft (SCA), at Los Angeles International Airport. (Photo Credit: NASA/Scott Andrews)

As Endeavour was undergoing its T&R phase, efforts were continuing in Los Angeles to prepare for the transport through the city streets. The route, which had been determined to best accommodate the orbiter's dimensions and weight was thoroughly reviewed for obstacles. The Cordoba Corp. and David Evans and Associates, both from Los Angeles, teamed up to provide high-definition 3D laser scanning services. They produced a list of all the obstructions including: trees, traffic signals, light poles, street signs and parking meters. A team from Plump Engineering of Anaheim also scanned public work documents to identify sewer and storm drains that the orbiter would pass over.

During the move, the SPMTs would straddle each side of the boulevard medians to maximize the curb-to-curb clearance. In probably the most controversial aspect of the plan, more than 390 trees had to be removed, the majority of which were located in the medians. Restoring the communities to their original state prior to the move was a priority to the Science Center. Working with the cities of Inglewood and Los Angeles, they made a commitment to plant four trees for every one that was removed. Another important task, performed by the workers from the Department of Water and Power and Southern California Edison, was to extend power and telephone poles to allow for raising power transmission lines as the orbiter's 58 foot vertical tail passed through.

ENDEAVOUR'S FINAL FERRY FLIGHT

The space shuttle Endeavour atop the 747 shuttle carrier aircraft is seen flying over the Hollywood sign in Los Angeles during the final portion of its tour of California.
(Photo Credit: NASA/Jim Ross)

After more than a year of intense planning, engineering and review, Endeavour was ready to begin its final mission. But planning is still not a match for Mother Nature. Rain along the ferry route postponed the September 17 departure date. Delayed for two days, the space shuttle Endeavour finally took to the air from the Kennedy Space Center for its final ferry flight and a trip to its new home atop the Boeing 747 SCA at 7:22 am EDT on September 19, 2012. It began a 3-day, 2-night trip that included a farewell tour to several NASA sites across the country and would end in Los Angeles, just 20 miles from the Downey plant where Endeavour was designed.

The first leg of the ferry flight included a series of 1500 foot flyovers above Florida's Space Coast, the Stennis Space Center near Bay St. Louis, Miss., and the Michoud Assembly Facility in New Orleans. The flight plan then took Endeavour over Houston, Clear Lake and Galveston before landing at Ellington Field near NASA's Johnson Space Center. On September 20, following a refueling stop at the El Paso's Biggs Army Airfield, the SCA did flyovers of the White Sands Test Facility and Missile Range in New Mexico and Tucson, Arizona before landing at EAFB to spend the night.

The last leg of Endeavour's journey began on the morning of September 21 at NASA's Dryden Flight Research Center at Edwards Air Force Base. The four-hour, 34-minute flight included low-level flybys over many California cities and landmarks, several of which had direct ties to NASA's Space Shuttle Program. The 747, with Endeavour riding piggyback, left a memorable image as they passed over such landmarks as the State Capitol in Sacramento, the Golden Gate Bridge in San Francisco and NASA's Ames Research Center at Moffett Field north of San Jose. Finally, after passing by Vandenberg Air Force Base on the California coast, the SCA entered Los Angeles airspace. It made passes by Griffith Observatory, the Hollywood sign, Dodger Stadium, NASA's Jet Propulsion Laboratory, Malibu, Santa Monica, Disneyland, The Queen Mary, the USS Iowa, the Science Center, and several low-level flyovers over Los Angeles International Airport before touching down on Runway 25L at 12:51 p.m. PDT.

THE FINAL DEMATE PROCEDURE

Space shuttle Endeavour is secured to the Overland Transporter in the early morning hours of September 22, 2012, **at Los Angeles International Airport.** (Photo Credit: NASA/Paul E. Alers)

The next major milestone was to demate Endeavour from the SCA and place it on the Overland Transporter. The MDD device used at the KSC was a fixed structure and only two existed, the other being at EAFB. In the event the orbiter did not land at either KSC or EAFB, NASA developed a mobile lift system, consisting of two large cranes, a sling similar to the one used in the MDD and four stabilizing masts to prevent any lateral movement. The mobile system enabled the demating of the orbiter in about 10 hours.

Several weeks before the ferry flight, a NASA and USA team of 45 engineers and technicians headed to Los Angeles to prepare for the orbiter separation from the SCA. That included sending the mobile lift system, which was comprised of 20 truckloads of equipment. The separation began in the early morning hours of September 22, in an effort to minimize the noise disruption generated from landing and departing jet aircraft, which could have interfered with crew communication during the operation.

By midmorning, Endeavour had been demated, placed on the OT and moved into the United Airlines hangar to undergo additional preparations prior to its move to the Science Center. This would be the last time an orbiter would be demated from the SCA. And in a reminder of the stark finality of the close of the shuttle program after thirty years of operation, 135 flights and more than 530 million miles traveled in space, this was also the final mission of the SCA.

Shuttle Carrier N905NA, which flew 70 of the 87 operational ferry flights and all three of the ferry missions to deliver Discovery, Enterprise and Endeavour, was also being retired. Originally earmarked to serve as a spare part donor for NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA), NASA 905 is now slated to be on public display at NASA's Johnson Space Center in Houston and share in Endeavour's new role of preserving the shuttle legacy.

Workers prepare to remove the tail cone **off of the space shuttle Endeavour in a hangar at Los Angeles International** Airport, September 24, 2012. Photo (Credit: NASA/Bill Ingalls)

PREPARING FOR TRANSPORT AND DISPLAY

Inside the hangar, technicians had several major tasks to complete. The first was to remove Endeavour's tail-cone, which was used on all ferry flights to reduce the aerodynamic drag and turbulence. With the tail-cone removed, technicians reconfigured Endeavour's SSME nozzles to a launch mode. They had been gimbaled in a close-in configuration for the ferry flight. Also, reinstalled were the OMS pod replica nozzles to replace the originals, which had been removed for cleaning and decontamination. A final preparation included entering the crew compartment, as the technicians configured the flight deck and mid-deck for display. (Disclaimer: None of the orbiters on display will allow for entry into the crew compartment.)

An important decision made by the Science Center officials was to keep the landing gear retracted and have Endeavour displayed on the overland transporter. To house Endeavour, the Science Center constructed the Samuel

The space shuttle Endeavour, sitting on the Overland Transporter and the Self-Propelled Modular Transporter, moves out of the Los Angeles **International Airport and onto the streets of Los Angeles.** (Photo Credit: NASA/Carla Cioffi)

Oschin Space Shuttle Endeavour Display Pavilion. Once the move was completed to the Samuel Oschin Pavilion, the OT and Endeavour will rest on seismic isolation pedestals to protect against the threat of earthquakes. As curator Phillips noted, "This display is only temporary as we are planning for a new facility in 2017 that will enable us to display Endeavour in a launch mode, with the orbiter attached to solid rocket boosters and an external tank." For the future display, the Science Center will use real solid rocket boosters that are currently in storage at the Dryden Flight Research Center at EAFB and they will construct a replica external tank.

Phillips added, "We had to anticipate the equipment and strategy for five years . . . how do you handle the orbiter five years down the line without the NASA infrastructure and logistic support that existed to help with this move?" Having Endeavour's landing gear retracted would eliminate many future processes and the required support equipment, making it just a little easier to prepare for the complicated maneuvers that will be required to place the orbiter into a vertical position without NASA's assistance.

With the move to the Science Center set for October 12, a last minute requirement surfaced from city engineers. There was great concern that the combined weight of the orbiter, OT and the SPMTs, which was more than 300,000 pounds, might damage underground utilities. To better distribute the combined load, steel plates had to be placed on the most vulnerable parts of the roadway. The plates used were either 1 or 1 ½ inches thick and most were 8 feet by 10 feet. In all, they used about 2600 plates rented from almost every outlet on the west coast. This was just another preparation that had several key objectives: 1) Move the orbiter safely and securely, 2) Ensure the safety of the public, and 3) Protect the city infrastructure.

A NEW HOME AND MISSION: ANOTHER TWELVE MILES TO GO

After all of the preparations, Endeavour left the LAX security gate at 2:00 am PDT on October 12, and moved onto the city streets for its 12 mile journey to the new Samuel Oschin Pavilion. Accompanying the orbiter was a team of almost one hundred people that included several astronauts. Preceding Endeavour was an advance team who had responsibility for clearing obstacles. They removed light posts and traffic signals, trimmed trees and raised power lines in order to let Endeavour pass. More than 200 street fixtures were removed and 100 power lines were raised. Taking up the rear was another team that replaced the removed street fixtures and restored the thoroughfare to its original state.

Power lines are hoisted upwards by a crane **in order to allow the space shuttle** Endeavour to traverse on its path to the California Science Center, October 12, 2012 in Inglewood. (Photo Credit: NASA/Carla Cioffi)

The procession was designed to move no faster than 2 mph, but it was apparent from the start that this would be an intricate technical ballet. The SPMT operator using a remote controlled joystick, slowly moved the large spacecraft forward and performed numerous zigzags as the orbiter passed only inches from the roadway obstacles. An early challenge for the Shuttle Delivery Team was the Manchester Boulevard Bridge which passed over the 405 Freeway.

The California Department of Transportation would not allow the use of the SPMTs on the overpass. So the delivery team had to perform a delicate switch-over. Prior to reaching the overpass, a dolly was slipped between the SPMTs and then raised to lift and support the OT. The SPMTs were moved out of the way and the dolly was attached to a Toyota Tundra pick-up, which towed Endeavour across the overpass. It was only a 100 yard trip that took about 3 minutes, but the Tundra had gone through extensive practice sessions towing a 300,000 pound load and performed its task effortlessly. Once over the bridge, the process was reversed and the OT was placed back on the SPMTs to continue its journey to the Science Center.

A technician for the Overland Transporter signals how much room is available between a tree and the orbiter's wing, (Photo Credit: NASA/Carla Cioffi)

The original plan had Endeavour arriving at the Science Center on the evening of October 13. Built into the schedule were several public celebrations at the Inglewood Forum and at Crenshaw Plaza. But just as with the intricacies and unexpected occurrences of space travel, Endeavour encountered similar experiences on its street travels. The Shuttle Delivery Team had to slow the transport down multiple times as the orbiter zigzagged around several obstacles and conduct additional maintenance breaks to keep the SPMTs functioning perfectly. Finally, at about 2 pm PDT on October 14, about 15 hours later than scheduled, Endeavour reached its new home at the California Science Center's new Samuel Oschin Pavilion.

More than 1.5 million people viewed some portion of Endeavour's final journey through Los Angeles neighborhoods. It was a once in a lifetime event, made possible with more than a year of planning and through the hard work of hundreds of dedicated and highly skilled individuals. These individuals were representing the Science Center, NASA, USA, the cities of Inglewood and Los Angeles and more than twenty other companies.

Many donated time and resources to ensure that Endeavour's final journey was a safe one so that current and future generations can enjoy, learn and be inspired by the many contributions of the space shuttle program. The Samuel Oschin Pavilion opened on October 30, 2012, and the Space Shuttle Orbiter Endeavour is now on display. For the shuttle designers, the thousands of skilled individuals who took part in operating the shuttle program over thirty years, and all of those who contributed to Endeavour's final journey, they can be assured that its legacy will be preserved and cherished.

About the Author:

Burt Dicht is currently Director of IEEE University Programs where he is **involved in engineering education accreditation activities and developing** programs for faculty and students. During his career, Burt held **engineering positions at NASA's KSC (Intern), Rockwell Space Transportation** Systems Division and Northrop Grumman. He has worked on projects such as the F-5E Tiger II, the F20A Tigershark, the F-18E/F Super Hornet, the YF-**23A Advanced Tactical Fighter and the Space Shuttle.** Burt is a member of IEEE, AIAA, and an ASME Fellow. As a member of ASME, Burt was instrumental in having the Apollo Command/Service Module, the Apollo Lunar **Module and the Voyager Spacecraft designated ASME Historic Mechanical Engineering Landmarks.** Burt has **published multiple articles on aerospace history and is a frequent guest speaker on aviation and space topics.** He currently serves as a volunteer exhibit explainer for the Intrepid Sea, Air and Space Museum in New York City.

Guests walk around space shuttle Endeavour after the grand opening ceremony for the California Science Center's Samuel Oschin Space Shuttle Endeavour Display Pavilion. (Photo Credit: NASA/Bill Ingalls)

The Mission and Engineering Challenges of the James Webb Space Telescope

By Jonathan Arenberg

Sunshield template. Image Credit: NASA

The James Webb Space Telescope (JWST) is NASA's flagship astrophysics mission for the next decade. I am with Northrop Grumman, a key member of the worldwide team designing, building, testing, and ultimately delivering the world's next-generation space observatory. As engineers, we face some great challenges in making JWST happen. To achieve this goal, we must understand JWST's mission, its design, and the technical challenges it presents.

The Mission of JWST

JWST's primary scientific goal is to see the very first luminous objects in the history of the universe — namely to see the earliest stars and galaxies that formed within the first few hundred million years after the Big Bang, when the universe was only a few percent of its current age. Prior to this epoch, the universe was either ionized plasma and opaque, or after recombination, the primordial hydrogen had not collapsed to form the first stars. These objects are over 13 billion years old and are receding from us at a high velocity, red shifting their ultraviolet and visible radiation into the infrared.

In addition to the detection of first light, JWST is also intended to achieve other scientific objectives. JWST will study the formation and evolution of galaxies throughout the universe. Its intra-galactic objectives include the study of star formation, extra-solar planets, and objects within our own solar system. To achieve these scientific goals, JWST must be a highly sensitive, stable, and large infrared observatory, capable of pointing anywhere in the sky, Figure 1.

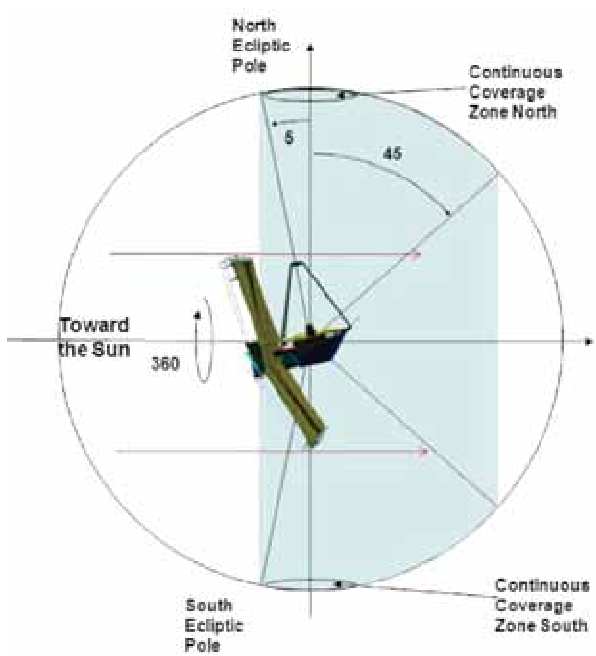


Figure 1. JWST's sunshield allows it to pitch 5 degrees forward and 45 degrees backward, and 360 degrees around the sun line. JWST sees ~39%. Image Credit: NASA

The team designing, building, testing, and delivering JWST is an international one from government, academia and industry. JWST team members are located in the United States, Canada and throughout Europe. NASA is partnered with the Canadian and European Space Agencies to make JWST a reality.

JWST's Mission Architecture

JWST is designed to be a highly efficient, long-lived scientific resource. JWST will operate 1,000,000 miles away from Earth, orbiting in the Second Lagrange point or L2, Figure 2. This will enable JWST to have an orbit that is free from the destabilizing influence of the Earth's radiated heat, eclipses and blockage of the observable sky. However, this location is close enough to allow high-rate communication without excessive commitment of mass. JWST will achieve this orbit by a direct injection trajectory, similar to that used on the European Space Agency's (ESA) Herschel/Planck mission. This orbit is affected by the gravity of the Earth in such a way that even though JWST is 94,000,000 miles from the sun, it completes its annual revolution in approximately one year. This means that the Earth is in approximately the same position at all times throughout the mission, facilitating command and communication.

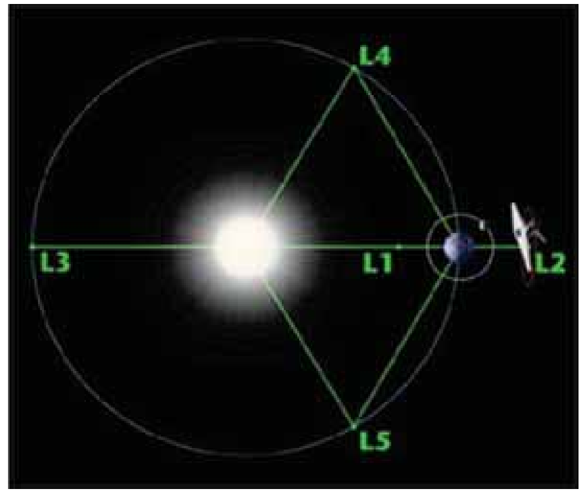


Figure 2. Lagrange points and JWST's orbit. Image Credit: NASA

The Design of JWST

JWST consists of three segments. The first, the flight segment, contains the optical telescope element, the sunshield, a spacecraft bus and the integrated science instrument module, Figure 3. The second segment is launch and is provided by ESA in the form of the Ariane V launch vehicle. The third segment is the ground segment, which will process the scientific proposals, generate commands for the flight segment, control spacecraft operations and archive and disseminate scientific data. The operations of JWST will be controlled through the Space Telescope Science Institute, just as the Hubble telescope is operated and its data are managed.

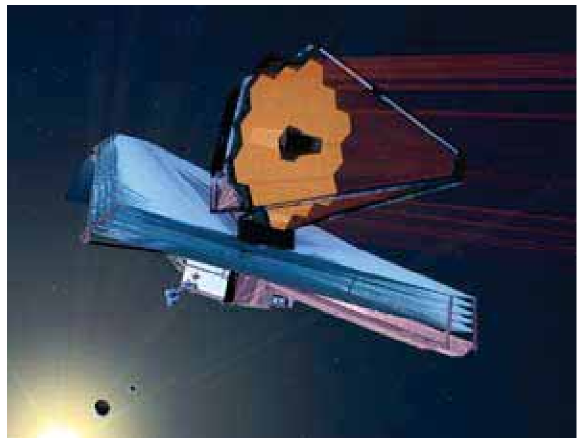


Figure 3. Artists rendition of deployed JWST. Image Credit: Northrop Grumman Aerospace Systems

The optical telescope element collects and focuses the light from the target down into the science instruments. The optical system consists of beryllium mirrors coated with a protected gold coating to enhance their infra-red reflectivity, Figure 4 shows six of the mirrors ready for test. The primary mirror consists of 18 hexagonal mirror elements each individually actuated in seven degrees of, three in translation, three in rotation, and one to alter the radius of curvature (if required). The secondary mirror is also made of beryllium and is also actuated in six degrees of freedom. The light is then directed to the tertiary mirror, the only fixed mirror in the optical train, and is then sent to the fine-steering mirror, which directs the light into the instruments. The mirrors have all completed manufacture and coating, and are being delivered to NASA's Goddard Space Flight Center (GSFC) for storage prior to integration. Ball Aerospace in Boulder, Colorado has led the efforts to manufacture the mirrors, actuators and control system, with major subcontractors Axsys, Tinsley Laboratories and Quantum Coating.

Figure 4. Six Primary Mirror Segment Assemblies ready for test a Marshall Space Flight Center, Huntsville, AL. Image Credit: NASA

The optical elements are held in their proper places by a high-performance structure. This high-performance structure, designed and built by ATK in Magna Utah, is primarily a graphite composite construction. It must be dimensionally stable to the order of nanometers per Kelvin.

The Integrated Science Instrument Module (ISIM), made by NASA's Goddard Space Flight Center, consists of a structure, international instruments, command and data handling systems, and electronics necessary to operate the instruments. JWST's suite of instruments comes from the United States, Canada, and Europe. The Near Infrared Camera, NIRCam, is provided by the University of Arizona with main industrial partner Lockheed Martin, and is the workhorse shortwave imager and wavefront sensing instrument. The Fine Guidance Sensor and Near Infrared Imaging Slitless Spectrometer, FGS/NIRISS, provided by the Canadian Space Agency, is the instrument that allows JWST to achieve its exquisite pointing performance and also offers science capability. The Near Infrared Spectrograph, NIRSpec, is provided by the European Space Agency with main industrial partner EADS. This instrument allows JWST to take hundreds of spectra in a single field, necessary for separating objects by red shift. The final instrument, the Mid-Infrared Imager, MIRI, is the only actively cooled instrument on JWST. MIRI provides the longwave, 5-27+ µm, capability for JWST, both as an imager and spectrometer. MIRI's focal plane is actively cooled using a cryo cooler provided by the Jet Propulsion Laboratory (JPL) through a contract with Northrop Grumman Aerospace Systems. The ISIM is beginning flight integration with its graphite composite structure completed and the initial flight instruments delivered.

Figure 5. Northrop Grumman Lead Venting Analyst Dan McGregor with a sunshield test article as it is placed in the vacuum chamber at Aerospace Systems' test facility in Redondo Beach, CA. Image Credit: Northrop Grumman Aerospace Systems

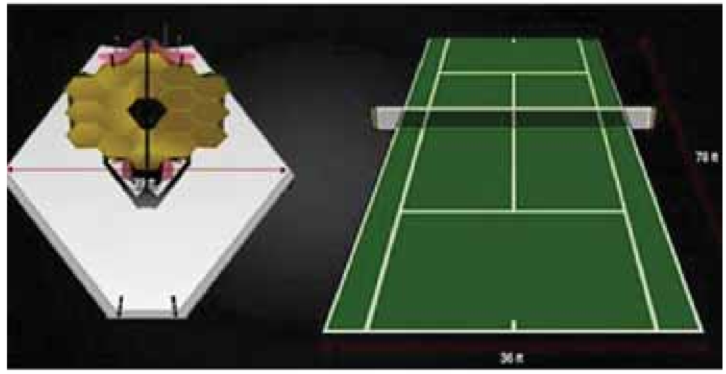


Figure 6. JWST sunshield and a doubles tennis court. Image Credit: NASA

The sunshield enables the mission of JWST by casting a deep, dark shadow in which the telescope lives, allowing it to radiate its heat to space and achieve the necessary cryogenic temperatures passively. For the sunshield to provide the necessary thermal attenuation of the approximately 200,000 W incident on its sunward facing surface, five precisely shaped membranes are used. These membranes must be stowed and restrained during the turbulence of launch, and subsequent depressurization to allow for deployment. The sunshield is approximately the size of a doubles tennis court, Figure 6.

The sunshield has been tested to demonstrate its thermal performance using a one-third scale model that is over 22 feet in length and 12 feet in width. In this test, solar simulators for incident on the sunward side and the temperatures of the membranes facing the telescope were measured and compared to prediction. This test validated thermal analyses and showed that the design of the JWST sunshield will meet requirements.

Learning how to stow and deploy the membranes is a major effort requiring technological extremes. The finite element models that predict the shape of the membranes under tension are highly complicated, containing many hundred thousand degree of freedom models that press the state of the computational art. Determining the location of the holes that are used as part of the restraints to manage the membranes through launch is done using full-scale models. The holes must line up when stowed, but they cannot line up when deployed for control of stray light and thermal management. This kind of analysis is not easily done using current computer based tools, so full scale mock-ups are needed.

In order to ensure that the membrane manufacturing processes account for handling and integration processes, a set of template membranes are being manufactured by membrane contractor Nexolve at their facility in Huntsville, Alabama. To date, three of the five template membranes have been completed. The sunshield structure — the large pallets that deploy forward and aft and contain the membranes for launch

— are being designed and manufactured by Northrop Grumman. The mid-booms that push the membranes out from the sides of the spacecraft are being manufactured by Astro Aerospace, a Northrop Grumman subsidiary, located in Carpinteria, California.

The last element is the spacecraft bus, which is beginning the final design phase ahead of its planned critical design review at the end of 2013. The spacecraft bus houses the traditional spacecraft subsystems, such as propulsion, electrical power, command and data handling and attitude control. It also contains the room -temperature electronics and compressors for the MIRI cryo cooler. The spacecraft has all of the usual challenges when designing a high performance spacecraft, including the need to be mass efficient, stable and easy to manufacture. The JWST bus has the additional challenge that there is no "cold side" that can dump heat. The sunshield and temperature-sensitive telescope and instruments prevent radiation of the heat toward the cold side of the observatory, and furthermore, the sunshield directs a large infrared load onto the spacecraft. The spacecraft is making excellent progress toward its planned review, and is being designed and manufactured by Northrop Grumman Aerospace Systems.

Figure 7. Chamber A with door open, note people at bottom of door for scale. Image Credit: NASA

To build and test these extremely large flight systems requires similarly large and complex ground support and test equipment. The program is also making excellent progress in these critical areas. The support equipment to assemble the optical telescope in the clean room at GSFC has been built and delivered, see www.jwst.nasa.gov/webcam.html. The ambient optical assembly stand weighs over 140,000 pounds. Additionally, the robot arms that will be used to precisely install the primary mirror segment assemblies and the secondary mirror have been developed and are currently being tested. Both the assembly stand and robot arms are being designed and built by ITT Excelis of Rochester, New York. JWST is also planning a system-level test in vacuum at cryogenic temperatures, where light will go through the entire optical system to assure proper assembly and workmanship. This test will take place at Johnson Space Center (JSC) in Houston, Texas in historic Chamber A, the location of the Apollo environmental tests, Figure 7.

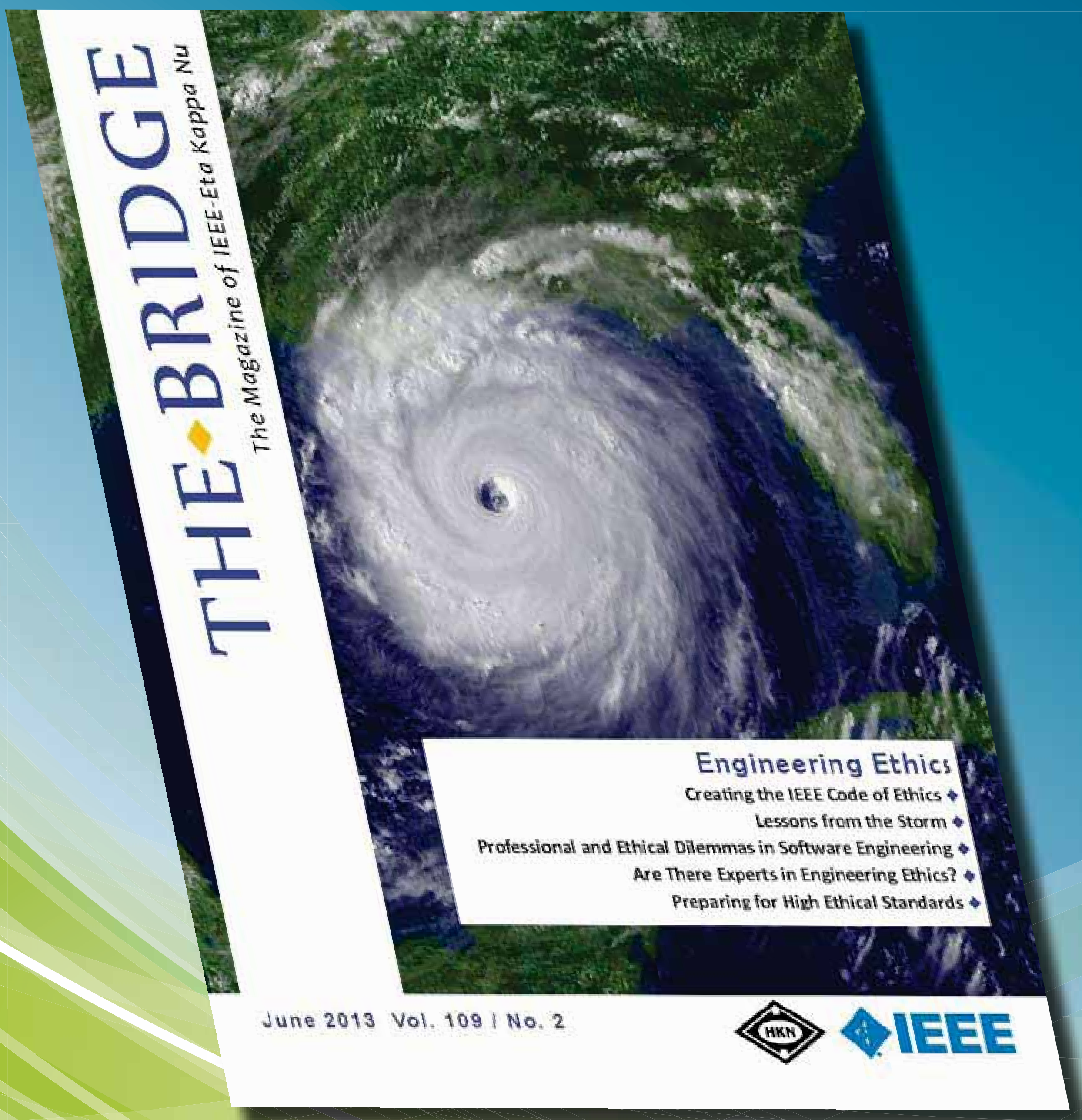
Bringing Chamber A up to date and making it a modern, clean cryogenic optical test facility is being undertaken by a team at JSC. All of the 1960s era equipment in the chamber has been removed, the air handling pipes and manifolds have been cleaned and coated consistent with clean room operations, and the two-stage cryogenic shrouds have been installed. The renovated Chamber A passed its first vacuum and cryogenic temperature tests earlier this year.

JWST is a complex mission with challenges for every engineer on the program, and promises to return ground breaking science. The JWST team is extraordinarily capable and is making excellent technical progress. The entire team is focused on mission success and looking forward to launch in late 2018.

About the Author:

Jonathan Arenberg has been with Northrop Grumman Aerospace Systems since 1989, having started with Hughes **Aircraft Company. His work experience includes optical, space** and laser systems. Dr. Arenberg has worked on such astronomical programs as the Chandra X-ray Observatory, James Webb Space Telescope, and helped develop the New Worlds Observer concept for the imaging of extra-solar planets. He has worked on major high-**energy and tactical laser** systems, laser component engineering and metrology issues. He is a member of the ISO sub-**committee charged with writing standards for laser and electro-optic systems and** components, SPIE, American Astronomical Society, and AIAA. Dr. Arenberg holds a BS in physics and an MS and PhD in engineering, all from the University of California, Los Angeles. **He is the author of many conference presentations and publications, and holds one European and 11 U.S. Patents** in a wide variety of areas of science and technology. He is currently the Chief Engineer for the James Webb Space Telescope Program (www.jwst.nasa.gov) and is a Charter Member of the Iota Gamma Chapter of Eta Kappa Nu.

June Reprint



Creating the IEEE Code of Ethics

The history behind the process...

By Emerson W. Pugh

Abstract

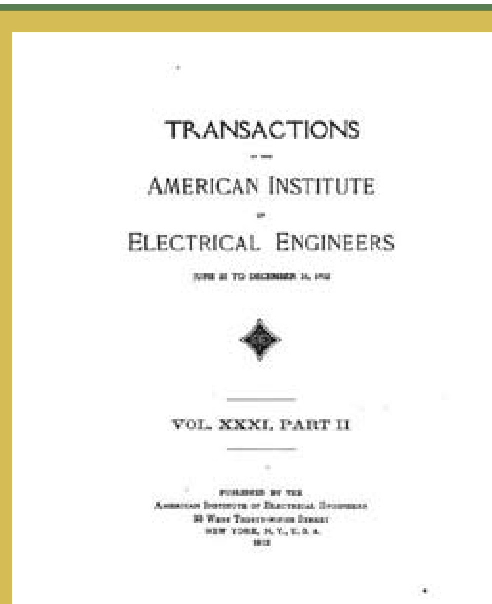
In 1912 the AIEE adopted its first code of ethics. It was called the "Code of Principles of Professional Conduct." Following the 1963 merger of AIEE and IRE that formed IEEE, a new code of ethics was adopted in 1974 and revised in 1979 and again in 1987. In 1990 the IEEE Board of Directors voted to adopt a shorter code, with content and wording more appropriate for a worldwide membership.

Prior to the early 1900s, ethics were viewed as a personal matter and therefore not a responsibility of engineering societies. Among those seeking a change in this point of view was Schuyler S. Wheeler, president of the American Institute of Electrical Engineers (AIEE).

In 1906 he gave his presidential address on the subject of "Engineering Honor." It was so enthusiastically received by the members that a committee (consisting of Schuyler P. Wheeler, H. W. Buck, and Charles P. Steinmetz) was established to begin work on creating an AIEE code of ethics.

Principles of Professional Conduct

It was not until six years later, in 1912, that a code of ethics was finally adopted. It was called the "Code of Principles of Professional Conduct" and was published in the December 1912 issue of the *Transactions of the American Institute of Electrical Engineers*. [See Figure 1]



TRANSACTIONS

AMERICAN INSTITUTE

ELECTRICAL ENGINEERS

VOL. XXXI, PART II

Figure 1. Title page of the ***Transactions*** of AIEE, Dec. 31, 1912, in which the "Code of Principles of Professional Conduct" first appeared.

It was a long document that filled three pages of the Transactions. The wording was quite specific and reflected the fact that many AIEE members were self-employed. Major topics of the Code were "General Principles," "The Engineer's Relations to Client or Employer," "Ownership of Engineering Records and Data," "The Engineer's Relations to the Public," and "The Engineer's Relations to the Engineering Fraternity." Associated with these five major topics were a total of 22 specific canons.

This "Code of Principles of Professional Conduct" provided ethical guidance for AIEE members until 1963 when AIEE and IRE (Institute of Radio Engineers) merged to form the IEEE (Institute of Electrical and Electronics Engineers).

In that same year, the Engineers Council for Professional Development (which had been founded in 1932 by seven engineering societies, including AIEE) revised and updated its "Canons of Ethics of Engineers," and it asked its constituent societies to adopt them. Many engineering societies did adopt them.

IEEE Seeks Its Own Code

The IEEE chose to develop its own code of ethics. As an interim measure, it endorsed the three Fundamental Principles of Professional Engineering Ethics, which were stated in the Canons of the Engineers Council of Professional Development as follows: "The Engineer . . . (1) Will be honest and impartial, and will serve with devotion his employer, his clients, and the public; (2) Will strive to increase the competence and prestige of the engineering profession; and (3) Will use his knowledge and skill for the advancement of human welfare."

It was not until December 1974 that a new volunteer-developed "IEEE Code of Ethics for Engineers" was approved by the IEEE Board of Directors, under the leadership of IEEE President John Guarrera. In early 1975 it was added to the IEEE Policy and Procedures Manual and also publicized in the IEEE Spectrumissue of February 1975. [See Figure 2]

IEEE CODE OF ETHICS FOR ENGINEERS

PREAMBLE

Engineers affect the quality of life for all people in our complex technological society. In the pursuit of their profession, therefore, it is vital that engineers conduct their work in an ethical manner so that they merit the confidence of colleagues, employers, clients and the public. This IEEE Code of Ethics is a standard of professional conduct for engineers.

ARTICLE I

Engineers shall maintain high standards of diligence, creativity and productivity, and shall:

1. Accept responsibility for their actions;
2. Be honest and realistic in stating claims or estimates from available data;
3. Undertake engineering tasks and accept responsibility only if qualified by training or experience, or after full disclosure to their employers or clients of pertinent qualifications;
4. Maintain their professional skills at the level of the state of the art, and recognize the importance of current events in their work;
5. Advance the integrity and prestige of the engineering profession by practicing in a dignified manner and for adequate compensation.

ARTICLE II

Engineers shall, in their work:

1. Treat fairly all colleagues and co-workers, regardless of race, religion, sex, age or national origin;
2. Report, publish and disseminate freely information to others, subject to legal and proprietary restraints;
3. Encourage colleagues and co-workers to act in accord with this Code and support them when they do so;
4. Seek, accept and offer honest criticism of work, and properly credit the contributions of others;
5. Support and participate in the activities of their professional societies;
6. Assist colleagues and co-workers in their professional development.

ARTICLE III

Engineers shall, in their relations with employers and clients:

1. Act as faithful agents or trustees for their employers or clients in professional and business matters, provided such actions conform with other parts of this Code;
2. Keep information on the business affairs or technical processes of an employer or client in confidence while employed, and later, until such information is properly released, provided such actions conform with other parts of this Code;
3. Inform their employers, clients, professional societies or public agencies or private agencies of which they are members or to which they may make presentations, of any circumstance that could lead to a conflict of interest;
4. Neither give nor accept, directly or indirectly, any gift, payment or service of more than nominal value to or from those having business relationships with their employers or clients;
5. Assist and advise their employers or clients in anticipating the possible consequences, direct and indirect, immediate or remote, of the projects, work or plans of which they have knowledge.

ARTICLE IV

Engineers shall, in fulfilling their responsibilities to the community:

1. Protect the safety, health and welfare of the public and speak out against abuses in these areas affecting the public interest;
2. Contribute professional advice, as appropriate, to civic, charitable or other non-profit organizations;
3. Seek to extend public knowledge and appreciation of the engineering profession and its achievements.

IEEE spectrum FEBRUARY 1975

Figure 2. Code of Ethics for Engineers as it appeared in IEEE Spectrum of February 2, 1975, on page 65.

This "IEEE Code of Ethics for Engineers" had a brief preamble and four articles. The preamble said:

Engineers affect the quality of life for all people in our complex technological society. In the pursuit of their profession, therefore, it is vital that engineers conduct their work in an ethical manner so that they merit the confidence of colleagues, employers, clients and the public. This IEEE Code of Ethics is a standard of professional conduct for engineers.

The articles that followed had a total of 19 canons that were divided among four areas of ethical concern for engineers: 1) maintaining their own capabilities, 2) behavior at work, 3) relations with employers and clients, and 4) responsibilities to the community.

As IEEE membership grew, many of the newer members were not trained as engineers, and they desired to be properly recognized for their own professional status. In response to this desire, the opening phrase of the first sentence of the Code's preamble was amended in February 1979. In the phrase, "Engineers affect the quality of life for all people," the single word, "Engineers," was replaced with "Engineers, scientists and technologists." The remainder of the Code's preamble and all four of its articles were amended to be consistent with this change.

Impact of a Dissident Member

The next change to the IEEE Code of Ethics was motivated by the activities of a dissident member of IEEE who portrayed himself as the "defender of working engineers," as distinguished from the volunteer leaders of IEEE, whom he characterized as "fat cats." In addition to attacking IEEE policies and activities in his newsletter, he personally attacked several IEEE volunteers in various ways, including writing damaging letters to their employers.

Finding there was nothing in the IEEE Code of Ethics that specifically forbid this type of behavior, the IEEE leadership corrected the omission in November 1987 by adding Article V, which is quoted below:

> Members shall, in fulfilling their responsibilities to IEEE, its members, and employees:
>
> 1. Make no statement that the member knows to be false or with reckless disregard as to its truth or falsity concerning IEEE or the qualifications, integrity, professional reputation, or employment of another member or employee;
> 2. Neither injure nor attempt to injure, maliciously or falsely, the professional reputation or employment of another member or employee.

The "defender of working engineers" immediately charged IEEE leadership with taking this action without proper notification of the membership. In February 1988, IEEE President Russell C. Drew appointed an ad hoc committee to examine these charges, and to determine if any IEEE policies or procedures had been violated. The members of this ad hoc committee were Edward Bertnolli (chair), Dennis Bodson, Thomas Grim, and Emerson Pugh. We determined that the process by which the Code of Ethics had been revised in 1987 was legal and in keeping with the rules of IEEE. Nevertheless, we did recommend that all IEEE members be given an opportunity to review and comment on any future changes in the Code of Ethics before the Board voted on them.

Finding My Mission

Through my involvement on President Drew's ad hoc committee, I became interested in the possibility of rewriting the Code to make it shorter, loftier in style, and with content and wording more appropriate for IEEE members throughout the world. I was especially interested in this later goal because IEEE was growing more rapidly outside the United States than inside. By the end of 1987, 20 percent of IEEE's 293,129 members lived outside the United States. Also, I was IEEE President-Elect in 1988, and one of my goals was to increase the rate at which IEEE was becoming a transnational organization in its philosophies and governance as well as in the geographic distribution of its members.

By May 1988 I had written a first draft and had obtained support from the other three members of the ad hoc committee. The draft retained what I believed to be the major concepts of the then-current Code, but it was much shorter and had exactly ten canons. I liked the number ten because people throughout the world have ten fingers, they use a decimal system for counting, and many are accustomed to having a moral code specified by ten commandments.

I circulated this first draft to the members of the Ethics Committee of the IEEE United States Activities Board and to several other individuals. Most comments were supportive, but others expressed concern over the loss of the long-revered IEEE Code of Ethics.

PRESIDENT'S COLUMN

Must we give up ethics to eat?

Emerson W. Pugh

"I gave up ethics—to eat!" is the title of an article that originally appeared in the December 1957 issue of *Consulting Engineer*. The problem the author faced 30 years ago is no less real today. His solution, regretfully, is still just as common.

The author described how, as head of his own engineering firm, he had been unable to obtain government contracts without bribing public officials. Faced with either giving up his business or giving up his ethical principles, he chose the latter. He hired a "public relations counsel" who made the necessary arrangements for a percentage of each deal.

Those of us who are employed by large organizations are generally not confronted with this problem, but all of us have faced ethical dilemmas during our careers. Indeed, the complexities of the issues and decision processes may be greater for those employed by large organizations, where authority and responsibility are shared with others.

Fundamental to ethical dilemmas is the question: To whom do we owe our allegiance? To ourselves? Our family? An organization? Or to a larger community such as our country or the world? Being ethical generally implies acting in a manner beneficial to the larger rather than to the smaller group. Thus at its limit—and for the IEEE as a transnational organization—ethical behavior must be considered in the context of the world community.

But how are our ethical principles to be established? Can they be applicable worldwide? Who judges our behavior? How can ethics be enforced? Should ethical principles be discarded if they cannot be enforced or if many people violate them?

I do not have good answers for many of these questions. But our members seem to believe they know what ethics are, and that it is sometimes as important to adhere to ethical principles as it is to eat. Furthermore, when the IEEE Code of Ethics was revised in 1987, many individuals and groups expressed a desire to participate in that process. Many also expressed a desire to have a code of ethics with clear, simple wording.

Following up on these desires—and to begin a dialogue on ethics—I have attempted to simplify and clarify the IEEE Code of Ethics. I have done this by making use of suggestions submitted when the code was last revised and by seeking advice from many others. The resulting "simplified" version, printed below, no doubt also reflects some of my own views, which may or may not be held by other IEEE members or their colleagues.

Members who have thoughts on this subject that they wish to share should write to: IEEE President, Code of Ethics, 345 E. 47th Street, New York, N.Y. 10017, U.S.A. I may not be able to respond directly to everyone, but I have asked Edward C. Bertnolli, Vice President-Professional Activities, to establish a committee to review the responses to this column.

If there is enough interest and sense of direction in the correspondence, the committee will take appropriate action. For example, it may modify either the "simplified version" or the present version to provide a basis for further discussion and possible change, or it may conclude that some completely different action is needed. On the other hand, if there is little response, we shall report that to you and take no further action. The present IEEE Code of Ethics is displayed on p.11.

Simplified Code of Ethics

We the members of the IEEE—in recognition of the importance of our technologies to the quality of life throughout the world, and in accepting our obligations to our profession, its members, and the community we serve—agree and covenant:

1. to conduct ourselves in the highest ethical manner;
2. to make engineering decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public;
3. to avoid real or perceived conflicts of interest where possible, and to disclose them to affected parties when they do exist;
4. to help improve public understanding of technology and its proper use;
5. to maintain and improve our technical competency and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;
6. to be honest and realistic in stating claims or estimates based on available data;
7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;
8. to neither offer nor accept bribes;
9. to treat fairly all persons regardless of race, religion, sex, age, or national origin, and never to attempt to injure maliciously or falsely the person, property, reputation, or employment of others;
10. to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

Figure 3. President's Column from ***The Institute*** of April 1989.

Some were concerned that the more general wording of the proposed code would make "enforcement" more difficult. The idea that IEEE should enforce its Code of Ethics was quite common at the time, and some even wanted to provide financial help to members who suffered financially by following the Code.

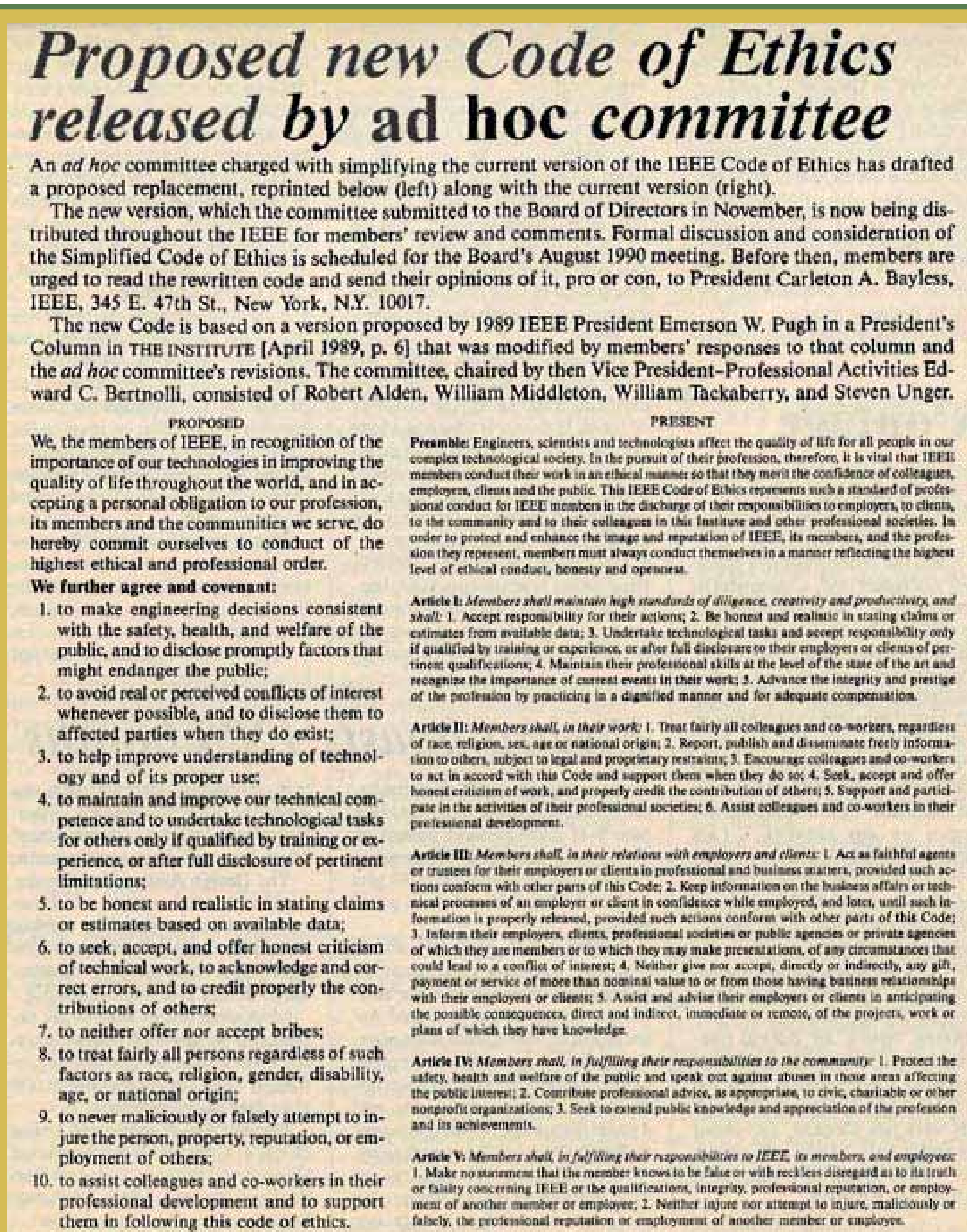
Taking Charge as President

On January 13, 1989, two weeks after becoming IEEE President, I held a meeting to discuss the IEEE Code of Ethics with a group of well-respected IEEE leaders. Based on these discussions, I made a number of minor changes and one major change to the proposed code of ethics.

The major change was to delete a provision that admonished IEEE members "to report, publish, and disseminate information freely to others, subject to legal and proprietary restraints" and replace it with one that admonished IEEE members "to neither offer nor accept bribes." Stephen H. Unger, especially, had urged that a statement against bribery be included, and I had concluded that the admonition to provide information freely to others "subject to legal and proprietary restraints" would be interpreted so differently in countries throughout the world that it would have little real meaning. In the April 1989 issue of IEEE's newspaper, The *Institute*, I published the proposed IEEE Code of Ethics at the end of my "President's Column." [See Figure 3.]

The title I gave my "President's Column" was, "Must we give up ethics to eat?" This title was based on an article titled, "I gave up ethics to eat," which had been published in a 1957 issue of the magazine, *Consulting Engineer*. The magazine article told how the author found he could not get government contracts without bribing government officials. In my column, I pointed out how this thirty-year-old story related to problems still faced by IEEE members and how important it was for IEEE to have a code of ethics that was easy to read and appropriate to IEEE members throughout the world.

I asked readers to compare the proposed simplified IEEE Code of Ethics at the bottom of my President's Column with the then-current Code, which was printed elsewhere in The *Institute*, and I asked them to send me their comments. Readers were also advised that I had "asked Edward C. Bertnolli, Vice President-Professional Activities, to establish a committee to review the responses." Subsequently, Robert Alden, William R. Middleton, William R. Tackaberry, and Stephen H. Unger were appointed to the committee.



Proposed new Code of Ethics released by ad hoc committee

An *ad hoc* committee charged with simplifying the current version of the IEEE Code of Ethics has drafted a proposed replacement, reprinted below (left) along with the current version (right).

The new version, which the committee submitted to the Board of Directors in November, is now being distributed throughout the IEEE for members' review and comments. Formal discussion and consideration of the Simplified Code of Ethics is scheduled for the Board's August 1990 meeting. Before then, members are urged to read the rewritten code and send their opinions of it, pro or con, to President Carleton A. Bayless, IEEE, 345 E. 47th St., New York, N.Y. 10017.

The new Code is based on a version proposed by 1989 IEEE President Emerson W. Pugh in a President's Column in THE INSTITUTE [April 1989, p. 6] that was modified by members' responses to that column and the *ad hoc* committee's revisions. The committee, chaired by then Vice President–Professional Activities Edward C. Bertnolli, consisted of Robert Alden, William Middleton, William Tackaberry, and Steven Unger.

PROPOSED

We, the members of IEEE, in recognition of the importance of our technologies in improving the quality of life throughout the world, and in accepting a personal obligation to our profession, its members and the communities we serve, do hereby commit ourselves to conduct of the highest ethical and professional order.

We further agree and covenant:

1. to make engineering decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public;
2. to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;
3. to help improve understanding of technology and of its proper use;
4. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;
5. to be honest and realistic in stating claims or estimates based on available data;
6. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;
7. to neither offer nor accept bribes;
8. to treat fairly all persons regardless of such factors as race, religion, gender, disability, age, or national origin;
9. to never maliciously or falsely attempt to injure the person, property, reputation, or employment of others;
10. to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

PRESENT

Preamble: Engineers, scientists and technologists affect the quality of life for all people in our complex technological society. In the pursuit of their profession, therefore, it is vital that IEEE members conduct their work in an ethical manner so that they merit the confidence of colleagues, employers, clients and the public. This IEEE Code of Ethics represents such a standard of professional conduct for IEEE members in the discharge of their responsibilities to employers, to clients, to the community and to their colleagues in this Institute and other professional societies. In order to protect and enhance the image and reputation of IEEE, its members, and the profession they represent, members must always conduct themselves in a manner reflecting the highest level of ethical conduct, honesty and openness.

Article I: *Members shall maintain high standards of diligence, creativity and productivity, and shall:* 1. Accept responsibility for their actions; 2. Be honest and realistic in stating claims or estimates from available data; 3. Undertake technological tasks and accept responsibility only if qualified by training or experience, or after full disclosure to their employers or clients of pertinent qualifications; 4. Maintain their professional skills at the level of the state of the art and recognize the importance of current events in their work; 5. Advance the integrity and prestige of the profession by practicing in a dignified manner and for adequate compensation.

Article II: *Members shall, in their work:* 1. Treat fairly all colleagues and co-workers, regardless of race, religion, sex, age or national origin; 2. Report, publish and disseminate freely information to others, subject to legal and proprietary restraints; 3. Encourage colleagues and co-workers to act in accord with this Code and support them when they do so; 4. Seek, accept and offer honest criticism of work, and properly credit the contribution of others; 5. Support and participate in the activities of their professional societies; 6. Assist colleagues and co-workers in their professional development.

Article III: *Members shall, in their relations with employers and clients:* 1. Act as faithful agents or trustees for their employers or clients in professional and business matters, provided such actions conform with other parts of this Code; 2. Keep information on the business affairs or technical processes of an employer or client in confidence while employed, and later, until such information is properly released, provided such actions conform with other parts of this Code; 3. Inform their employers, clients, professional societies or public agencies or private agencies of which they are members or to which they may make presentations, of any circumstances that could lead to a conflict of interest; 4. Neither give nor accept, directly or indirectly, any gift, payment or service of more than nominal value to or from those having business relationships with their employers or clients; 5. Assist and advise their employers or clients in anticipating the possible consequences, direct and indirect, immediate or remote, of the projects, work or plans of which they have knowledge.

Article IV: *Members shall, in fulfilling their responsibilities to the community:* 1. Protect the safety, health and welfare of the public and speak out against abuses in those areas affecting the public interest; 2. Contribute professional advice, as appropriate, to civic, charitable or other nonprofit organizations; 3. Seek to extend public knowledge and appreciation of the profession and its achievements.

Article V: *Members shall, in fulfilling their responsibilities to IEEE, its members, and employees:* 1. Make no statement that the member knows to be false or with reckless disregard as to its truth or falsity concerning IEEE or the qualifications, integrity, professional reputation, or employment of another member or employee; 2. Neither injure nor attempt to injure, maliciously or falsely, the professional reputation or employment of another member or employee.

Figure 4. The proposed new Code of Ethics and the old Code of Ethics published side-by-side in ***The Institute*** in February 1990.

Seeking Broad Support

From time to time during 1989, I met with this committee to consider a variety of changes that might make the Code more appealing to all members and also more likely to be approved by the IEEE Board of Directors. Of considerable concern was the strong disapproval of the proposed Code of Ethics by some IEEE volunteers who had spent many years working with the old version. Several of them believed a Code of Ethics should be written in precise legal language so that each provision could be enforced. At least one of them was known to be lobbying members of the Board of Directors to defeat the new Code of Ethics.

Also during my year as IEEE President, I discussed the proposed simplified Code of Ethics with IEEE members wherever I went. I was especially pleased that the provision on bribery was most strongly supported by members in countries were bribery was endemic. Previously, I had been concerned that members in such countries would reject the new Code of Ethics on the grounds that adhering to the provision on bribery was not realistic.

However, these members said bribery was a serious problem that needed strong refutation. They believed that a code of ethics should record what people aspire to do rather than what they may actually do. Clearly they did not believe IEEE could, or should try to, enforce its Code of Ethics – except possibly in regard to internal IEEE matters.

In February 1990 the simplified Code of Ethics was again presented in *The Institute* for comment by all IEEE members. This time it was printed side-by-side with the old Code. The old Code of Ethics had 591 words, whereas the simplified Code had 238. This was a 60 percent reduction in the number of words. [See Figure 4.]

The comments received from members indicated that no significant changes were needed. Nevertheless I continued to work with the committee to achieve the best possible wording throughout the document. In August 1990 the IEEE Board of Directors approved the simplified IEEE Code of Ethics, which became effective on January 1, 1991.

Unlike the old Code of Ethics, this shorter version has been broadly distributed and read throughout the world. For example, it is prominently displayed in the "IEEE Society & Special Interest Memberships & Subscriptions" document that is updated each year.

A Minor Change

The Code of Ethics remained unchanged for 15 years, until 2006 when the word "engineering" was removed from the first canon. This canon had said, in part, that IEEE members were "to accept responsibility in making engineering decisions consistent with the safety, health, and welfare of the public." With the word "engineering" deleted, they are now admonished, in effect, to "accept responsibility in making decisions (of all types) consistent with the safety, health, and welfare of the public." [See Figure 5.]

IEEE Code of Ethics

WE, THE MEMBERS OF THE IEEE, in recognition of the importance of our technologies in affecting the quality of life throughout the world, and in accepting a personal obligation to our profession, its members and the communities we serve, do hereby commit ourselves to the highest ethical and professional conduct and agree:

1. to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;
2. to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;
3. to be honest and realistic in stating claims or estimates based on available data;
4. to reject bribery in all its forms;
5. to improve the understanding of technology, its appropriate application, and potential consequences;
6. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;
7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;
8. to treat fairly all persons regardless of such factors as race, religion, gender, disability, age, or national origin;
9. to avoid injuring others, their property, reputation, or employment by false or malicious action;
10. to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

Figure 5. "IEEE Society & Special Interest Memberships & Subscriptions" pamphlet of 2008 showing the IEEE Code of Ethics which is also prominently displayed in the current online version.

This change was motivated in part by the IEEE Board of Directors approval in February 2004 of a revision to IEEE Bylaw 1-104 that opens membership to professionals who do not see themselves as engineers. Following this change in the Bylaws, the IEEE Ethics and Member Conduct Committee reviewed the IEEE Code of Ethics, consistent with its mandate to promote ethical behavior and to advise the Board of Directors on ethics policy and concerns.

Not surprisingly, the opportunity to review the document caused some Committee members to think of many things that might be reworded or expanded. Fortunately, however, with the wise guidance of Theodore A. Bickart, the Committee generally focused on the target issue. Ultimately, the Committee recommended that the word, engineering, be deleted in the first canon of the Code. Consistent with the recommendation of President Drew's ad hoc committee of 1988, IEEE members, worldwide, were notified of this proposed change in the Code of Ethics by the Internet in November 2005 and then in the print edition of the Institute in December. The reaction of the membership was judged to be positive, and the Board of Directors approved the revision in February 2006.

From one perspective, it is surprising that any change was needed. After all, the Code of Ethics adopted in 1990 had been crafted to apply to members throughout the world – including those who did not consider themselves to be engineers. From another perspective, however, the use of the word, engineering, had been a troubling consideration even in 1990.

As we saw it then, if we failed to insert the word "engineering" it would have suggested that the IEEE Code of Ethics was being applied well beyond IEEE's normal areas of interest – an unacceptable concept for many. However, using the word, engineering, might have been objectionable to others who did not consider themselves to be engineers.

In the environment of 1990, we ultimately inserted the word "engineering." A major justification was our belief, that decisions made by scientists, engineers, or technologists, concerning the development or use of IEEE technologies in ways that could affect the "safety, health, and welfare of the public" were, by definition, "engineering" decisions.

By 2006 the environment had changed. No longer did it seem appropriate to limit the Code's applicability to decisions normally defined as "engineering decisions" when the "safety, health, and welfare of the public" was at issue. When no suitable replacement for the word "engineering" could be found, it was simply deleted.

Worldwide Focus and Personal Commitment

The IEEE Code of Ethics adopted in 1990, and revised in 2006, necessarily has much in common with those of other technical societies, but it is unique in many ways. Perhaps most important, it puts less emphasis on a member's responsibility to other members and greater emphasis on a member's responsibility to all people. Indeed, the IEEE Code of Ethics is consistent with IEEE's stated purpose of "fostering technological innovation and excellence for the benefit of humanity." This statement is often shortened to the tagline, "IEEE: Advancing Technology for Humanity."

IEEE members live in many countries, each with its own heritage, culture, and economy. By the end of 2012, 52 percent of IEEE's 429,085 members were living in countries other than the United States. The decision of the IEEE Board of Directors in 1990 to replace the old IEEE Code of Ethics with one tailored to an international membership is now well justified. Because of where they live or because of personal circumstances, many IEEE members will find it difficult to adhere to all provisions of the IEEE Code of Ethics. Nevertheless, it is a Code to which all members can aspire, and that is a good thing.

The structure, brevity and clarity of the IEEE Code of Ethics are important, but probably the Code's most obvious unique feature is the opening phrase: "We the members of the IEEE." Many readers will recognize the similarity of this phrase to the opening phrase of the Constitution of the United States of America, which was adopted in 1787. I chose this opening phrase because it indicates a personal commitment to the IEEE Code of Ethics by each IEEE member.

Acknowledgements

This article is based on an earlier article, with the same title, that I wrote for the Conference Proceedings of the 2009 IEEE Conference on the History of Technical Societies. I am grateful to IEEE for allowing me to reuse so much of that material without change. In writing that article, I expressed my gratitude to Theodore A. Bickart (who chaired the IEEE Ethics and Member conduct Committee in 2006 and 2007) for many helpful discussions, and I also thanked Tamara A. Seeley who (as Tamara A. Walsh in her role as Administrator, Governance, IEEE Ethics Committee Staff Secretary) prepared a report in 2001 and an updated report in 2006 on the History of the IEEE Code of Ethics. Her reports are available through the office of the IEEE Ethics and Member Conduct Committee. I am once again indebted to these individuals for their help, and especially to Theodore A. Bickart who read and commented on this article.

About the Author:

Emerson W. Pugh has a Ph.D. in physics and worked for IBM for 36 years in various capacities, including research scientist, product development manager, and corporate executive. He is the author or coauthor of a college physics text book and four books on the history of IBM and the computer industry. He is a long-**time volunteer for IEEE, having served most recently as president of IEEE in 1989, chair of the IEEE History Committee in 1996-1998, and president of the IEEE Foundation in 2000**-2005. Currently he is chair of the IEEE STARS Program on the IEEE Global History Network.

Lessons from the *Storm*

(Photo credit: NOAA)

Hurricane Katrina and the Challenges of Engineering Socio-Technical Systems

By Byron Newberry

Introduction

In his popular book To Engineer is Human: The Role of Failure in Successful Design, Henry Petroski stresses the importance of engineers learning from mistakes – sometimes catastrophic mistakes. Petroski, a civil engineer, illustrates his point using examples of famous structural failures resulting from design miscalculations, such as the Tacoma Narrows Bridge. But Petroski's advice for engineers applies beyond just erroneous technical analyses, or the failure of a single structure. Engineers of all types are frequently engaged in work on socio-technical systems – complex networks of technologies, people, and organizations. Examples include electrical power grids, cellular communications networks, or air transportation systems. Like the collapse of a bridge, failures of such systems can be catastrophic – a 2003 power grid failure in the northeastern United States and Canada left 55 million people without power for days, resulting in several fatalities and billions of dollars in economic loss. But unlike some bridge collapses, failures in socio-technical systems are not likely to be traced to a specific design error. More often, they result from the accumulation and complex interplay of many factors, comprising technical missteps, miscommunications, organizational dysfunction, and human foibles, no one of which may seem that severe when viewed in isolation. Despite these convoluted causes, or rather because of them, it is imperative that engineers learn as much as possible from failures of socio-technical systems.

To illustrate some of these problems, we can look to the 2005 Hurricane Katrina disaster in New Orleans and surrounding areas. The New Orleans Hurricane Protection System (HPS) that was in place in 2005 is a good example of a socio-technical system. It employed a variety of technologies, including levees, floodwalls, barriers, gates, and pumping stations, and it protected hundreds of square miles of area containing hundreds of thousands of people. The design, construction, operation, and maintenance of the HPS depended upon a variety of organizations, including the U.S. Army Corp of Engineers (USACE), the Sewerage and Water Board of New Orleans (SWBNO), the Orleans Levee District (OLD), and a multitude of construction firms, environmental organizations, and citizens' groups, not to mention the political bodies charged with authorizing and funding the system. And the HPS was intimately interwoven into the lives of the people who lived and worked in proximity to it every day.

Hurricane Katrina was a large scale disaster by any metric we might use: over 1800 fatalities; hundreds of thousands displaced from their homes and jobs; severe disruption and degradation of quality of life; hundreds of billions of dollars of economic loss from extensive destruction of property and infrastructure; and, the need for copious outside assistance in relief and recovery efforts. Further, Katrina was a complex disaster. The potency of a natural hazard intersected with and exposed the vulnerabilities of human-constructed systems. But the structural failures of levees, which allowed floodwaters into the city, were only proximal causes of the tragedy. In what follows, we will explore some of the underlying problems in more detail.

Figure 1. U.S. 90 Bridge in Biloxi, MS (Photo credit: NOAA)

Failure Modes

Often the most visible problems in a socio-technical system failure—and the ones most readily associated with engineers—are the technical problems. One of the prime tasks of a design engineer is to anticipate the ways in which something can fail and then design to ensure such failures do not occur. A premium is placed on getting it right, particularly when the consequences of failure are high. The Katrina case reveals a variety of technical problems associated with unaccounted-for failure modes. One example is a series of bridge failures along U.S. Highway 90 in coastal Mississippi, just east of New Orleans. As seen in Figure 1, much of the bridge decking was removed from its piers. The combination of storm surge and large wind-driven waves allowed the water level to reach the bridge deck, uplifting sections and sliding them landward. The attachments between the deck and the piers were not designed to resist such forces, though they could have been.

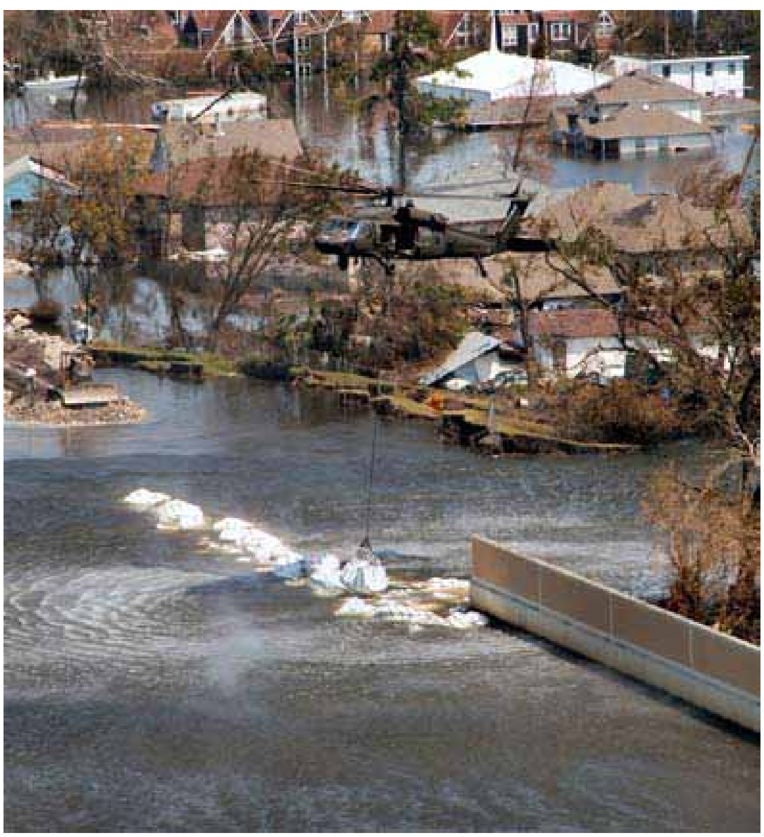


Figure 2. 17th Street Canal Breach
(Photo credit: U.S. Army Corps of Engineers)

Some of the most devastating structural failures in New Orleans occurred along the canals that penetrate into the heart of the city. These breaches contributed to the majority of flooding in the city and were among the most prominent images in the media coverage of the disaster, such as seen in Figure 2, where a helicopter works to plug a breach.

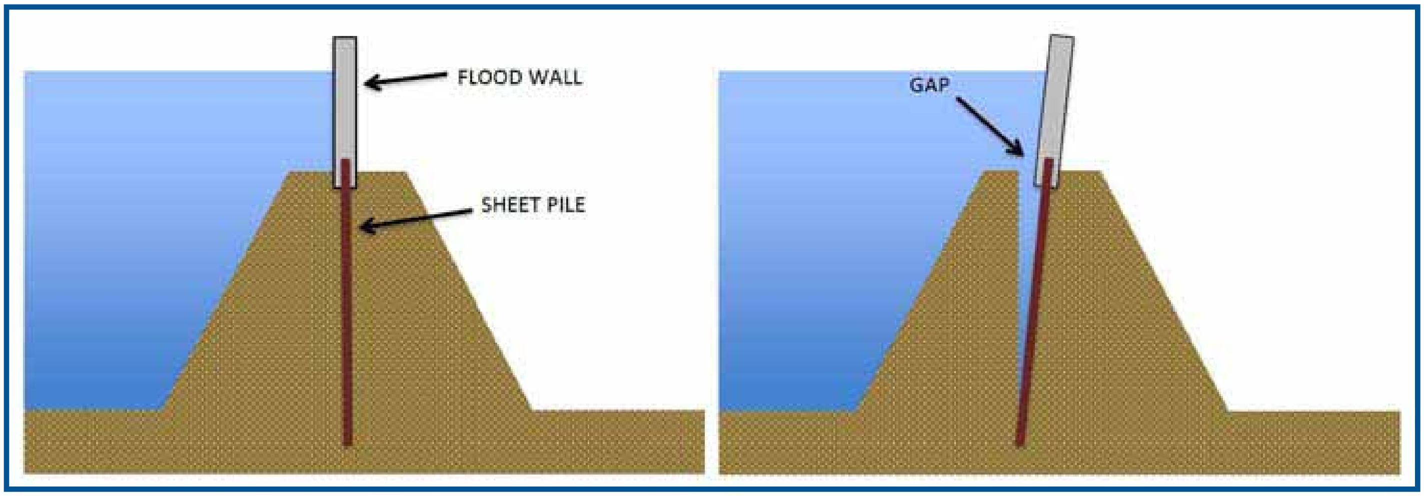


Figure 3. Levee -Sheet Pile -Flood Wall System with Gap (Illustration Credit: Byron Newberry)

These failures were also due, in part, to problems of unanticipated failure modes.

Along these canals, the earthen levees were topped with concrete floodwalls. These floodwalls attach to the tops of sheet piles, which are corrugated metal curtains that extend down into the centers of the earthen levees, as shown in Figure 3. The design was intended to withstand water levels up to the tops of the floodwalls. However, during Katrina the canal levees failed in several places before the water levels reached that high.

When water levels rose partway up the floodwalls, similar to what is seen in the illustration, the floodwall and sheet pile rotated backwards slightly in many places. This opened a vertical gap in the levee, allowing water to enter and exert pressure directly on the face of the sheet pile, effectively cutting the levee in half. The back half of the levee then slid away from the canal in several locations, allowing floodwaters free passage. The tilted floodwall and water-filled gap can be seen in Figure 4. This mechanism of failure was not envisioned during the design of the levees, and therefore was not designed against.

Incomplete Information

Engineering decisions are always made with incomplete information. The practical necessity of completing projects in a timely fashion must be balanced against the risks of uncertainty. In making such tradeoffs, it is incumbent upon engineers to draw upon the best information available. Of course, some information only becomes available after the fact. A main reason technologies evolve over time—improving in performance or safety—is because of new information gained through experience. But experience depends on having first tried something. Thus there is an inevitable chicken and egg relationship between technological development and knowledge. This fact dictates that engineers should exhibit a healthy prudence when venturing very far into the technological unknown. Unfortunately, there are times when important information is available, but is overlooked,

Figure 4. Water -filled gap along London Avenue Canal (Photo Credit: U.S. Army Corps of Engineers, IPET)

miscommunicated, misinterpreted, or simply left unused, and with negative consequences.

For just one example, consider the water-filled gap problem just discussed. Information existed that could have helped identify the failure mode, but that information was never properly used. In the mid-1980s, the USACE conducted a full-scale test of a sheet pile/floodwall system. During the test, larger than expected tilting of the floodwall occurred, resulting in incipient failure at water levels below those predicted in the design. It is likely that the observed movement of the structure caused the soil to separate from the front side of the floodwall, but there was no record of this being observed due to a plastic liner that obscured the view of the base of the floodwall. Later, as follow up to the tests, more advanced analytical methods were developed which did consider the possibility of a water-filled "tension crack" in front of the floodwall. These results appeared in both USACE technical reports and in the peer-reviewed literature. But this new knowledge was never properly translated from testing and research into practice, and floodwall design proceeded without considering this failure mode.

Figure 5. Scour from overtopping along the Inner Harbor Navigation Canal (Photo Credit: U.S. Army Corps of Engineers, IPET)

Resiliency

The New Orleans HPS in place at the time of Katrina has been described as a series system. A series system, like a chain, is only as strong as its weakest component. For example, the East Bank protected area of New Orleans—the heart of the city—is essentially a bowl surrounded by a ring of levees. A few localized breaches of the canals within that ring permitted floodwaters to fill the entire bowl. But systems protecting such high value areas ought to demonstrate resilience—i.e., the ability to tolerate local failures without compromising the entire system, or, when conditions temporarily exceed design conditions, to endure and resume functioning once excessive conditions have passed. Resilient systems are characterized by multiple lines of defense (parallel system instead of series), ductility (the ability to perform even when capacity is exceeded), and excess capacity (margin of safety).

An example of a lack of ductility in the HPS system was the scouring of trenches on the inboard sides of floodwalls due to water flowing over the top of the wall. Figure 5 shows such a scour trench behind a section of the Inner Harbor Navigation Canal (IHNC) floodwall. Such trenches on the inboard side of the wall reduce foundational stability and make the wall more susceptible to toppling due to the force of the water on the outboard face. The fact that the floodwalls were overtopped at various locations during Katrina indicates that design heights were exceeded by water levels at the peak of the storm surge. But that alone would not have been disastrous. While overtopping allows some amount of floodwater into protected areas, the amount is relatively small compared to the amount of water that can enter through a breach. Overtopping abates as soon as the surge subsides, whereas flow through a breach may continue for quite some time (for days in the case of the New Orleans outflow canal breaches). A levee that remains intact after overtopping exhibits ductility—even though it is temporarily overwhelmed, it continues doing its job as the water level drops. A levee that suffers a breach as a result of overtopping is brittle—it ceases to function, allowing flooding to continue even as the water recedes. Brittleness of this type was observed at many locations throughout the New Orleans HPS, including possibly contributing to a particularly destructive breach along the IHNC.

Figure 6. Floodwall with new splash pad, Orleans Avenue Canal (Photo Credit: John McQuaid)

What makes this type of failure particularly vexing is that they may have been preventable with relatively little expense. Splash pads behind floodwalls, along with other types of armoring on the levees to prevent erosion mechanisms, would have made the system much more ductile. In the aftermath of Katrina, the USACE has worked to retrofit many levees with armoring, as shown in Figure 6.

Complex System Changes Over Time During the Design

Large, complex projects, which often span long time frames, are subject to changes in physical, societal, and organizational environment, and in technological tools and knowledge. This makes the design a challenge for engineers who, in general, would prefer to meet a fixed set of specifications given a fixed set of constraints. Difficult conundrums can arise when changing conditions render partially-completed design objectives obsolete. One very prominent example of the effects of time on the New Orleans HPS project involved land subsidence . The New Orleans HPS project had been ongoing for over forty years. During that time, the land in the New Orleans area was sinking due to the compaction of silty deltaic soils, in some cases by several feet. This contributed to measurement errors and a progressive mismatch between initial design targets and eventual system performance. In some places levees/floodwalls wound up a couple of feet lower than intended.

With construction of the system spread over the entire time interval, and with knowledge accumulating about the changing conditions while construction was ongoing, the Corps was faced with difficult decisions. They could continue working off the original plan, effectively ignoring subsidence, and produce an end result that, while looking correct relative to current ground level, was really much too low. Alternatively, they could progressively revise the specifications for components yet to be built. This would mean they would take subsidence into account by incrementally increasing new levee/floodwall heights with time. But this would have caused some new problems. First, it would have greatly increased construction expense since higher levees/floodwalls are more costly. Second, it would have resulted in a non-uniform system, with component heights stair-stepping from oldest to newest. This has some potentially severe consequences due to the introduction of stress concentration points (as will be discussed in the next section). Another alternative was that they could continually revise specifications for the entire system, which would mean a continuous cycle of going back and renovating already-built components to bring them up to current standards. This would entail significant added time and cost. Approval and funding from Congress would have been difficult, and such never-ending construction would have been a tough sell to local residents.

The Corps would have been subject to significant criticism no matter which of these paths it took. On the one hand, we might make an ethical argument that the Corps should have refused to do anything other than pursue the latter course, because that was the only one with a chance of satisfying the original intent with respect to level of protection. Not surprisingly, this is the course that, in hindsight, many observers said the Corps should have taken. On the other hand, the first course (and more or less the one actually followed) might be defended on the grounds that it provided the quickest and least expensive path to getting a complete baseline protection system in place, even if the latter stages were knowingly being built to inadequate specifications. In fact, a former chief of engineering for the Corps' New Orleans District gave just such a rationale.

This problem of change-with-time in long-term projects suggests the need for adaptable designs. There are always uncertainties in the future, so if flexibility can be incorporated in the design upfront to account for a range of possible futures, time and cost can potentially be saved down the road. As an example, a major source of future uncertainty for society's infrastructure is climate change. Though there is much agreement that climate changes will cause challenges in the next century for water resources, energy production, and flood protection, among other things, the great uncertainly associated with the magnitude of such changes makes the planning of engineered infrastructure difficult. Thus, much research is currently being devoted to developing adaptable designs – designs that will not be economically wasteful for the best-case scenarios, but which can be easily adapted to worst-case scenarios if needed.

Physical Interfaces

As a long-time teacher of engineering design classes, my experience has been that interfaces are the most frequent source of problems for students trying to implement their designs. Student teams will routinely partition their designs into subsystems and then work diligently to perfect each one independently. But when they attempt to integrate their subsystems into the larger system they find that there were important details that needed to be considered at the interface.

There were many problems that occurred during Katrina due to physical interfaces—or transitions. Figure 7 shows a failure along the New Orleans East back levee. This failure was typical of many failures throughout the system. Here, a section of levee topped with a concrete floodwall transitioned into a section of levee without a floodwall. But at the point where the sections joined, the top of the bare levee was lower than the height of the adjacent floodwall. When the storm surge overtopped this area, the height mismatch at the point of the transition had a stress concentration effect—the water behind the higher floodwall was funneled around the corner where it joined the lower levee. The water current generated at this discontinuity scoured and eroded the back side of the levee. This caused the sheetpile to overturn, creating a breach that allowed floodwaters to continue entering long after the surge level had subsided below the original levee crest.

Organizational Interfaces

Another series of transitional failures occurred at penetrations in the levee system. Penetrations are locations where railways, roadways, or other features intersect with levees and floodwalls. These locations may have transitions between types of earthen materials and between structural elements such as floodwalls and gates. For example, at one location along the IHNC, a gap existed in the floodwall where a rail line crossed the levee and

Figure 7. Transition failure along the New Orleans East back levee (Photo Credit: US Army Corps of Engineers, IPET)

continued onto a railroad bridge over the canal. There was also a roadbed that ran through the gap parallel to the rail line, which provided access to canal-side facilities operated by the Port of New Orleans. In the event of a storm, the gap in the floodwall was supposed to be sealed by rolling a steel floodgate into position. In the months before Katrina struck, the floodgate was damaged by a train and had been removed for repair. As Katrina approached, sandbags were piled in the gap, but these were easily washed away by the storm surge, creating a major breach through which floodwaters passed. To make matters worse, the soils used to fill the levee at this location were highly-erodable sands, unlike the denser clays to either side, which resulted in considerable erosion of the levee through the gap. The earthworks at the location of the gap were apparently constructed by organizations more concerned with the transportation features, not those responsible for flood control.

This example highlights the influence that organizational interface problems can have on physical interface problems. There were at least five agencies with overlapping responsibilities at the site: the USACE (responsible for levee construction and flood control), the rail company, the Port of New Orleans (responsible for shipping within the canal), the State Highway Department, and the local levee board (responsible for levee maintenance). Each of these agencies had different agendas with respect to the design, construction, operation, and maintenance of the site. But it was not clear which, if any, assumed ultimate responsibility. Sometimes when everyone is responsible, then no one is responsible. The details of interface points in a system are critical for system performance, but unfortunately these points and their details often fall between the cracks. This is either because different organizations responsible for adjacent features do not communicate effectively. Or, it may be that due to the long project duration newer features are built adjacent to older features without sufficient attention to making smooth transitions. It behooves engineers to pay careful attention to interfaces and transitions, and to ensure that someone has definitive responsibility for such transitions. This latter observation also has implications for public policy for engineering in socio-technical systems.

Risk perception

In the aftermath of Hurricane Katrina, New Orleans faced conflicting objectives with respect to recovery. A major question was simply whether it was wise to rebuild and repopulate the riskiest areas. Discussions of whether certain areas should be repurposed for lower-risk uses must contend either with appeals to preserve traditional places and ways of living, or with economic drives to return properties to profitability. But a significant problem that plagues such discussions is the ability—or lack thereof—to sustain over the course of time an accurate perception of the risks, along with the initiative to adequately mitigate them. Many factors contribute to this problem, including the massive physical scale of the system and its corresponding costs, a lack of awareness of accurate information about levels of risk and protection, the long timescales involved, and short term desires and objectives. All of these factors provide fuel for various peculiarities of human psychology that can lead to inadequate responses to risk.

Figure 8. Orleans Avenue Canal
(Photo Credit: US Army Corp of Engineers)

A false sense of security about levees is an endemic problem, not only in New Orleans, but wherever levee systems are built. Levees, like many other types of technologies, provide an impression of human control over nature. For the people behind the levees, this impression has unfortunate consequences, since failures of levee systems are a fact of life. On the one hand, people can become vulnerable to disasters because they are naïve about the protection afforded by levees; they move into high-risk areas without a true understanding of the possible consequences. Figure 8 shows housing developments in the shadow of the Orleans Avenue Canal. On the other hand, agencies, groups, and individuals often facilitate exposure to risk, either wittingly or unwittingly, by developing flood-prone land in the pursuit of short-term benefits. This latter is part of a cycle of flood plain development that has been termed the levee effect. The levee effect is a paradox in which the construction of levees designed to protect assets in flood-prone areas actually serves to increase the ultimate exposure to risk by providing an aura of protection that invites the placement of additional assets in harm's way. This increase in development may prompt the construction of additional flood defenses, which in turn serves to accelerate additional development. Thus, the quality of additional defenses does not necessarily keep pace with the increase in value of what is being defended. The levee effect is a manifestation of a more general phenomenon that has been called the safe development paradox, whereby attempts to design protective measures to facilitate some type of development in the face of serious hazards inadvertently results in greater risks and the potential for future catastrophes.

Historical contingency and lock-in

Engineering work often is constrained by previous decisions. Sometimes the basis for those prior decisions may now seem to have little relevance. For example, the design of a new automobile is constrained width-wise by the standard width of roadways. A car too wide for typical roads would be of little value to consumers. But road lane widths are little different from ancient times, and were initially dictated by factors such as the strength of wooden axles and the pulling power of draft animals. In order to be useful, early automobiles had to conform to existing roads. So, modern engineers are still constrained in some sense by considerations that are no longer relevant. Even if we decided there was some advantage for modern cars and roadways to have different widths, the cost of converting our entire road transportation system would be prohibitively expensive, so it would not be likely to happen without some overriding impetus. This is an example of a network effect. When a technology grows into an interdependent network (such as road systems, or communications systems, say), issues of standardization can make it difficult to make fundamental changes without significant costs. The cost of converting everything at once is prohibitive, but incremental conversion is problematic since early converts face incompatibilities with the rest of the system. Thus, historical contingencies concerning the adoption of certain practices and standards have significant consequences for future engineers, at times effectively locking them in to certain courses, even when the rationales for those courses may no longer be relevant.

In the case of New Orleans, if we could erase the slate and begin planning the city and its flood defenses from scratch, we would likely come up with something that looks much different from what now exists. In fact, we might well locate the city somewhere else. But abandoning the city, or razing it and starting over, is not going to happen. Certain realities are locked-in for New Orleans due to the historical contingency of where it was founded, and of the actions that have been taken over the years to grow the city while defending it from storms. The problem of flood protection in New Orleans is not amenable to being solved with any finality. Land subsidence, loss of coastal wetlands, predicted sea level rise, the inexorable flow of the Mississippi River, and the human drive to preserve—and further develop—the city, will mean that protection efforts will not only be never-ending, but likely ever-escalating. Also, the hurricane protection levees comprise a network that is interdependent with the city's drainage system, as well as with the levee system that constrains the flow of the Mississippi River, both in New Orleans and in locales upstream. Contemporary decisions about flood defenses must contend with these network effects, as well as with the legacy of countless previous decisions going back to the first levees built shortly after New Orleans was settled by Bienville in 1718. Figure 9 shows a portion of a 1759 map of New Orleans, which notes a "Bank to Preserve the Town from the Inundation." The city's drainage canals, for example, are an integral part of the current hurricane protection system, and their failures during Katrina played a prominent a role in the disaster. Yet those drainage canals owe their existence not to considerations of hurricane protection, but to efforts to improve sanitation, reduce disease, and develop new land going back to the early to mid 19th Century.

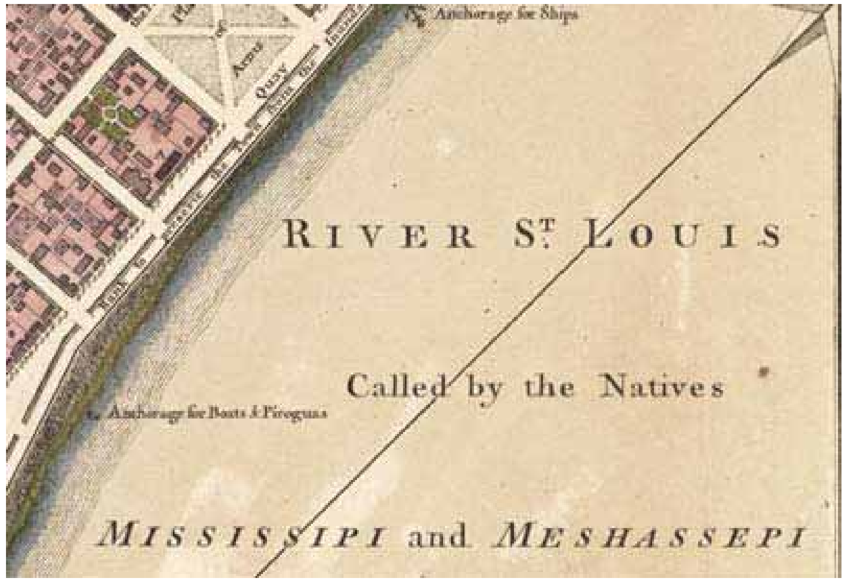


Figure 9. 1759 Jefferys Map of New Orleans
(Image credit: Leventhal Map Center at the Boston Public Library)

Conclusion

The more insight engineers, and engineering students, develop into the sometimes subtle pitfalls that bedevil complex systems and projects, the greater the chance that far-sighted planning can be brought to bear to minimize them. With that in mind, we have attempted to use the Katrina case to highlight a number of issues that pervade such engineering work. These include problems of unanticipated failure modes, lack or misuse of information, the importance of resiliency, the effects of time, balancing competing interests, attending to the details of interfaces, the fickleness of risk perception, and how the past constrains the present. As we have seen, these issues intertwine, with the examples used for one often overlapping several others.

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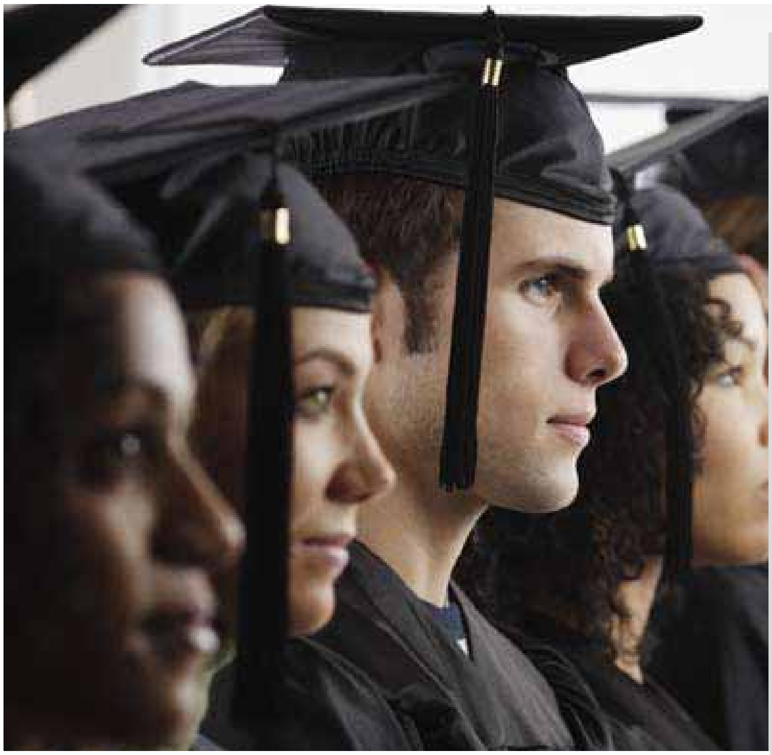


Preparing for High Ethical Standards

Embracing ethics and upholding integrity while at university......

By Steve Starrett

INTRODUCTION

Engineering education is principally focused on building technical skills and problem solving abilities of students. However, learning about professional ethics as related to engineering work is necessary as well. Various Code of Ethics for Engineers have been adopted by engineering societies such as IEEE, ASCE, NSPE, etc. These codes set forth the obligations that engineers have to society and other standards of conduct. These codes are typically presented as components of any ABET accredited engineering program and are content for the fundamentals of engineering examination. Formal curricula components of ethics lectures, workshops, and courses supplement the morals and ethical standards that students have developed from their parents, childhood friends, adult friends. In addition, honor societies like IEEE-Eta Kappa Nu promote high ethical standards as part of membership. The academic standards in the classroom are yet another learning opportunity as engineering students face situations that are not dissimilar from those that they will face in engineering work. College and university campuses often promote ethical behavior in the academic setting through the application and enforcement of an Honor Code or Honor Pledge. The university community (i.e., joint effort with students and faculty working together) declares expected academic integrity standards and then determines appropriate sanctions for when standards are not met.

ACADEMIC HONOR STATEMENTS

Many universities and colleges have an Honor Code or Pledge. The Honor Pledge at Kansas State University is "On my honor, as a student, I have neither given nor received unauthorized aid on this academic work." The College of William and Mary has had a student administered Honor Code that started in 1736. Their Honor Code is very detailed and over 20 pages long. Texas A&M University has a long-standing tradition of honor. Their Aggie Honor Code is "An Aggie does not lie, cheat or steal, or tolerate those who do." Military academies have similar honor codes such as the U.S. Military Academy at West Point, "A cadet will not lie, cheat, steal, or tolerate those who do." Some top-ranked schools, such as Harvard and Yale, do not have Honor Codes, however, now after recent cheating scandal at Harvard are now considering creating one (Harvard considers instituting honor code, Peter Schworm, Boston Globe, 4/6/13). The purposes of an Honor Code or Pledge are to instill in students that they are part of the entire university community, to build trust among the individuals that make up the community, and to define the expected behavior for remaining a part of the educational community.

Last summer, I became the Director of the Honor and Integrity System at Kansas State University. The Honor and Integrity

System office administers Honor Pledge violation reports. We have an Honor Council that is made up of 27 students (undergraduate and graduate) and 27 faculty and staff members. Each college is represented on the Honor Council, and the faculty senate and student senate approve of the nominations. Honor Council members serve as hearing panel members and as case investigators. Students do have the majority vote on hearing panels and they are often tougher on their peers that violate the Honor Pledge than the faculty members are. They view academic dishonesty as a threat to the hard work, dedication and reputation of those that uphold the Honor Pledge and ultimately obtain degrees from Kansas State University. The Honor Council student members will not stand for that.

The Honor and Integrity System office assists faculty in upholding academic integrity in their courses. When professors or instructors determine an Honor Pledge violation has occurred then they submits a violation report to the Honor and Integrity System. The report includes what the violation was (e.g. unauthorized collaboration, plagiarism, falsification, or unauthorized aid), and what the recommended sanctions are. There is a clear and detailed process available for a student who contests the alleged violation. Professors and instructors can issue up to an XF grade (failing due to honor violation) as a sanction. The X can be removed from the transcript if the violator takes the Development and Integrity 1-hr course. For students that have multiple violations then an Honor Council hearing panel will determine what additional sanctions are needed such as grade changes, permanent XF, and they can recommend suspension or expulsion to Provost.

The Honor Pledge and related system was created after a cheating scandal involving a few hundred students rocked our campus and gained national news. A student was given permission to take a test early because of a conflict with other obligations. The student began the misconduct by informing some friends about what was going to be on the exam, until eventually, by the end of the semester, hundreds of students were informed of exam questions ahead of time. The hard-working students of Kansas State University were outraged by this poor conduct because it jeopardizes the reputation of their degrees. Correspondence from alumni poured into campus expressing their strong concern. The message was clear, academic integrity is vital to Kansas State University and it must be ensured.

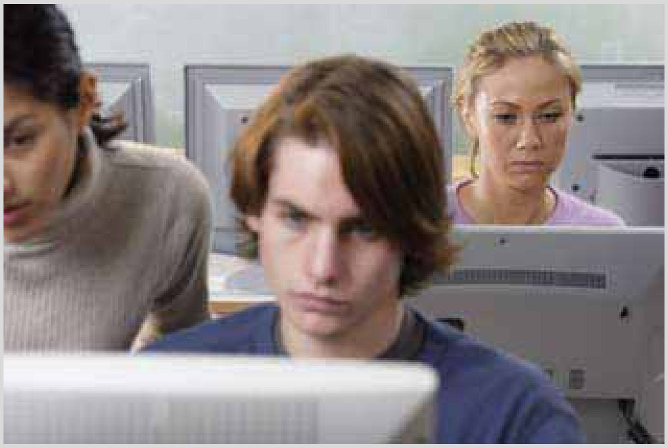
There are currently over 25,000 students on three Kansas State University campuses, so each semester, there are bound to be some individuals taking shortcuts on academic work. Having been at Kansas State for about 19 years now, and as the Director of the Honor and Integrity System, I am very supportive of universities having an active Honor Pledge or Honor Code, and a related office to administer violation reports. This provides a vital resource for faculty and teaching staff to ensure academic integrity, it provides a valuable learning experience for those students that receive Honor Pledge violations, and it provides excellent leadership experiences for those students on the Honor Council. The decisions they make effect lives, and the long-standing reputation of Kansas State University.

IDEAS AND WORK AS A STUDENT AND ENGINEER

There is a natural transition from being a student being committed to an Honor Pledge or other academic standards and an engineer committed an engineering Code of Ethics. The concept of an individual upholding integrity to benefit the greater community is the same. Following are some of the more common Honor Pledge violations:

? **Unauthorized collaboration in the classroom.** This is when the professor has declared that an assignment/exam/ project is to be done independently. For example, an assignment is to write a computer code independently. Certainly students must learn how to create code from others (i.e., professors, teaching assistance, internet, peers, etc.). The violation occurs when a student works with another student to create a segment of code, copies code from another student (current or previous), copies a segment of code from the internet, has someone else write the code, … Creating the code independently assignment process maximizes the learning experience for the students. One of the most extreme cases over the 15 years of our Honor and Integrity System is when a student posted a course project on freelancer.com. The senior student accepted bids on the project, selected a contractor, paid contractor $350 to complete the project, and turned it in exactly as created by contractor. The professor was notified by individuals on freelancer.com that a course project had been posted to the site. This is not acceptable to the freelancer.com community. The student also had previous Honor Pledge violations and was expelled.

? **Unauthorized collaboration in an engineering career.** As an engineer, the protection of intellectual property is very important. Planning, design, construction and/or production of a specific solution to a problem or need is why engineers are compensated. Taking of other people's ideas or intellectual property without proper credit,



“The internet has made it so easy to find knowledge about anything, copy and paste it into an assignment document, print and turn it in for a grade.”

acknowledgement or permission is against the IEEE Code of Ethics Canon #9, “…avoid injuring others…”

? Plagiarism in the classroom. The internet has made it so easy to find knowledge about anything, copy and paste it into an assignment document, print and turn it in for a grade. Referencing and citing other people’s work is very important while studying at American universities and colleges. Middle schools and certainly high schools teach students how to reference materials properly. Students are expected from their first day on campus to understand how to reference and cite materials. Having said that, some instructors also believe plagiarism happens when structures of papers or even paragraphs follow a source’s format and style too closely. This isn’t so widely taught in high school. So, it’s important to visit with professors in heavy writing classes to thoroughly understand their expectations. There are also plagiarism checking software that can be used, such as those at www.grammarly.com and www.plagtracker.com. There is also computer code plagiarism checking software available too.

Many students have violated the Honor Pledge by plagiarizing something from the internet. Most are sanctioned with a zero on the assignment and the requirement to take an academic integrity related 1-hr course. An example situation was when a graduate student had a writing assignment to write a life-story type document. The student made a poor decision to copy a blog entry word for word and submit it as his life story. The student had multiple Honor Pledge violations related to plagiarism in graduate courses. The student’s comments were, “I have attended many universities. I have an undergraduate degree and a master’s degree from different schools. I have never before seen a university so interested in verifying that assignment content was not plagiarized.” The student was expelled.

? Plagiarism in an engineering career. Engineers write lots of reports. Students do not like to hear that but its true. There is easy access to knowledge online and its inappropriate for an engineer to find a similar report and copy text. This type of conduct is against IEEE Code Ethics item #9 and #3, “to be honest…”

? Unauthorized aid in the classroom. Virtually any solution manual can now be found online. Using references to learn how to solve a problem is encouraged and is what engineers do in the profession. Copying solutions and submitting them as original academic work, however does not represent knowledge that a person possesses. Faculty are trying to teach subject matter to students. They cannot assess whether that knowledge has been learned if a student copies solutions from a solutions manual. The student is also violating their main reason for going to college, to learn skills and knowledge to apply in a career.

? Unauthorized aid in an engineering career. The bid process can be very competitive with companies doing all they can to obtain information about their competitors. When engineers give bribes to obtain confidential information that gives them an unfair advantage then that is directly against IEEE Code of Ethics item #4, “to reject bribery in all its forms.”

I do hear students say something like, “I won’t take shortcuts like I do while in college when I start working.” These students do not realize that a person cannot turn integrity on and off like a switch. Future behavior is naturally based on previous behavior and decisions. University students are developing and creating their approaches to academic integrity, personal ethics; and for engineering students, their commitment to high engineering ethical standards. It is important for an engineer’s development to maintain high academic integrity standards while pursing an engineering degree. Ethical decisions and judgment become second nature. There are many ethical situations engineers can face: safety vs. financial gain, marketing vs. truthful statements, what to do with undesirable testing results, offers of gifts and favors, and the appropriate use of high-technology devices. In brief, the following presents an idea on how to approach engineering ethical dilemmas.

DEVELOPING PROFESSIONAL JUDGMENT AND SOLVING ENGINEERING ETHICAL DILEMMAS

People take a variety of approaches to solving ethical dilemmas. Following are some ideas to consider:

? Consult IEEE Code of Ethics or other relevant codes. Use this information as strong ammunition when being pressured to do something that is against the Code.

? solve situations like an engineer. Analysis, study, consider, develop solutions just like it was a technical problem.

? Consult with trusted and respected others about the situation.

? Study engineering ethics educational materials available.

? Take a webinar or a class on engineering ethics.

? Consider what is best for most.

? Consider what virtue is critical for you and make sure that requirement is met in solution.

? Consider if people close and important to you fully understood your actions and decisions, would they respect your decision?

Years ago I gave an engineering ethics workshop to a group of about 50 professionals at a very nice dinner club. I was in my early 40s and was about the youngest person in the room. The atmosphere was friendly, the food was excellent and there were many friendships several decades in the making. I presented a situation where the engineer had to decide if he was going to proceed way up the chain-of-command to rectify what he knew was a major threat to public safety. His non-engineering supervisor did not think the safety issue was a crisis like the engineer did. I presented the question of, “What would you do if you were the engineer faced with this situation?” One person spoke his opinion of, “I would follow the directive of my supervisor. I have a family to feed, you are asking to get fired to buck the instructions of your boss, it just wouldn’t be worth it.” Immediately, his peers criticized his remarks. One individual stated it so well. “You have to protect the safety, health and welfare of the public. When the situation goes from bad to awful then someone is going to get injured or killed. The engineer’s reputation will be forever ruined. The company is not going to protect engineer or care about his reputation. The engineering community isn’t going to accept the excuse of “My boss told me to keep my mouth shut.” You can always get another job, but you cannot get another reputation. As I near the end of my working career, I believe this strongly.”

“People take a variety of approaches to solving ethical dilemmas...”

As students pursue engineering education they should be aware that they are building upon their foundations of integrity, the foundations their parents started. It is just the beginning to a long and dedicated engineering career upholding the safety, health and welfare of the public.

About the Author

Steve Starrett, Ph.D., P.E., D.WRE, F.ASCE, is Associate Professor of Civil Engineering and Director of the Honor and Integrity System at Kansas State University. Dr. **Starrett earned his B.S. degree in civil** engineering from the Missouri University of Science and Technology, an M.S. and Ph.D. in civil engineering from Iowa State University. He has been on that faculty at Kansas State University for 19 years. His **technical expertise is in water resources** engineering. He also teaching engineering ethics graduate level courses and serves **on the Executive Board of the National Institute of Engineering Ethics.** He is a founding member of the nearly **established Committee on Ethical Practice** with the American Society of Civil Engineers.

November Reprint

Bistatic Radar

Looking Back...Looking Forward

By Hugh Griffiths

Bistatic Radar

Radar is a technology that is over 100 years old – the first example of what we would now call a radar was actually demonstrated and patented by a German inventor, Christian Hülsmeyer, in 1904, though it was not a commercial success. Nowadays radar is used for a wide range of purposes, including Air Traffic Control (ATC), marine navigation, geophysical monitoring of Earth resources from space, automotive safety, weather tracking, as well as numerous applications in defense and security.

Bistatic radar, in which the transmitter and receiver are at separate locations rather than being co-located, has a history almost as long as radar itself. Not surprisingly, the separation of transmitter and receiver introduces some complications, but there are some advantages as well. A quotation from the philosopher George Santayana reads: 'Those who cannot learn from history are doomed to repeat it'. And that is just as true in engineering, not only in understanding just how things were conceived and made to work, but also in understanding ideas from the past which maybe did not work, but only because the technology was not then available. So the purpose of this paper is to look at some historical developments of bistatic radar – some of which have only just come to light – and to show how they can help guide our thinking in present-day radar engineering.

Klein Heidelberg

In the years leading up to the Second World War, developments took place in several countries to try to devise a reliable means to detect hostile aircraft. In the UK this led to the development of a radar system called Chain Home (Figure 1), which was installed all around the south and east coast (Figure 2). By many standards it was quite primitive: it used a relatively low frequency between 20 and 30 MHz, broad antenna beams and long transmit pulses [1]. But it was a crucial factor in winning the Battle of Britain. In fact the key to its success was the way in which it formed part of an air defense system, so that the information from its detections was brought to a central control room and used to guide the scarce fighter resources so that they were in the right place at the right time.

In Germany, radar was being developed too, in some ways more sophisticated and better-engineered than in the UK. Both sides were able gradually to find out about each other's radars, by intercepting and analysing the signals and in some cases from captured hardware, and quite naturally they each devised countermeasures to jam and otherwise upset the operation of their opponents' systems. This was the origin of what we now call Electronic Warfare.

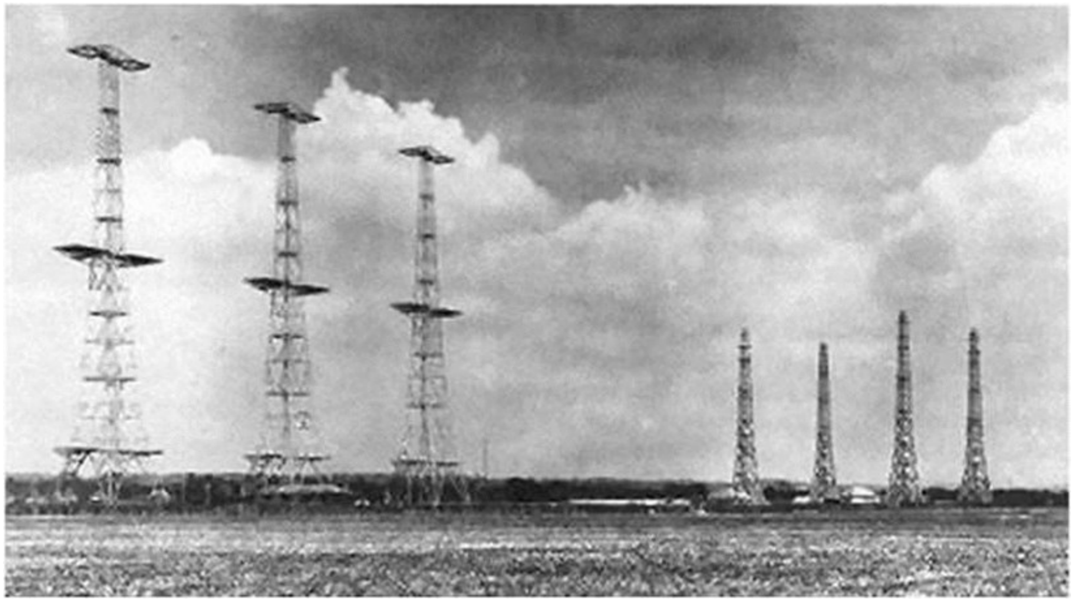


Figure 1. The British Chain Home radar. The transmit antennas are suspended between the towers on the left; the receive antennas are on the four wooden towers on the right, with each tower initially operating on a separate frequency.

German radar engineers realized that they could exploit the transmissions from the British radar, and devised a system called Klein Heidelberg which used the British Chain Home transmitters as their radar source [2]. The principle is very simple: the Klein Heidelberg receiver would receive the direct transmitted pulse from the Chain Home transmitter, then a fraction of a second later, the echo from an aircraft target. That time difference defines an ellipse, with the transmitter and receiver as the two focal points, on which the target must lie (Figure 3). A measurement of the direction of arrival of the echo, using a directional antenna (Figure 4), then provides the position of the target on the ellipse.

Of course, the big advantage of such a system was that it was undetectable, since it emitted no signal of its own. The antenna was disguised, by mounting it on the back on an existing radar. Not only that, but even if its existence was known it was impossible to jam, since to do so would also have jammed the British Chain Home radars. Six of the Klein Heidelberg radars were built (though only four reached full operational status), and in fact, the British did not find out about it till November of 1944, several months after the D-Day landings. Information from an intelligence document from the time reveals, from interrogation of a captured radar operator, that

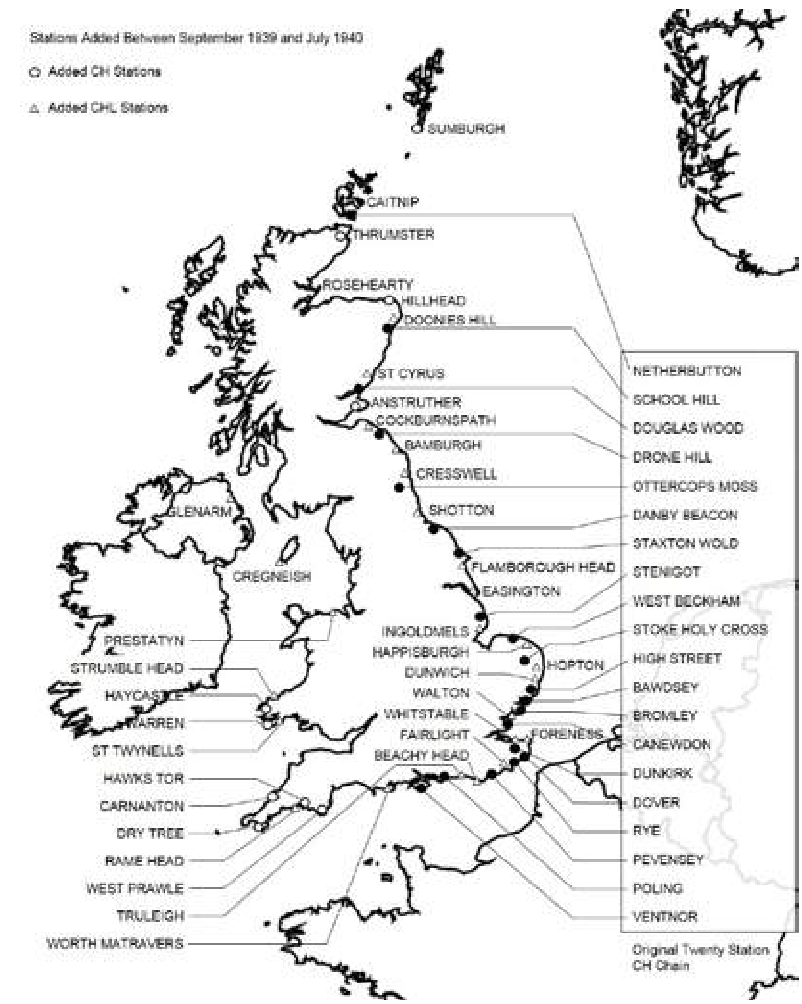


Figure 2. Locations of the British Chain Home radars on the south and east coast of the United Kingdom (adapted from [1]).

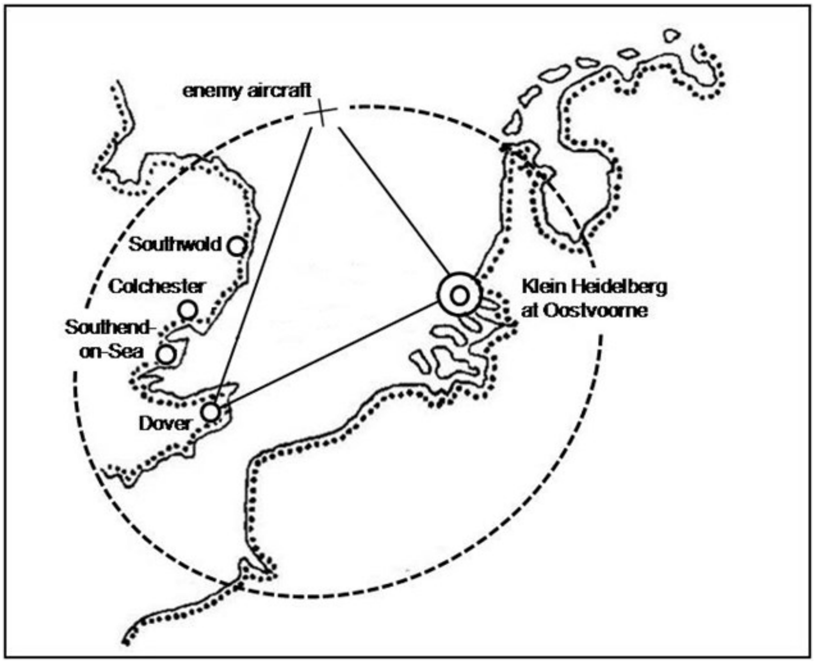


Figure 3. Geometry of the Klein Heidelberg system (adapted from [2]). The difference in delay between the direct pulse from the Chain Home transmitter and the target echo defines an ellipse with the transmitter and receiver at the two focal points. In this case the receiver is at Oostvoorne in The Netherlands and the transmitter is at Dover. Three other transmitters are shown as well.

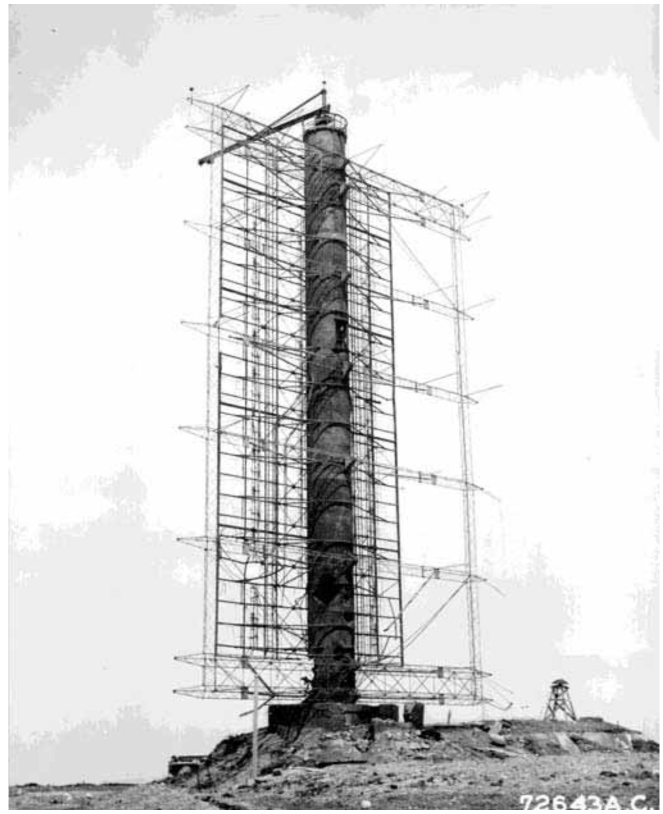


Figure 4. Klein Heidelberg antenna, mounted on the back of a Wassermann -S tower (Conseil Régional de Basse -Normandie / National Archives USA).

the maximum detection range achieved each day was of the order of 450 km – which would be regarded as impressive even today. It was an example of an idea that was decades ahead of its time.

Radar Detection of V-2 Rocket Launches

Although not explicitly a bistatic radar, another example of innovative radar engineering from that time was the British use of radar to detect and track the launches of the German V-2 rockets towards London [3]. The V-2 was the world's first ballistic missile (Figure 5), and carried a warhead of 750 kg of explosive. Its range was about 200 km and the time of flight was only about 5 minutes. The threat was given the codename 'BIG BEN', and the document from which this information came had the rather delightful title: 'Visibility of BIG BEN to Radar' [4] and was highly classified at the time. It calculates the form of the radar signature of a V-2 rocket, using electromagnetic scattering theory. This was almost certainly the first-ever example of this kind of radar signature calculation. Of course, in those days the equations would have had to be evaluated by slide rule or mechanical calculator, and plotted by hand, which would have represented a substantial task.

It showed that the low radar frequency of the Chain Home radar was quite well suited to this task since the radar signature of the V-2 was quite broad in angular extent, which meant that it could be detected and tracked for a minute or more of its trajectory. This gave little or no time to provide a warning to Londoners, but it did allow the tracks to be traced back to find the launch points, which meant that they could subsequently be attacked. These same techniques form the basis of today's counter-battery radars.

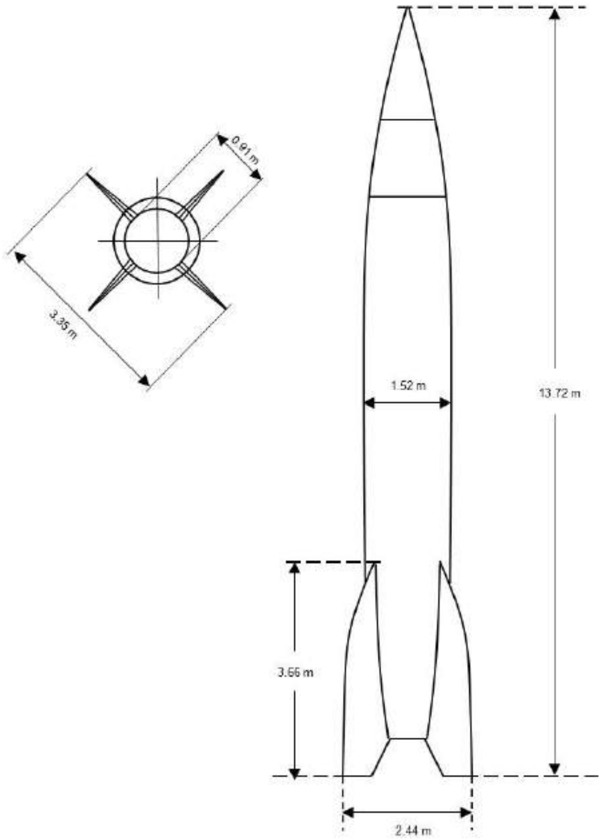


Figure 5. The V -2 rocket (adapted from [4]).

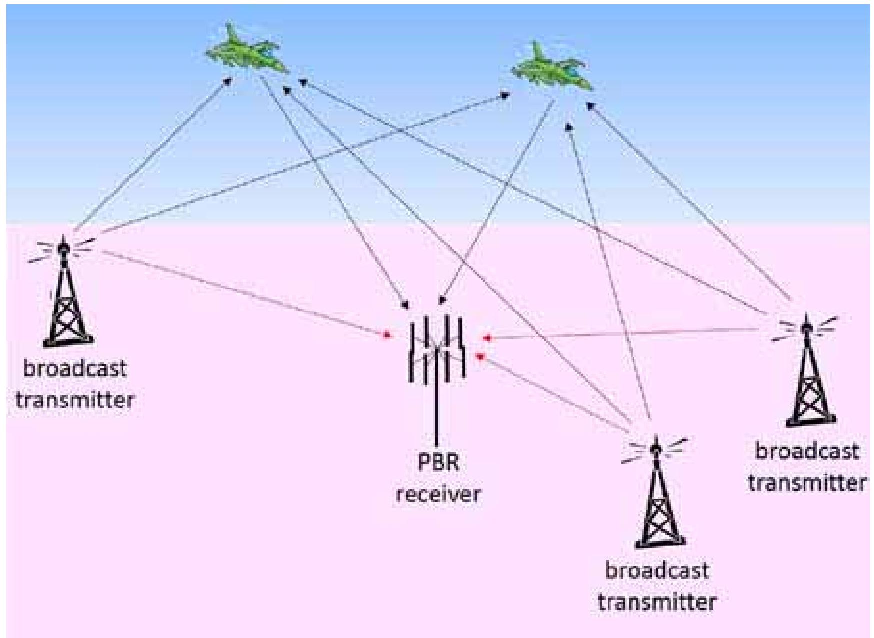


Figure 6. Principle of Passive Bistatic Radar. In this case a single PBR receiver receives direct signals from three transmitters, plus echoes of the signals from all three transmitters from two targets. From measurements of delay, angle of arrival and Doppler shift it is possible to detect and track multiple targets.

Bistatic Radar Today

Bistatic radar is now a subject of great interest and research activity – as evidenced by the number of papers on the subject in journals and at conferences. There are several reasons for this. First of all, the same advantages that were identified with the Klein Heidelberg system: that the bistatic receiver is potentially undetectable and difficult to jam. There are also several applications to which bistatic operation is suited, especially ones where the heavy transmitter and its power supply can be on one platform and the smaller, lighter receiver on another. But as well as this, the enormous advances in digital signal processing power mean that processing that was previously very difficult can now readily be carried out in real time with standard hardware. Another factor is that geolocation and synchronisation between transmitter and receiver, which were also very difficult in the past, are now easily achieved using GPS.

Passive Bistatic Radar

One of the most exciting current developments is Passive Bistatic Radar (PBR). Here, rather than using a dedicated radar transmitter, the system makes use of existing transmissions – such as broadcast, communications or radionavigation signals (Figure 6). Such sources tend to be high-power and sited to give wide coverage. The hardware required for an experimental system is usually simple and low-cost, and there are no licensing issues because the transmitter sources already exist. As well as this, PBR may also allow VHF and UHF frequencies to be used which are not normally available for radar purposes, and where in a defense context there may be an advantage against stealthy targets compared to conventional microwave radar frequencies. Finally, since such radars do not cause any additional spectral congestion, the technique has been described as ‘green radar’.

Early PBR experiments were based on analog TV or FM radio signals. It was soon realized that such signals are not quite ideal for radar, since their waveforms are time-varying and depend on the instantaneous modulation – so cacophonous rock music is better (for radar purposes, at least) than a person speaking! Digital modulation is much better in this respect, since the signals are more noise-like, without periodic features which would lead to ambiguities, and do not depend on the program content.

PBR systems based on TV or radio transmitters are easily capable of detecting and tracking aircraft targets at ranges of 100 km or more (Figure 7). There are several applications that are being considered. It is well known that the coverage of air traffic control and air defense radars is affected by wind farms. PBR may be used as a low-cost gap-filler to restore full coverage. Another application is as a possible substitute for air traffic control – though the need for complete coverage and reliability represents a significant challenge. At shorter range, WiFi or WiMAX transmissions can be used as the basis for detecting people within buildings, or for border or perimeter surveillance.

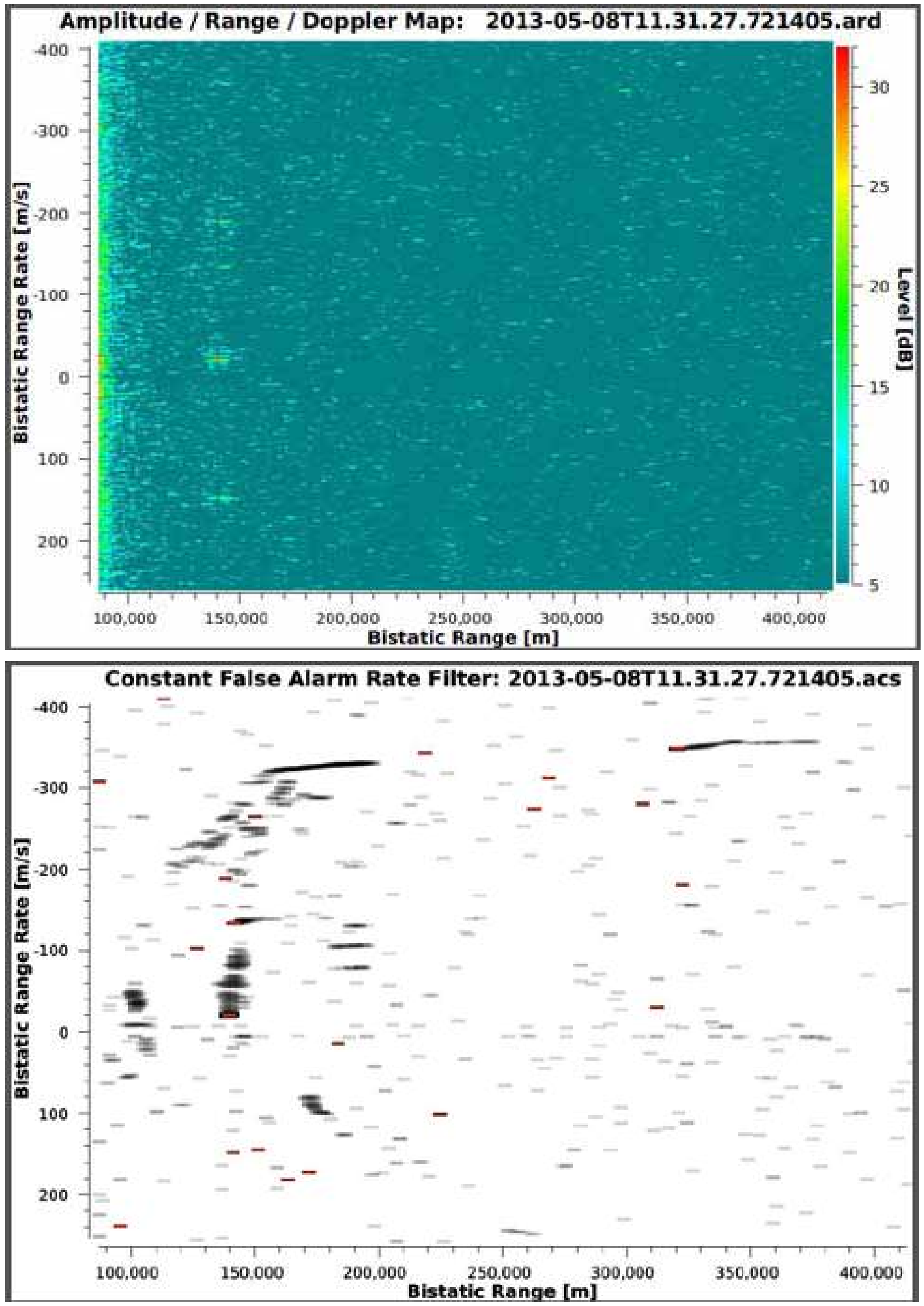


Figure 7. Passive Bistatic Radar tracking of aircraft using 98.0 MHz FM radio transmitter in Johannesburg, South Africa, presented as Range-Doppler plots (upper: raw data, lower: target tracks), and showing tracking of aircraft at bistatic ranges of well over 200 km. Image courtesy of Craig Tong and Mike Inggs, University of Cape Town.

This potential had led several companies, including Lockheed Martin, Thales and Selex-SI, to build prototype PBR systems. The market for the next ten years is estimated to be worth $10bn [5].

The Intelligent, Adaptive Radar Network

Looking further into the future, there is therefore an imperative to think in new ways about sensor systems, and to devise concepts that are more flexible, of higher performance, and yet more affordable. We realize that the conventional single-platform radars that have been the norm for so many years may not actually be the best approach, and ideas have begun to emerge that point towards the 'adaptive intelligent radar network' [6]. Here, the 'radar' consists of a set of nodes, on fixed or (preferably) moving platforms, working in an adaptive, intelligent manner. Such a scheme has a number of attractions:

? It is inherently flexible. The number and the locations of the individual platforms can be optimized to the particular tasks, and varied dynamically.

? The network has the same advantage of 'graceful degradation' of a phased array radar, in which the failure of one element of the array does not cause catastrophic failure but only degrades the overall performance slightly. In the case of the sensor network not only may the loss of one node of the network be tolerated, but also the network may be reconfigured accordingly in response.

? The platforms and the sensors carried by them need not be homogeneous. Different types of platform and sensors can be used according to the requirement.

? The locations of the platforms can give multiple perspective views of targets ('spatial diversity') to aid in target classification and identification.

? Radar sensors can be used multistatically, giving potential advantages in detecting stealthy targets, including the enhancement of target signatures that occurs in forward scatter (whilst recognising that this gives poor range and Doppler resolution). Some platforms might be receive-only and hence potentially covert, and may operate closer to the target scene.

Seen in this way the network has some similarities to a phased array radar – except that here the target is actually inside the network. In an analogous way to a multifunction phased array radar, the waveforms, beam pointing directions and hence dwell times and update rates for a particular target can be varied dynamically according to the behaviour of the targets within the scene.

All of this represents a bold vision, but there are many issues to be resolved before such a system could genuinely be realized. Three particular challenges are (i) synchronization and geolocation, particularly in a situation where GPS may be denied; (ii) communication between nodes, and (iii) control and management of the network.

In this respect there is much to be learned from natural, cognitive systems such as bats, so the network may operate in an adaptive, intelligent manner.

The Future ...

So radar systems of the future may be rather different to the ones we are used to today, and may certainly take advantage of bistatic and multistatic radar techniques and intelligent, cognitive control schemes. That inspires us to think in new ways – but at the same time we ignore the lessons from the past at our peril. Today's engineers should not only understand and embrace all new technologies and techniques, but also devote adequate time to understanding the successes – and failures – from the past.

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About the Author:

Hugh Griffiths (h.griffiths@ieee.org) is President of the IEEE Aerospace and Electronic Systems Society and holds the THALES/Royal Academy of Engineering Chair of RF Sensors at University College ***London. He has published over 400 technical articles*** and books in the fields of radar, sonar and antennas. He recently received the IET A F Harvey Research ***Prize for his work on bistatic radar.***

IEEE Milestones: Birthplace of the Internet, 1969

IEEE Milestone Plaque at UCLA
Image Credit: Courtesy of the Iota Gamma HKN Chapter and the Computer Science Department, the University of California, Los Angeles, October 2013

At 10:30 p.m., 29 October 1969, the first ARPANET message was sent from this UCLA site to the Stanford Research Institute. Based on packet switching and dynamic resource allocation, the sharing of information digitally from this first node of ARPANET launched the Internet revolution.

The plaque can be seen at the UCLA Henry Samueli School of Engineering and Applied Sciences, 405 Hilgard Ave., Los Angeles, California, U.S.A.

The deployment of the ARPANET set in motion a train of developments that led to the Internet as we know it today. The ARPANET was the first global packet-switching based network, and allowed remote network access to varied applications from multiple users among different computer platforms. It also applied the concept of protocol layering to communications. This development was the key to allowing a diverse set of users to operate over the telephone network of the time, which was optimized for voice and not suited to data traffic. With the introduction of a highly-adaptive and robust technology for network access, the ARPANET formed the foundation of today's Internet.

The application of packet switching and demand access are fundamental differences between the Internet and previous circuit switching based networks. It uses network resources by dynamically sharing them among many streams. This leads to significantly improved efficiency and robustness of the network. The layering scheme it introduces has allowed the development of flexible protocols, as well as the efficient communication between different computing platforms.

ARPANET differed from previous computer networks (e.g. SAGE) in that those networks were specialized constructions, designed to link specific machines of a similar type, whereas ARPANET was designed to allow machines to communicate efficiently irrespective of type.

UCLA was selected as the site of the very first IMP (Interface Message Processor). The major reason for this choice was due to the fundamental work and involvement of UCLA's Professor Kleinrock with many early developments of the ARPANET/Internet. His work in extending and applying queuing theory to data network design and his development of the network measurement technology were keys in the decision to make UCLA the first Internet node, and to serve as the Network Measurement Center. Many further research contributions crucial to the Internet's development and growth were generated by the UCLA team.

The reigning switching technology of the 1960s was circuit switching, which was suited to the long holding times of voice traffic. Voice traffic was so dominant, and computer-generated and related traffic was so sparse, that it was difficult to see the merit of packet switching. When packet switching technology was first suggested, the large networking companies considered the technology to be unworkable and unimportant. It was necessary to overcome their dismissal of packet switching and develop it without their support.

What are Milestones?

The IEEE Milestones in Electrical Engineering and Computing program honors significant technical achievements in all areas associated with IEEE. It is a program of the IEEE History Committee, administered through the IEEE History Center. Milestones recognize the technological innovation and excellence for the benefit of humanity found in unique products, services, seminal papers and patents. Milestones are proposed by any IEEE member, and are sponsored by an IEEE Organizational Unit (OU) such as an IEEE section, society, chapter or student branch. Learn more about the IEEE Milestones program. See "IEEE Milestones" link at the IEEE Global History Network (www.ieeeghn.org).

First Message on the Internet – "Lo[gin]" on 10:30 p.m., 29 October 1969

"The procedure was for us to type "log" with the system at SRI set up to be clever enough to complete the rest of the command, namely, to add "in" and thus create the word "login." Charlie and Bill Duvall, the programmer at the SRI end, each had a telephone headset so they could communicate by voice as the message was transmitted. At the UCLA end, we typed in the "l" and asked SRI if they received it; "Got the l," came the voice reply. We typed in the "o" and asked if they got it and received "Got the o." UCLA then typed in the "g" and asked if they got it, and the system crashed! This was quite a beginning. However, on the second attempt, it worked fine! So, the first message on the Internet was a crash, but more accurately, was the prescient word "lo" (as in "lo and behold!")."

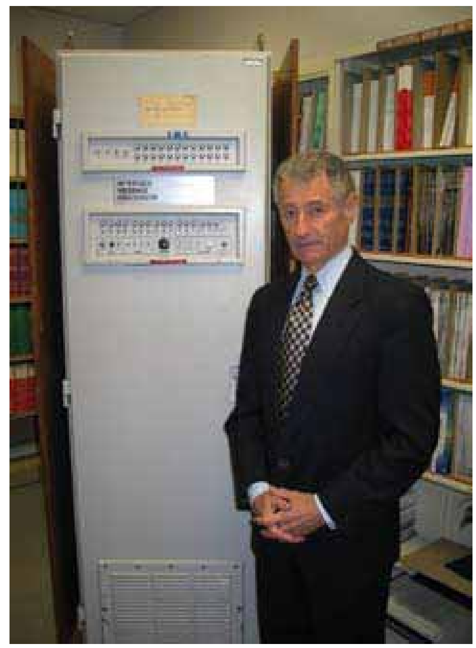
Leonard Kleinrock, "History of the Internet and Its Flexible Future," *IEEE Wireless Communications*, Feb. 2008, pp. 8–18.

Dr. Leonard Kleinrock

Eminent Member of IEEE-HKN, Elected 2011

Professor Leonard Kleinrock is Distinguished Professor of Computer Science at UCLA. Known as a "Father of the Internet", he developed the mathematical theory of packet networks, the technology underpinning the Internet as an MIT graduate student in 1961. His host computer at UCLA became the first node of the Internet in September 1969. He wrote the first paper and published the first book on the subject; he also directed the transmission of the first message ever to pass over the Internet. Kleinrock's work was recently recognized when he received the 2007 National Medal of Science, the highest honor for achievement in science bestowed by the President of the United States. His other honors include membership in the National Academy of Engineering and a membership in the American Academy of Arts and Sciences; he is an IEEE fellow and an ACM fellow.

Leonard Kleinrock received his Ph.D. from MIT in 1963. He has served as a Professor of Computer Science at the University of California, Los Angeles since then, serving as Chairman of the department from 1991-1995. He received his BEE degree from CCNY in 1957 and his MS degree from MIT in 1959. He has published over 250 papers and authored six books on a wide array of subjects, including packet switching networks, packet radio networks, local area networks, broadband networks, gigabit networks, nomadic computing, performance evaluation, intelligent agents and peer-to-peer networks. During his tenure at UCLA, Dr. Kleinrock has supervised the research for 47 Ph.D. students and numerous M.S. students.



Dr. Leonard Kleinrock with Internet Message Processor
Image Credit: Courtesy of Computer Science Department, the University of California, Los Angeles, September 2013

Interactive Extras and More Information:

? Audio interview with Dr. L. Kleinrock

? IEEE Global History Network Resources

? The Kleinrock Internet History Center at UCLA

? DARPA Internet Resource Page

? Computer History Museum

Four-Node ARPANET in 1969

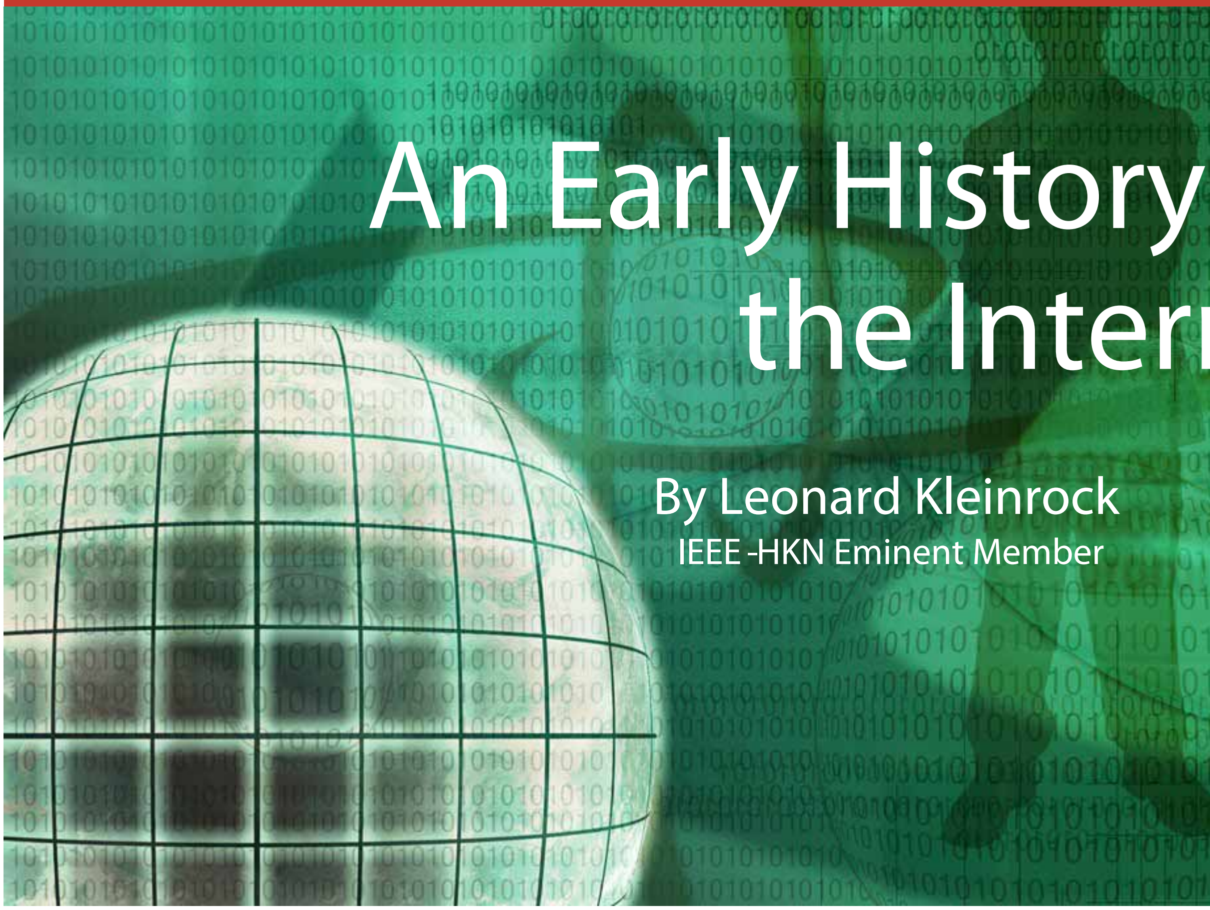
A Technical History of the ARPANET

A timeline of major events in the history of the ARPANET, providing an overview of the ARPANET's conception, growth, and development.

1958	Eisenhower forms the Advance Research Projects Agency (ARPA) in response to the USSR's launch of Sputnik.
1966	December: The ARPA Computer Network (ARPANET) project begins.
1967	April: It is suggested that the ARPANET utilize a separate computer between the host and the network. This computer would perform the packet switching and routing. This separate computer dubbed the Interface Message Processor or IMP.
1968	December: Contract to build the IMPs is won by Bolt Beranek and Newman Inc. (BBN). BBN designs the IMP (cf. BBN reports 1763, 1783, 1837, and 1890) and releases the first specification for Host to IMP communication (BBN report 1822).
1969	April: The discussion of the Host to Host Protocol begins with RFC 1. The Network Working Group (NWG) forms to deal with the task of Host-Host layer communication protocols.
	September: The first IMP is delivered and connected to a SDS Sigma 7 computer at UCLA. This IMP constitutes the first node of the ARPANET. The IMP is located in the Network Measurement Center, which will keep statistics, stress the network, and evaluate network performance.
	October: The second node of the ARPANET is installed at Stanford Research Institute (SRI). The IMP is connected to an SDS 940 Computer. The first host-to-host message is sent across the network and received.
	November: The third node of the ARPANET is installed at UCSB.
	December: The fourth node of the ARPANET is installed at The University of Utah.
1970	The network is stressed by inducing congestion. Several problems are revealed.
	March: The ARPANET now spans the United States, with the installation of an IMP at BBN, in Cambridge, MA.
	March: The Network Control Center (NCC) at BBN begins operation. All IMPs have to report to the NCC every minute to confirm they are alive.
	November: The IMP's software is upgraded to allow the IMPs to be able to download any new software from each other. This allows IMP software to be installed on one IMP, and the software will propagate throughout the IMP-subnet. Likewise, if a problem occurs, and an IMP needs to restore its software, it can download it from a neighboring IMP.
1971	The first host-to-host protocol is implemented, NCP (Network Control Program).
	September: The Terminal IMP (TIP) is installed in the ARPANET, allowing direct terminal access to the network.
1972	March: SNGMSG and READMAIL allow the first e-mail basic system on the ARPANET.
	July: The first File Transfer Protocol (FTP) specification is released (RFC 354).
	October: First public demonstration of the ARPANET occurs at the International Conference on Computer Communication (ICCC), Washington.
1973	The first attempt at internetworking two networks (ARPANET and Packet Radio Network) begins.
	May: The first Ethernet operation at Xerox Palo Alto Research Center.
1974	May: Transmission Control Protocol (TCP), is specified. This protocol allowed for internetworking and eventually replaced NCP.
1977	October: TCP operations begins over the ARPANET, Packet Radio Net, and the Satellite Network (SATNET).
1978	March: TCP is split into TCP and IP, where TCP is the end-to-end process, and IP is the network routing process.
1983	MILNET (Military Network) is split off of ARPANET, leaving the ARPANET with 68 nodes. The two networks are connected by a gateway.
	January: The ARPANET officially transitions to TCP/IP.
	November: Domain Name System (DNS) is designed. (.com, .gov, .mil, .org, .net, .int)
1990	After 20 years, ARPANET is shutdown.

http://www.cs.utexas.edu/users/chris/nph/ARPANET/ScottR/arpanet/timeline.htm

An Early History of the Internet



By Leonard Kleinrock
IEEE -HKN Eminent Member

Observations from the origins and development of the ARPANET

INTRODUCTION

It is impossible to place the origins of the Internet in a single moment of time. One could argue that its roots lie in the earliest communications technologies of centuries and millennia past, or the beginnings of mathematics and logic, or even with the emergence of language itself. For each component of the massive infrastructure we call the Internet, there are technical (and social) precursors that run through our present and our histories. We may seek to explain, or assume away, whatever range of component technologies we like. It is equally possible to narrow Internet history down to specific technologies with which we are the most familiar.

There are also many individuals that may be said to have "predicted" the Internet. In 1908, Nikola Tesla foresaw [1] a technology that would allow "a business man in New York to dictate instructions, and have them instantly appear in type at his office in London or elsewhere" and would allow global access to "any picture, character, drawing, or print." Thirty years later, H. G. Wells articulated [2] his idea of a "World Brain" as "a depot where knowledge and ideas are received, sorted, summarized, digested, clarified and compared." These ideas were followed by a 1945 essay [3] by Vannevar Bush, predicting a machine with collective memory that he called the memex, with which "Wholly new forms of encyclopedias will appear, ready-made with a mesh of associative trails running through them, ready to be dropped into the memex and there amplified."

These predictions, however, do not help us understand why the specific events, innovations, people, and circumstances that formed our Internet emerged when they did. Doing so is not possible from the scale of centuries or single individuals. This column's focus is on the defining inventions and decisions that separate early technologies that were clearly not the Internet, from a wide range of recent inventions that may help characterize our Internet, but were also built within it. Thus, in this column we trace both the early history of the science and infrastructure that emerged as the ARPANET, and the trajectory of development it set for the even broader construct that we now call the Internet.

As one of many individuals who participated in the Internet's early history, I also offer a personal account of the same events, as an autobiographical element in this story. In doing so, I aim to further contextualize publications from the period — my primary source materials — with details from firsthand experience. This perspective may add to our depth of historical understanding, in which the extent of personal detail does not imply a greater importance to the events presented. In focusing on the work of individual researchers and developers, I rely on the various publications that followed the work of these individuals to link this story to the factual historical record we will follow. There are, of course, many important personal and institutional stories that have yet to be told. The University of California at Los Angeles (UCLA) is heavily mentioned in this column, as it was the site of so much foundational work. I view this period as a synergistic surge of technology, engineered by a magnificent group of researchers and developers amidst a defining period of challenge, creativity, invention, and impact.

BEFORE THE BEGINNING: TWO THREADS THAT MEET

The Internet did not suddenly appear as the global infrastructure it is today, and neither did it form automatically out of earlier telecommunications. During the late 1950s and early 1960s, two independent threads were being woven. One was the research thread that eventually led to the packet switching networks of today's Internet. This thread followed three possible paths to the technologies that eventually emerged; the researchers involved were, in chronological order, myself, Paul Baran, and Donald Davies. Below we explore these three paths, which were independently pursued in the quest to provide data networking theory, architecture, and implementation. The second thread was the creation and growth of the Advanced Research Projects Agency (ARPA), the institution that funded and deployed these technologies — a process that, as we will see, was by no means automatic. These two threads merged in the mid-1960s, creating the historical "break" that led to the ARPANET. Once these threads merged, the implementation and deployment phase began, bringing in other key contributors and successive stages of development in Internet history. I present these threads and phases chronologically so we can revisit the history as it unfolded. One may find elaborations on this history in two earlier papers [4, 5].

THE RESEARCH THREAD

In January 1957[1] I began as a graduate student in electrical engineering at Massachusetts Institute of Technology (MIT). It was there that I worked with Claude Shannon, who inspired me to examine behavior as large numbers of elements (nodes, users, data) interacted; this led me to introduce the concept of distributed systems control and to include the study of "large" networks in my subsequent thesis proposal. In that MIT environment I was surrounded by many computers and realized that it would soon be necessary for them to communicate with each other. However, the existing circuit switching technology of telephony was woefully inadequate for supporting communication among these data sources. This was a fascinating and important challenge, and one that was relatively unexplored. So I decided to devote my Ph.D. research to solving this problem, and to develop the science and understanding of networks that could properly support data communications.

"The internet did not suddenly appear as the global infrastructure it is today..."

Circuit switching is problematic because data communications is bursty, that is, it is typically dominated by short bursts of activity with long periods of inactivity. I realized that any static assignment of network resources, as is the case with circuit switching, would be extremely wasteful of those resources, whereas dynamic assignment (I refer to this as "dynamic resource sharing" or "demand access") would be highly efficient. This was an essential observation, and in 1959 it launched my research thread as I sought to design a new kind of network. Its architecture would use dynamic resource allocation to support the bursty nature of data communications, and eventually provide a structure for today's packet-switched networks.

This concept of resource sharing was emerging at that time in a totally different context: that of timesharing of computer power. Timesharing was based on the same fundamental recognition that users generate bursty demands, and thus expensive computer resources were wasted when a computer was dedicated to a single user.

"I sought to develop a model with dynamic resource sharing, incorporating the fact that data traffic was unpredictable as well as bursty."

To overcome this inefficiency, timesharing allocated the computer to multiple users simultaneously, recognizing that while one user was idle, others would likely be busy. This was an exquisite use of resource sharing. These ideas had roots in systems like SAGE [6] and in the MIT Compatible Time-Sharing System (CTSS [7]), developed in 1961 by Fernando Corbato (among the first timesharing systems to be implemented). The principles and advantages of timesharing were key to my realization that resource sharing of communication links in networks could provide for efficient data communications, much like the resource sharing of processors in timeshared systems was accomplishing.

In addition, there was already an example of a special-purpose data network that used resource sharing: the store-and-forward telegraph network. The challenge I faced was to create an appropriate model of general-purpose data communications networks, to solve for their behavior, and to develop an effective design methodology for such networks.

To do this, I sought to develop a model with dynamic resource sharing, incorporating the fact that data traffic was unpredictable as well as bursty. In order to clear up some misconceptions regarding what I and other investigators were doing in the field in the early days, I will devote some space in the following paragraphs to discuss the relationship between dynamic resource sharing and packet switching, where the latter is but one of many ways to realize the former. The basic structure I chose was that of a queue since it is a perfect resource sharing mechanism. A queue is dynamic, adaptive, and efficient, and does not wait for a message that is not there, but rather transmits a message already waiting in the queue. Moreover, the performance measures one considers in queueing theory are response time, throughput, efficiency, buffering, priorities, and so on, and these are just the quantities of interest in data networks. In the late 1950s, the published literature contained almost no work on networks of queues. However, a singular exception to this was the work by James Jackson, who published a classic paper [8] on open networks of queues. As we see below, I was able to apply Jackson's result to represent the data networks of interest by making serious modifications to his model.

So the stage was set: There was a need to understand and design general purpose data communication networks that could handle bursty data traffic, there was an emerging approach based on resource sharing in timeshared systems, there was an existing special-purpose network that suggested it could be done, and there was a body of queueing theory that looked promising.

As a result, I prepared and submitted my MIT Ph.D. thesis proposal [9] in May 1961, entitled "Information Flow in Large Communication Nets" in which I developed the first analysis of data networks. I chose a queueing theoretic model based on Jackson's model to characterize a data network as a network of communication channels whose purpose was to move data messages from their origin to their destination in a hop-byhop fashion. Each channel was modeled as a resource serving a queue of data messages awaiting transmission; I discussed how "The nets under consideration consist of nodes, connected to each other by links. The nodes receive, sort, store, and transmit messages that enter and leave via the links…." My underlying model assumed that the stream of messages had randomly chosen lengths and, when applied to data networks, yielded a problem whose exact solution turned out to be hopelessly intractable. I altered the model and also introduced a critical mathematical assumption, the Independence Assumption,[2] which tamed the problem and allowed for an elegant solution. With this solution, I was able to solve for the many performance measures of these networks. For example, I showed that by scaling up the network traffic and bandwidth properly, one could reduce the system response time, increase the network efficiency, and increase the network throughput, all simultaneously [10].

In the course of examining data network performance, it became clear to me that it was important to explore the manner in which mean response time was affected when one introduced a priority queueing discipline on the traffic. I chose to understand this influence in the case of a single node first and then to apply the results to the general network case. This led to a publication in April 1962, which turned out to be the first paper [11] to introduce the concept of breaking messages into smaller fixed-length pieces (subsequently named "packets," as explained below). In it I provided a mathematically exact analysis of the mean response time, and showed the advantages to be gained by utilizing packet switching for this new network.[3] Note that the fixed length packets I introduced did not match the randomly chosen lengths of the model, but fortunately, the key performance measure I solved for, the overall mean system response time, did not require that assumption, so the mathematical model properly reflected the behavior of fixed length packets as well.

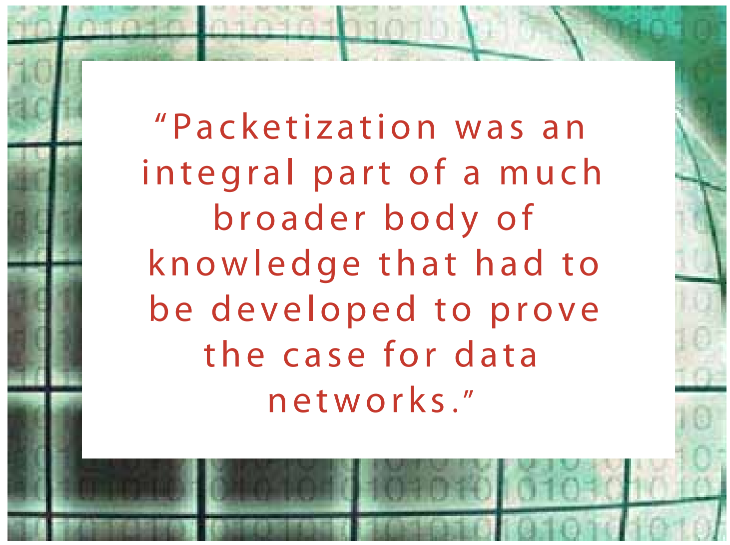
I also developed optimal design procedures for determining the network capacity assignment, the topology, and the routing procedure. I introduced and evaluated distributed adaptive routing control procedures, noting that network/ routing control is best handled by sharing control among all the nodes rather than relegating control to one or a small number of nodes. This distributes the control load (thereby not unduly loading any one node), introduces the ability to change routes on the fly dynamically (based on current load, connectivity, and destination address), enables the network to scale to a very large number of nodes, and dramatically improves the robustness of the network.

Whereas my focus was not principally on the engineering details of packet networks, I did address engineering details when I built a complete network simulation model and conducted extensive simulation experiments confirming the correctness of the theory. These experiments included detailed message blocks (with headers, origin and destination addresses, priority indicators, routing labels, etc), dynamic adaptive routing tables, priority queueing structures, traffic specifications, and more.[4]

Packetization was an integral part of a much broader body of knowledge that had to be developed to prove the case for data networks. Indeed, packetization alone was not the underlying technology that led to ARPANET design fundamentals. To be sure, packetization was and remains a core element of today's networking technology, but it is not identical to network efficiency. Rather, the fundamental gain lies in dynamic resource sharing. It is important to point out that there are many ways in which dynamic resource sharing can be accomplished, with packet switching being only one such method; other methods include polling [12], message switching [13], asynchronous time-division multiple access (ATDMA) [14], carrier sense multiple access with collision detection (CSMA/CD) [15], and others.

I completed and filed my Ph.D. dissertation [16] in December 1962, having created a mathematical theory of packet switching for dynamic resource sharing, thus providing the fundamental underpinnings for ARPANET technology. I showed that these networks were efficient, stable, scalable, robust, adaptive, and, most of all, feasible. Decades of important research on these topics have since taken place around the world.

By the time my dissertation was published as the first book [17] on computer networks in 1964, the idea of packetization itself was appearing more broadly. The next contributor to packet switching was Paul Baran of the RAND Corporation, who was busy working on military command and control systems during the early 1960s with the goal of using redundancy and digital technology to design a robust multilateral military communications network. He recognized the vulnerability of the telephone



"Packetization was an integral part of a much broader body of knowledge that had to be developed to prove the case for data networks."

network due to its centralized architecture. In September 1962 he published a paper [18] on how "hot potato" adaptive alternate routing procedures and distributed principles could utilize a "standard message block," also to fall under the "packet" umbrella, which will be addressed below. His purpose was to create a network capable of functioning after a Soviet nuclear attack [19]. In August 1964 he produced a set of 11 important reports [20] reinforcing his prior description with simulations and elaborating on many details of the design. He, too, discovered the importance of going to digital networks and of the robustness provided by distributed routing. He attempted to get AT&T to implement the design, but failed to convince them (presumably due to their analog mindset). In 1965 RAND approached the Air Force to implement it, but they deferred to the DCA[5]; at this point, Baran decided not to pursue the implementation any further. Baran's work was done independently of the work that I had done earlier at MIT and, in many ways, the results we achieved in addressing the problem of packet networks were complementary.

The third early contributor to packet switching was Donald Davies, of the National Physical Laboratory (NPL) in the

United Kingdom. He began thinking about packet networks in 1965 and coined the term "packet" that year. In a privately circulated paper [21] dated June 1966, he described his design for a data network and used my earlier theory to calculate its performance. Davies lectured to a public audience in March 1967, recommending the use of his technology for the design of a public switched data network, and published an October 1967 paper [22] with his NPL group in which details of the design were first described in an open publication. This plan was for an NPL Data Communications Network, but the U.K. Department of Trade and Industry only authorized the implementation of one node. That node became operational in 1970. Further details of a full network design were described by the NPL team in 1968 [23, 24] and 1969 [25]; it is not clear where a multiplenode deployment by this team might have led, but it obviously had potential. This reluctance to support an NPL packet-switched network was reminiscent of the view taken by AT&T and DCA in not supporting an implementation of the RAND work.

The work of Baran and Davies focused on the engineering and architectural issues of the network design. My work emphasized and provided the mathematical underpinnings and supporting simulation experiments of the network analysis and design, including optimization as well as formulating the basic principles of packet networks that include dynamic resource sharing; this quantitatively showed that these networks were feasible. My trajectory was more fortunate as the ARPA thread rolled out and adopted my principles for their design of the ARPANET, and provided me the opportunity to participate in its implementation and deployment. Different trajectories were taken by Baran and then later by Davies, with Baran's unsuccessful attempts to get his ideas implemented and with Davies' frustration by the foot-dragging of the U.K. government. It was not enough to put good ideas forward, but it was also necessary to prove that the concepts were quantitatively sound, and then to implement and deploy an operational network that would bring these ideas and designs to use.

THE ARPA THREAD

Let us step back chronologically and now pursue the second thread: the role of ARPA in defining the need for a data network, putting the management structure in place to enable its development, and providing the funding necessary for its implementation and deployment.

J. C. R. Licklider ("Lick") entered the story when he published his landmark 1960 paper [26] "Man-Computer Symbiosis." He defined the title as "an expected development in cooperative interaction between men and electronic computers." This work envisaged a system "to enable men and computers to cooperate in making decisions and controlling complex situations without inflexible dependence on predetermined programs"; he had seen such a flexible system in the aforementioned SAGE system. Once again, we find a forecast of what future telecommunications might provide — and Lick was perhaps the first to write at a time when viable ways to create that future were emerging. Although a visionary, Lick was not a networking technologist, so the challenge was to finally implement such ideas.

"It was not enough to put good ideas forward, but it was also necessary to prove that the concepts were quantitatively sound..."

In May 1962 Lick and Welden Clark outlined their views on how networking computers could support social interaction, and provide networked access to programs and data [27]. This extended his earlier ideas of what he now referred to as a Galactic Network (in fact, he nicknamed his group of computer experts "The Intergalactic Network").

Lick was appointed as the first director of ARPA's newly formed Information Processing Techniques Office (IPTO) in October 1962. He quickly funded new research into advanced computer and networking technologies as well as areas that involved man-computer interaction and distributed systems.

By the end of 1962, Lick had articulated his grand vision for the Galactic Network, of which I was unaware, and I had laid out the mathematical theory of packet networks, of which Lick was also unaware. These ideas would soon intersect and reinforce each other in a series of key events between 1962 and 1969. I joined the UCLA faculty in 1963. Lick passed the directorship of IPTO to Ivan Sutherland, an MIT colleague of mine, in September 1964. In that role Sutherland wished to connect UCLA's three IBM mainframes in a three-node on-campus computer network, which would have been easy to accomplish with the means I had laid out in my Ph.D. dissertation.

However, the UCLA network was never realized due to administrative discord. Nevertheless, the seeds for an ARPA-funded network had now been sown.

Early the next year (1965), Sutherland awarded Larry Roberts (another MIT colleague of mine who was quite familiar with my networking research) a contract to create a dialup 1200 b/s data connection across the United States. Later that year, Roberts accomplished this in collaboration with Thomas Marill, demonstrating that such a connection required a different, more sophisticated network than the telephone network offered [28].

Meanwhile, at ARPA, Sutherland recruited Robert Taylor to become associate director of IPTO in 1965. While there, Taylor also recognized the need for a network, this time specifically to connect ARPA research investigators to the few large expensive research computers across the country. This would allow them to share each other's hardware, software, and applications in a cost-effective fashion.[6] Taylor then dropped into the office of the ARPA director, Charlie Herzfeld, to request funding for this nascent networking project. Herzfeld was a man of action who knew how to make a fast decision, and within 20 minutes he allocated $1 million to Taylor as initial funding for the project. Taylor, who had since succeeded Sutherland as IPTO director in August 1966, brought in Roberts as the IPTO chief scientist that December. Bringing Roberts in to manage the networking project turned out to be a critical hire as Roberts was to contribute at all levels to the coming success of data networking.

The research and ARPA threads had now merged, and the project would soon become the ARPANET.

These were critical steps in Internet history, for not even in the post-war United States did technological progress flow directly from ideas. In contrast to refusals from the private sector to fund the beginnings of the project, ARPA made available the will and funding of the U.S. government.[7] ARPA's management and support fostered the early culture of shared, open research that was crucial to the success of the ARPANET program.

THE BEGINNING: THE ARPANET LAUNCH

The commitment to create the ARPANET was now in play. Roberts was empowered to develop the network concept based on Lick's vision, my theory, and Taylor's application.

There were basically two matters to be considered in this project. One was the issue of creating the switches and links underlying the network infrastructure, with the proper performance characteristics, including throughput, response time, buffering, loss, efficiency, scalability, topology, channel capacity, routing procedure, queueing discipline, reliability, robustness, and cost. The other was to create the appropriate protocols to be used by the attached (host) computers[8] so that they could properly communicate with each other.

Shortly after his arrival, Roberts called a meeting of the ARPA Principal Investigators (PIs) in April 1967 at the University of Michigan, where ARPANET planning was discussed in detail. It was there that the basic specifications for the underlying network were debated among us PIs. For example, Wesley Clark put forward the concept of using an unmanned minicomputer at each location to handle all of the switching and communications functions; it was to be called an Interface Message Processor (IMP). This would offload the networking functions from the host, greatly simplify the design by requiring only one interface to be written for each host to the standard IMP, and at the same time would decouple the network design from any specific host hardware and software. Another specification had to do with the measure of reliability of the planned network; this we specified by requiring that the topological design[9] produce a "two-connected net," thus guaranteeing that no single failure would cause any non-failed portion of the network to lose connectivity.

"These were critical steps in Internet history, for not even in the post-war United States did technological progress flow directly from ideas."

Yet another requirement we introduced was for the network to provide an experience as if one were connected to a local timeshared computer even if that computer was sitting thousands of miles across the network; for this we specified that short messages should have response times no greater than 500 ms (the network design provided 200 ms at its inception). Moreover, since this was to start out as an experimental network, I insisted that appropriate measurement tools be included in the

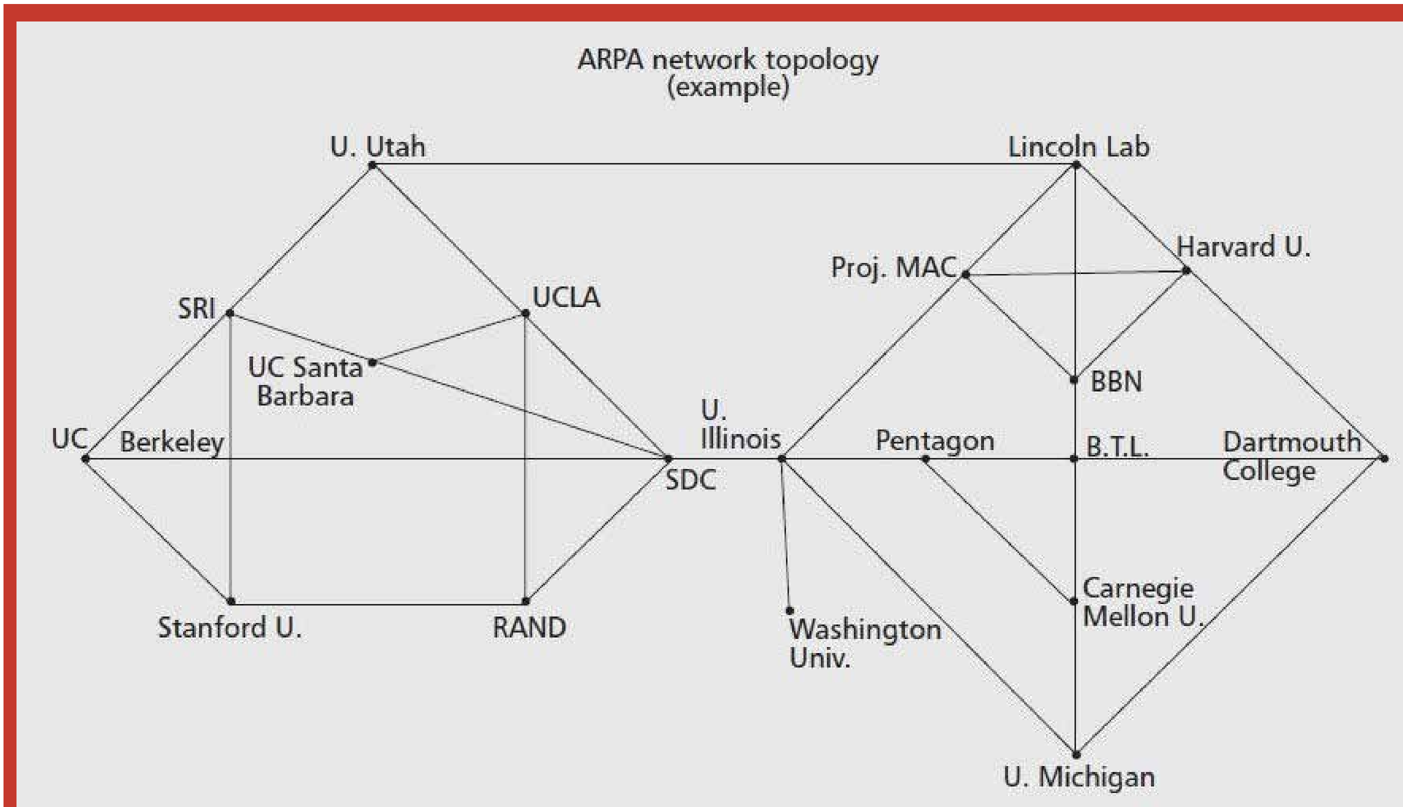


Figure 1. 19-node ARPANET as shown in the original RFQ.

IMP software to allow for tracing of packets as they passed across the network, taking of snapshots of the IMP and host status at any time, artificial traffic generation, gathering and forwarding of statistics about the network, and a mechanism for controlling these measurements.

Following this April meeting, Roberts put together his outstanding plan for the ARPANET design and presented it as a paper [29] at a conference in Gatlinburg, Tennessee in October 1967. At this conference, Roger Scantlebury of the NPL also presented their aforementioned jointly published paper [22] describing a local network they were developing. It was during a conversation with Scantlebury at this meeting that Roberts first learned of the NPL work as well as some details of the work by Baran at RAND. The research by myself at MIT, by Baran at RAND, and by Davies, Scantlebury, et al. at NPL had all proceeded independently, mostly without the researchers knowing about the others' work. There was, though, some cross-fertilization: Davies had used my analytical model for data networks in his work; as a result of discussions at this conference, Roberts adopted Davies' word "packet" for the small fixed length pieces I had suggested we break messages into, and which Baran referred to as "message blocks"; its fixed length was chosen to be 1024 bits for the ARPANET design (both Baran and Davies had suggested this same length); as a result of the discussion with Scantlebury, Roberts decided [30] to upgrade the backbone line speed from 9.6 kb/s to 50 kb/s for the ARPANET design.

Following these 1967 meetings, a sequence of drafts for the IMP specification was prepared.[10] This culminated in March 1968 when Roberts and Barry Wessler produced the final version of the IMP specification, which they then discussed at an ARPA PI meeting later that month. On June 3, 1968, the ARPANET Program Plan [31] was formally submitted to ARPA by Roberts, and it was approved on June 21, 1968. The ARPANET procurement process was now officially underway.

By the end of July 1968, a Request for Quotation (RFQ) [32] for the network IMPs was mailed to 140 potential bidders. The 19-node example to be delivered by the contractor is shown in Figure 1.

The handling of data streams specified that the hosts would communicate with other hosts by sending messages (of maximum length 8192 bits) to their attached IMPs, that these messages would be broken into packets (of maximum length 1024 bits each — thus, at most 8 packets per message) by the IMP, and that IMPs would communicate with each other using these packets. The movement of packets through the subnetwork of IMPs was to be controlled by a distributed dynamically updated routing algorithm based on network connectivity and loading as well as packet destination and priority. Errors in packet transmission between IMPs were managed by error detection and retransmission. Packets were to be reassembled into their original messages at the destination IMP before delivery to the destination host. The basic structure of this IMP specification contained contributions from a number of individuals, including my own research. Roberts had been well aware of my work since my time at MIT, where we were officemates, later stating,[11] "In order to plan to spend millions of dollars and stake my reputation, I needed to understand that it would work. Without Kleinrock's work of Networks and Queueing Theory, I could never have taken such a radical step." [33]

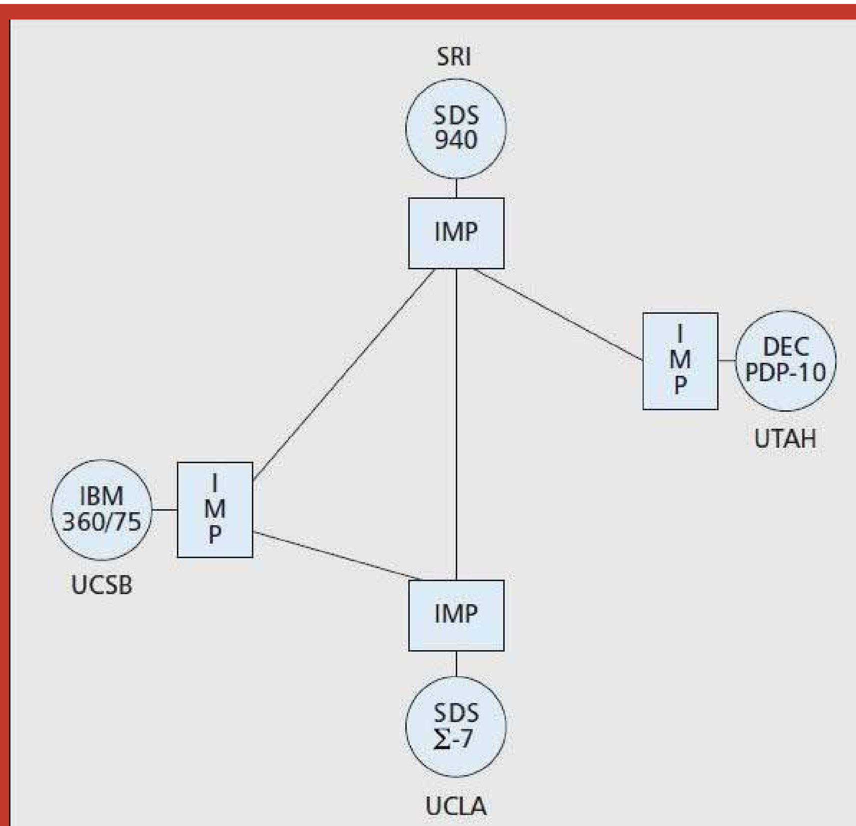


Figure 2. The initial four-node ARPANET (1969).

The RFQ resulted in 12 proposals being submitted in August 1968 (notably missing were IBM and AT&T). As these proposals were being evaluated at ARPA, Roberts awarded a research contract to me at UCLA in October to create the Network Measurement Center (NMC). The task of the NMC was to measure the behavior of the ARPANET by conducting experiments to determine its faults, performance, and outer limits (through the use of stress tests). I was fortunate to have a star team[12] of graduate student researchers, developers, and staff for this project; a number of these appear in continued roles later in this story. A week before Christmas 1968, Bolt, Beranek and Newman (BBN) won the competitive bid and was awarded the contract to develop the IMP-to-IMP subnetwork. The BBN team,[13] supervised by Frank Heart, produced some remarkable accomplishments. This team had selected the Honeywell DDP-516 minicomputer with 12 kb of memory for the program to be the machine on which the IMP would be based; they were contracted to implement the IMP functions by modifying the hardware and software of the DDP-516, to connect these IMPs to long-haul 50 kb/s lines leased by Roberts from AT&T under the DoD Telpak tariff, and to deploy the subnetwork. The BBN team developed an elegant host-IMP design that met the ARPA specifications; this specification was written as BBN Report 1822 [34] by Robert Kahn, who was in charge of the system design at BBN (Kahn appears later in this story in some very significant roles, as we shall see below). One of the BBN team, Dave Walden, points out that he was most likely the first programmer on the Internet by virtue of having done code design for the IMP in their 1968 response to the RFQ. Whereas members of the BBN team were busy testing the IMP's ability to provide IMPto- IMP data exchanges, testing the behavior of a network of IMPs was difficult to do in a laboratory environment; the true behavior was more properly tested in the deployed network with real traffic and with many nodes, which is exactly what the NMC was designed to do. Basically, BBN was given less than nine months to deliver the first IMP to UCLA by early September 1969. Their performance was outstanding. The first IMP at UCLA was to be followed by the second IMP in October to SRI, the third IMP in November to the University of California at Santa Barbara (UCSB), and the fourth IMP in December to the University of Utah. The initial network was to be that shown in Fig. 2.

These four sites were selected due to their ability to provide specialized network services and/or support. Specifically, UCLA (connecting an SDS Sigma-7 Host computer) would provide the NMC (under my supervision), SRI (connecting an SDS 940 host computer) would provide Doug Englebart's Human Intellect Augmentation System (with an early version of hypertext in his NLS system) as well as serve as the Network Information Center (under Elizabeth [Jake] Feinler's supervision), UCSB (connecting an IBM 360/75 host computer) would provide interactive graphics (under Glen Culler's and Burton Fried's supervision), and the University of Utah (connecting a DEC PDP-10 host computer) would provide advanced 3D graphics (under the supervision of Ivan Sutherland). The fact that Heart and his team at BBN succeeded in delivering this new technology with new applications and new users in an ontime, on-budget fashion was incredible.

But this contract to develop the underlying network was only the first of the two key tasks that were needed to deploy a working packet-switched network. Recall that the other task was to create the appropriate protocols to be used by the attached (host) computers so that they could properly communicate with each other.

This second task was assigned to the four chosen ARPANET research sites to figure out on their own. Thus began another thread of innovative development that characterized the ARPANET culture. This thread actually begins in the summer of 1968 when Elmer Shapiro of SRI, in response to a request by ARPA, called a meeting of programmers from among those first sites that were to be connected into the ARPANET. Their main charge was to study and resolve the issues of host-tohost communication. Present at this meeting was one programmer from each of the first four sites to receive IMPs as follows: Steve Crocker (UCLA), Jeff Rulifson (SRI), Ron Stoughton (UCSB), and Steve Carr (University of Utah). This group, plus the many others who joined later, were soon to be named the Network Working Group (NWG) with Shapiro its first chairman.[14] UCLA's Jon Postel served as the Request for Comments (RFC) editor (a role he held until his untimely death in 1998). They had no official charter against which to work, and so were afforded the unique opportunity to invent and create as needed. There was no sense of qualifying membership; all one had to do was to contribute and participate. Their focus moved to the creation of high level interactions and, eventually, to the notion of a layered set of protocols (transport services below a set of application-specific protocols). Basically, this was a highly resourceful, self-formed, collegial, loosely configured group of maverick graduate students who we (the ARPA PIs) had empowered to design and implement the protocols and software for the emerging network. They took on the challenge we ceded to them and created an enduring NWG structure that later led to today's Internet Engineering Task Force (IETF).[15]

Once the IMP-host specification was released by BBN in the spring of 1969, the NWG began to focus on the lower level issues such as message formats. They decided to exchange ideas through a very informal set of notes they referred to as "Requests for Comments" (RFC). The first RFC [35], entitled "Host Protocol," was written by Crocker in April 1969. Crocker became the second Chairman of the NWG early on.

We now had the two main ARPANET development efforts underway:

? A formal contract with BBN to create the IMP-IMP subnetwork

? An informal group of programmers (mostly graduate students) who were charged with developing the Host -to-Host Protocol

Things began to move rapidly at this point. The date of the first IMP delivery, scheduled to arrive to us at UCLA in early September 1969, was fast approaching. Meanwhile, at the NMC, we were busy collecting data so that we could predict performance of the network based on my earlier theory. For this, it was necessary to estimate the traffic loads that the host sites would present to the network. Roberts and I contacted a number of the early sites and asked them how much traffic they expected to generate and to which other sites. We also asked them how much traffic they would allow into their sites; to my surprise, many refused to allow any traffic from the network to use their hosts. Their argument was that their hosts were already fully utilized serving their local customer base. Eventually they relented and provided their expected traffic loads. That traffic matrix was used in the July 1968 RFQ [32] and in a paper I published [36], thereby sealing their commitment.

On July 3, 1969, two months before the IMP was due to arrive, UCLA put out a press release [37] announcing the imminent deployment of the ARPANET. In that release I described what the network would look like, and what would be a typical application. I am quoted in the final paragraph as saying, "As of now, computer networks are still in their infancy, but as they grow up and become more sophisticated, we will probably see the spread of 'computer utilities,' which, like present electric and telephone utilities, will service individual homes and offices across the country." It is gratifying to see that the "computer utilities" comment anticipated the emergence of web-based IP services, that the "electric and telephone utilities" comment anticipated the ability to plug in anywhere to an always on and "invisible" network, and that the "individual homes and offices" comment anticipated ubiquitous access. However, I did not foresee the powerful social networking side of the Internet and its rapidly growing impact on our society.

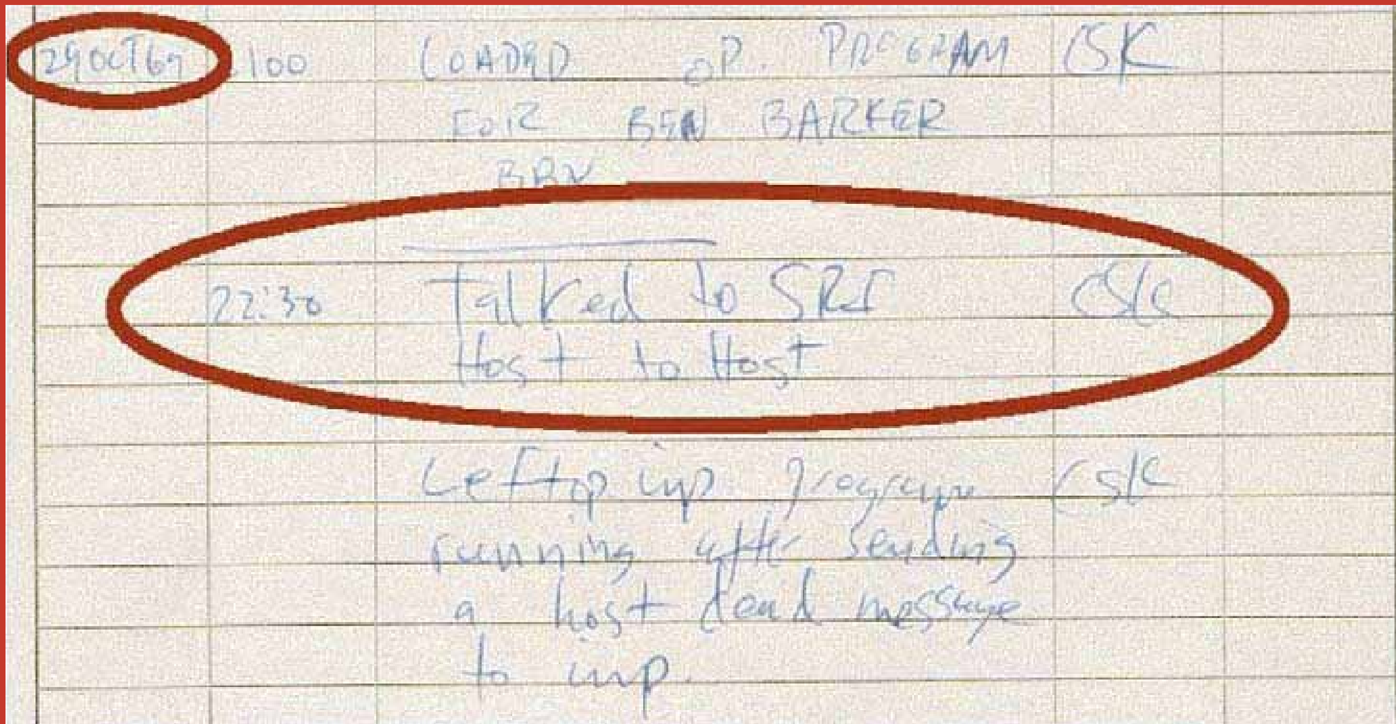


Figure 3. The entry in the original IMP log, which is the only record of the first message transmission on the Internet.

On Saturday, August 30, 1969, the first IMP arrived at UCLA. On September 2, the day after Labor Day, it was connected via a 15-foot cable to the UCLA host computer, our SDS Sigma- 7 machine. This established the first node of the fledgling network, as bits moved between the IMP and the Sigma- 7. This is often regarded as a very significant moment in the Internet's history.

In early October the second IMP was delivered by BBN to SRI in Menlo Park, California. The first high-speed link of what was to become the Internet was connected between those two IMPs at the "blazing" speed of 50 kb/s. Later in October, SRI connected their SDS 940 host computer to their IMP.

The ARPANET's first host-to-host message was sent at 10:30 p.m. on October 29, 1969 when one of my programmers, Charley Kline, and I proceeded to "login" to the SRI host from the UCLA host. The procedure was for us to type in "log," and the system at SRI was set up to be clever enough to fill out the rest of the command, adding "in," thus creating the word "login." Charley at our end and Bill Duvall at the SRI end each had a telephone headset so they could communicate by voice as the message was being transmitted. At the UCLA end, we typed in the "l" and asked SRI "did you get the l?"; "got the l" came the voice reply. We typed in the "o," "did you get the o?," and received "got the o." UCLA then typed in the "g," asked "did you get the g?," at which point the system crashed! This was quite a beginning. So the very first message on the Internet was the prescient word "lo" (as in, "lo and behold!"). This, too, is regarded as a very significant moment in the Internet's history.

The only record of this event is an entry in our IMP log recording it as shown in Figure 3. Here we see that on October 29, 1969, at 10:30 pm, we at UCLA "Talked to SRI Host to Host."

In November and December the IMPs and hosts at UCSB and the University of Utah were connected, respectively, thus completing the initial four-node network. Further IMP deliveries were halted until we had an opportunity to test this four-node network, and test it we did. Among other things, we were able to confirm with measurements some of our theoretical models of network delay and throughput as presented by Gerry Cole [38].

The ARPANET had now been launched. We now turn to the story of its rollout through its first decade.

THE FIRST DECADE: FOUR NODES AND THEN THE WORLD

By the time the first four nodes were deployed in

December 1969, Roberts (who had succeeded Taylor in September to become the IPTO director) once again met with the NWG and urged them to extend their reach beyond what they had articulated in their first RFC [35], "Host Protocol." This led them to develop a symmetric Host-to-Host Protocol, the first implementation of which was called the Network Control Program (NCP) and was described by Crocker in RFC 36 in March 1970 [39]. This protocol stack was to reside in the host machines themselves and included a hierarchy of layered protocols to implement more complex protocols. As NCP began deployment, the network users could begin to develop applications. The NCP was the first protocol stack to run on the ARPANET, later to be succeeded by TCP/IP. The trajectory of protocol stack development touched on below is another example of multiple possible paths that led the way from the ARPANET as it evolved into the Internet.

After the short evaluation period following the initial four-node deployment, a continual succession of IMPs and networks were then added to the ARPANET. In May 1970, at the AFIPS Spring Joint Computer Conference, a landmark session was devoted to the presentation of five papers [40] regarding the newly emerging ARPANET technology; these papers were packaged into a special ARPA pamphlet that was widely circulated in the community and spread information of the then-current technology that had been deployed. (Two years later, in May 1972, another key session at the same conference was devoted to the presentation of five papers [41] that updated the ARPANET state of the art; this, too, was packaged into a second special ARPA pamphlet.) In mid-1970 the first cross-country link was added with a connection from UCLA to BBN, and by July the network contained 10 IMPs. The net grew to 15 IMPs by March 1971. In September 1971 BBN introduced a terminal interface processor (TIP) that conveniently would allow a terminal to connect directly to the ARPANET without the need to connect through an attached host. Later in the year, BBN slipped in a "minor" feature called electronic mail. Electronic mail had existed since the mid-1960s for standalone timeshared computer systems, but in late 1971 at BBN, Ray Tomlinson added a small patch to it that allowed the mail to pass between different computers attached to the ARPANET using an experimental filesharing network program called CPYNET. Once he saw that it worked, he sent an email message to his group at BBN announcing this new capability, and so "The first use of network email announced its own existence." [42]. This capability went out as a general TENEX release in early 1972. By July 1972, Roberts added a management utility to network email that allowed listing, selective reading, filing, forwarding, and replying to email messages. In less than a year email accounted for the majority of the network traffic. The network's ability to extend communication between people was becoming evident, a nascent image of Lick's vision.

The reaction of the computer manufacturers to this ARPANET phenomenon was to create proprietary network architectures based on their own brand of computers.

Later that year, in October 1972, the first public demonstration of the ARPANET technology took place at the International Conference on Computer Communications (ICCC) in Washington, DC. Kahn, who by now had been hired into ARPA by Roberts, organized this large and very successful demonstration in which dozens of terminals in Washington accessed dozens of host computers throughout the United States in a continuously reliable fashion for the three-day duration of the conference.

The reaction of the computer manufacturers to this ARPANET phenomenon was to create proprietary network architectures based on their own brand of computers.[16] The telephone company continued to ignore it, but the open network that was the ARPANET thrived.

Soon, additional networks were added to the ARPANET, the earliest of which were those whose origins came out of work on wireless networking. Connecting the ARPANET with these different networks proved to be a feasible but not seamless interoperability issue, and it received a great deal of attention. The interconnection of networks was referred to as "internetworking" during the 1970s, a neologism from which the expanded ARPANET was eventually renamed as the Internet.

Let us briefly trace the work on wireless networking that led to these additional networks, which themselves forced attention on improving interoperability solutions. As pointed out above, these networks were based on wireless multi-access communications in which a shared channel is accessed by many users. By late 1970, Norm Abramson had developed AlohaNet [43] in Hawaii, a 9600

In 1972 Roberts extended the ARPANET to Norway over a leased line that ARPA had already installed to receive seismic data and then extended it to London in the United Kingdom. This was the ARPANET's first international connection.

b/s packet radio net based on the novel "unslotted (pure) ALOHA" multi-access technique of random access. In this scheme (unsynchronized) terminals transmit their fixed length packets at any time over a shared channel at random times; if more than one transmission overlaps (i.e., collides), then destructive interference prevents any of the involved packets from succeeding. This tolerance of collisions was a departure from the more standard methods of wireline communications to control multi-access systems that used demand access methods (queueing, polling, etc., as mentioned earlier) and allowed only one transmission at a time (thus precluding such collisions). In 1973 Abramson calculated the capacity of the unslotted ALOHA system [44], which had a maximum efficiency of 18 percent, and in 1972 Roberts calculated the capacity of a synchronized version (i.e., slotted ALOHA) [45] whose capacity was doubled to 37 percent. However, these analyses ignored an essential issue with random access to shared channels: that they are fundamentally unstable, and some form of dynamic control was needed to stabilize them, for example, a backoff algorithm to control the way in which collided transmissions are retransmitted. This stability issue was first identified and addressed by Lam and myself [46, 47].

It is interesting to note that the ALOHA systems studies eventually led to an investigation of carrier sense multiple access (CSMA) as another wireless access method. CSMA itself led Robert Metcalfe to consider a variation called CSMA with collision detection (CSMA/CD), which was the basis for the original Ethernet development. Based on these concepts, Metcalfe and David Boggs implemented CSMA/CD on a coaxial cable network, which was up and running by November 1973. In sum, they created the Ethernet, which is today perhaps the world's most pervasive networking technology [48]. Ethernet is crucial to the story of NCP and TCP/IP, for researchers at Xerox PARC built on this technology in efforts to address the challenges of internetworking. Implemented in 1974 and published in 1975, the PARC Universal Packet (PUP) remained an internetwork architecture as late as 1979 [49]. PUP was one potential means through which to improve on NCP, although as we see below, that role was later taken on by TCP/IP. This is one of many stories that call out for more research into the histories and the individuals involved.

Let us now return to the story of the above-mentioned wireless technologies to help explain the motivation that led to TCP/IP (as different from that which motivated PUP). These technologies led to wireless networks that attached to the ARPANET, thereby exposing the nature of the problems of supporting connectivity among heterogeneous networks.

The first step was taken in December 1972, when an IMP in California used a satellite channel to connect to AlohaNet through an ALOHA host in Hawaii. Thus, the ARPANET, running the existing host-to-host Network Control Protocol, NCP, was now connected to a ground radio packet network, the AlohaNet. This was the first new network to connect to the ARPANET. AlohaNet had its own protocol and was working independent of ARPANET, yet a gateway provided internetwork connectivity between the two. In 1972 Roberts extended the ARPANET to Norway over a leased line that ARPA had already installed to receive seismic data and then extended it to London in the United Kingdom. This was the ARPANET's first international connection. In London Peter Kirstein then built a gateway to connect the ARPANET to a network built with another protocol between the U.K. universities. This was another case of different networks "internetworking," and as this function became an increasingly important focal point of ARPANET development, the network came to be known as the Internet to reflect this growth. NCP was now handling the network- to-network interconnection of AlohaNet and the U.K. university network, both of which were attached to the ARPANET. The problems resulting from interconnected heterogeneous networks were becoming clear, and included the network-to-network protocol conversion needed between any (and every) pair of networks that were interconnected. It was clear that the combinatorial complexity of this pairwise protocol conversion would present considerable problems as the number of attached networks scaled up. TCP/IP was soon to emerge as the response chosen to address these problems.

At DARPA[17] in early 1973, Kahn was the program manager responsible for, among other things, the ground packet radio network and the satellite packet radio network. He

It was around this time that pressure for supporting unreliable transport in TCP came from Cohen, now joined by John Shoch and Reed, and with involvement from Crocker and Bob Braden. That is, they advocated modifying TCP such that type 3 packet functionality would be supported alongside reliable data transport. Cohen convinced Jon Postel of this, and Postel added a further concern, addressing layer violations, stating "We are screwing up in our design of internet protocols by violating the principle of layering. Specifically we are trying to use TCP to do two things: serve as a host level end-to-end protocol, and to serve as an Internet packaging and routing protocol. These two things should be provided in a layered and modular way. I suggest that a new distinct internetwork protocol is needed, and that TCP be used strictly as a host level end to-end-protocol." [52] Postel then went on to describe how to break TCP into "two components: the hop-by-hop relaying of a message, and the end-to-end control of the conversation." A robust internetworking solution was no easy task, and today's TCP/IP was built with much experimentation on the ground laid by NCP.

Thus, there was a clear call to cleave TCP, splitting the function of network layer connectivity, which involved addressing and forwarding, from its transport-layer end-to -end connection establishment, which also involved flow control, quality of service, retransmission, and more. TCP Version 3 (1978) introduced the split into two components, but it was only in TCP Version 4 (1980, with an update in 1981) that we see a stable protocol running that separated out the Internet Protocol (IP) from TCP (which now stood for Transport Control Protocol) and was referred to as TCP/IP. This version has come to be known as IPv4. Along with the split into TCP and IP, the capability to support unreliable transport (i.e., type 3 packet functionality) was included. The formal name for this unreliable transport support was the User Datagram Protocol (UDP) [53].

In 1980 the U.S. Department of Defense (DoD) declared [54] the TCP/IP suite to be the standard for DoD. In January 1983, TCP/IP became the official standard [55] for the ARPANET; after a short grace period of a few months, no network was allowed to participate in the Internet if it did not comply with IPv4. Of course, Internet protocols never stop developing, and the 1998 upgrade to Version 6 dramatically extends the address space and introduces some significant security enhancements. It is still in the process of being deployed worldwide.

Meanwhile, as the 1970s rolled out, in addition to the ARPANET and TELENET, other packet networks were being designed across the globe in this period. Peter Kirstein, in his earlier paper [56] in this IEEE Communications Magazine History of Communications series, addresses much of the international work, especially the U.K. story (to which we refer the reader for more details). As a result of these national and international activities, an effort, spearheaded by Roberts, was put forth that resulted in the International Consultative Committee on Telephone and Telegraph (CCITT) Recommendation X.25. This agreed-upon protocol was based on virtual circuits — which was to be the CCITT's own equivalent of TCP — and was adopted in 1976 [57]. During this period, the Network Measurement Center (NMC) at UCLA was deeply involved in measuring, testing, stressing, and studying the ARPANET. Bill Naylor and I published a summary of the tools used by the NMC as well as details of a weeklong measurement and evaluation of the results in 1974 [58]. In 1976 I published the first book that described the ARPANET technology, including its analytical modeling,

"Of course, Internet protocols never stop developing, and the 1998 upgrade to Version 6 dramatically extends the address space and introduces some significant security enhancements."

design, architecture, deployment, and detailed measurements. A summary of the ARPANET principles and lessons learned appeared in a 1978 paper [59] after almost a full decade of experience with the use, experimentation, and measurement of packet networks; this paper was part of a special issue on packet communications which contains a number of key papers of that era [60]. One of the first measurements we made was to determine the throughput from UCLA to UCSB in the initial four-node network shown in Figure 2; note that there are two paths between these two nodes. Whereas only one path was tagged as active in the routing tables at any one time, we found that both paths were carrying traffic at the same time since queued traffic continued to feed one of the paths when the other path was tagged. Among the more spectacular phenomena we uncovered were a series of lockups, degradations, and traps in the early ARPANET technology, most of which were unintentional and produced unpredicted side effects. These measurements and experiments were invaluable in identifying and correcting design issues for the early ARPANET, and in developing a philosophy about flow control that continues to inform us today. Moreover, it provided us, as researchers, a wealth of information for improving our theoretical models and analysis for more general networks. In July 1975 responsibility for the ARPANET was given to DCA. This terminated the systematic measurement, modeling, and stress testing that the UCLA NMC had performed for almost six years, and was never again restored for the Internet.[18]

It is outside the scope of this column to address Internet histories beyond those of its early period as the ARPANET. Likewise, I have not done justice to the untold stories that abound, but I hope to have convinced the reader that many people contributed to its success. This early history of the Internet, the first decade of design and deployment of the ARPANET, laid foundations on which today's networks depend and continue to develop.

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ENDNOTES

1 Later that year on October 4, I experienced a widely shared feeling of surprise and embarrassment when the Soviet Union *launched Sputnik, the first artificial Earth satellite. In response,* President Eisenhower created ARPA on February 7, 1958 to regain and maintain U.S. technological leadership.

2 *Chapter 3 of my dissertation [16] elucidates this problem and the role of the Independence Assumption*.

3 One of the important advantages of using packets turned out to be that short messages would not get "trapped" behind long messages; I was able to show this gain in response time exactly.

4 Access to my simulation notes can be found at http://ucla.worldcat.org/title/leonard-kleinrocks-correspondence-course-and-research-notes-1961-1972/oclc/263164964?referer=brief_results

5 Defense Communications Agency, which was renamed in 1991 to be today's (2010) Defense Information Systems Agency — DISA.

6 This sharing of resources was the primary motivation for creating the ARPANET. Paul Baran developed a network design (described above) that would maintain communications — and specifically, Second Strike Capability — in the event of a nuclear attack by the USSR. His and my work served different aims. When ARPA began work on the ARPANET, my work was used for the reasons described herein. His application to military communications gave rise to the myth that the ARPANET was created to protect the United States in case of a nuclear attack. This is not to take away from Baran's accomplishments; indeed, by the time the ARPANET began in 1969, he had moved on to different projects, including the Institute for the Future (he stepped back into the ARPA foray in 1974-1975 to recommend that an early commercial version of the ARPANET be instituted beside the original research-driven network).

7 In sharp contrast to ARPA's enthusiasm for networking, in the early 1960s, when I introduced the ideas of packet-switched networks to what was then the world's largest networking company, AT&T, I met with narrow-minded and failed thinking, and was summarily dismissed by them. They commented that packet switching would not work, and even if it did, they wanted nothing to do with it. Baran had a similar reaction from AT&T.

8 A major challenge for such a network was that it would connect computers with incompatible hardware and software.

9 To assist with the topological design, Network Analysis Corporation (NAC), whose CEO was Howard Frank, was brought in as a contractor.

10 Among those involved in these first drafts were Frank Westervelt, Elmer Shapiro, Glen Culler, and myself.

11 Roberts also goes on to say that my dissertation was "critical to my standing up to them and betting it would work."

12 Key members of my UCLA team included a research team (Jerry Cole, Al Dobieski, Gary Fultz, Mario Gerla, Carl Hsu, Jack Zeigler), a software team (Vint Cerf, Steve Crocker, Gerard DeLoche, Charley Kline, Bill Naylor, Jon Postel), a hardware engineer (Mike Wingfield), and others.

13 Key members of Heart's team included Ben Barker, Bernie Cosell, Will Crowther, Robert Kahn, Severo Ornstein, Truett Thach, Dave Walden, and others.

14 The names of some of the other key individuals who participated early on in the NWG include Bob Braden, Vint Cerf, Danny Cohen, Bill Duvall, Michel Elie, Jack Feinler, Jon Postel, and Joyce Reynolds.

15 It is remarkable how effective the RFCs, the NWG and the IETF have served the network community. In spite of the fact that they are loosely structured and involve large numbers of outspoken professionals, they have been able to move forward on a number of critical Internet issues.

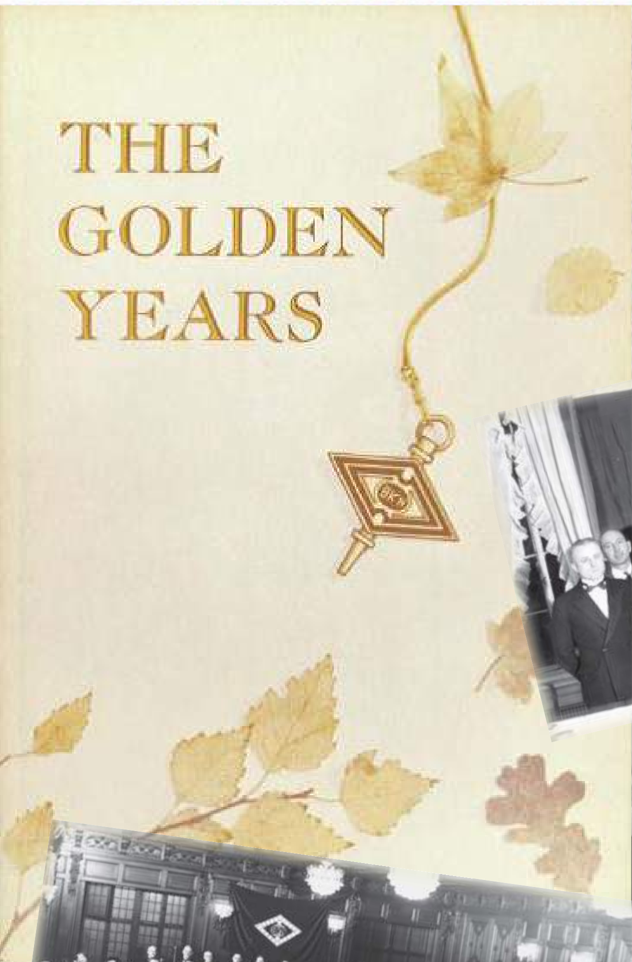
16 Among the proprietary networks were IBM's SNA and DEC's DECnet.

17 ARPA was renamed DARPA in March 1972 when the word "Defense" was prepended.

18 The work of the NMC required a strong degree of cooperation from BBN since it was they who controlled any changes to the network code and architecture. At the NMC, each time we discovered a lockup, hardware problem, or other measured network problem, we alerted BBN so that they would take corrective action. Over time we developed an efficient working relationship with them, and errors were dealt with more expeditiously. It is worthwhile noting that the history of packet networks has met with institutional impediments to its progress, as have so many other technical advances over the course of history. In this case I have called out three with which I was personally involved: AT&T's lack of interest in packet switching, the researchers' reluctance to connect to the early network, and the above-mentioned negotiation with BBN.

About the author

Leonard Kleinrock's contributions to the internet are well-documented. Over the span of his 50-year career at UCLA, he has graduated 48 PhD students and taught thousands more. He judges these **interactions and the research they have produced with him as his most gratifying and enriching activities. Outside of the** University, Kleinrock has co-founded a number of successful companies and enjoys biking, skiing, marathoning, karate and world travel. His webpage can be found at www.lk.cs.ucla.edu.



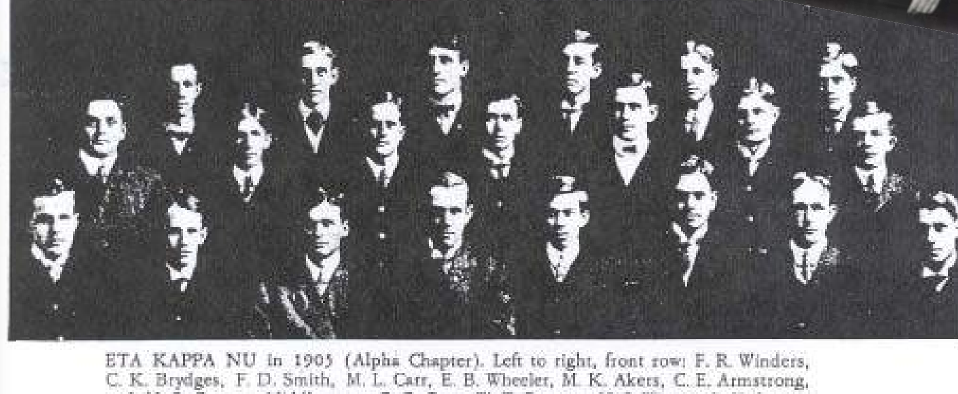
From the Shade of a Cottonwood Tree

HKN's Early Days

Dr. James B. Owens, President of I.E.E.E., delivering the Keynote Address at the Eta Kappa Nu Award Dinner in New York in honor of Outstanding Young Electrical Engineers.

Alton Zerby
Executive Secretary 1935-1958

The late Carl T. Koerner who was President in 1958, and his wife Edith Ann. Mrs. Koerner established the Carl T. Koerner Perpetual Memorial Trust from which substantial gifts are made to the Student Award Winners.



ETA KAPPA NU in 1905 (Alpha Chapter). Left to right, front row: F. R. Winders, C. K. Brydges, F. D. Smith, M. L. Carr, E. B. Wheeler, M. K. Akers, C. E. Armstrong, and H. S. Greene. Middle row: C. C. Carr, W. T. Burnett, H. J. Weaver, L. V. James, O. Wiemer, L. Moseman, and R. E. Bowser. In rear: L. F. Wooster, M. H. Brightman, H. D. Cornell, T. H. Amrine, G. W. Saathoff, and H. A. Bergert.

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Delta Omega	University of Hawaii at Manoa
Epsilon Beta	Arizona State University
Epsilon Omicron	University of Delaware
Gamma Mu	Texas A&M University
Gamma Rho	South Dakota State University
Gamma Theta	Missouri University of Science and Technology
Iota Gamma	University of California, Los Angeles
Kapp Psi	University of California, San Diego
Lambda Eta	Bharati Vidyapeeth's College of Engineering
Lambda Nu	University of Scranton
Mu	University of California, Berkeley
Nu	Iowa State University
Psi	University of Texas Austin
Rho	University of Colorado at Boulder
Sigma	Carnegie Mellon University
Zeta Beta	Texas A&M University, Kingsville

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Alpha	University of Illinois at Urbana-Champaign
Beta	Purdue University
Beta Kappa	Kansas State University
Beta Mu	Georgia Institute of Technology
Beta Tau	Northwestern University
Beta Theta	Massachusetts Institute of Technology
Delta Omega	University of Hawaii at Manoa
Epsilon Beta	Arizona State University
Epsilon Kappa	University of Miami
Epsilon Sigma	University of Florida
Gamma Chi	New Mexico State University
Gamma Mu	Texas A&M University
Gamma Rho	South Dakota State University
Gamma Theta	Missouri University of Science & Technology
Gamma Xi	University of Maryland, College Park
Iota Gamma	University of California, Los Angeles
Lambda Eta	Bharati Vidyaeeth's College of Engineering
Mu	University of California, Berkeley
Nu	Iowa State University
Psi	University of Texas at Austin
Sigma	Carnegie Mellon University
Theta Mu	Stony Brook University
Theta Tau	University of Michigan at Dearborn

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