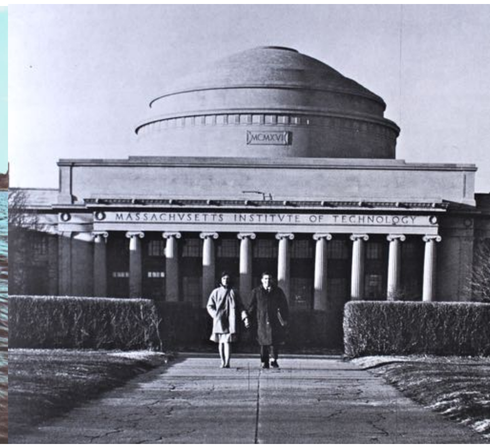
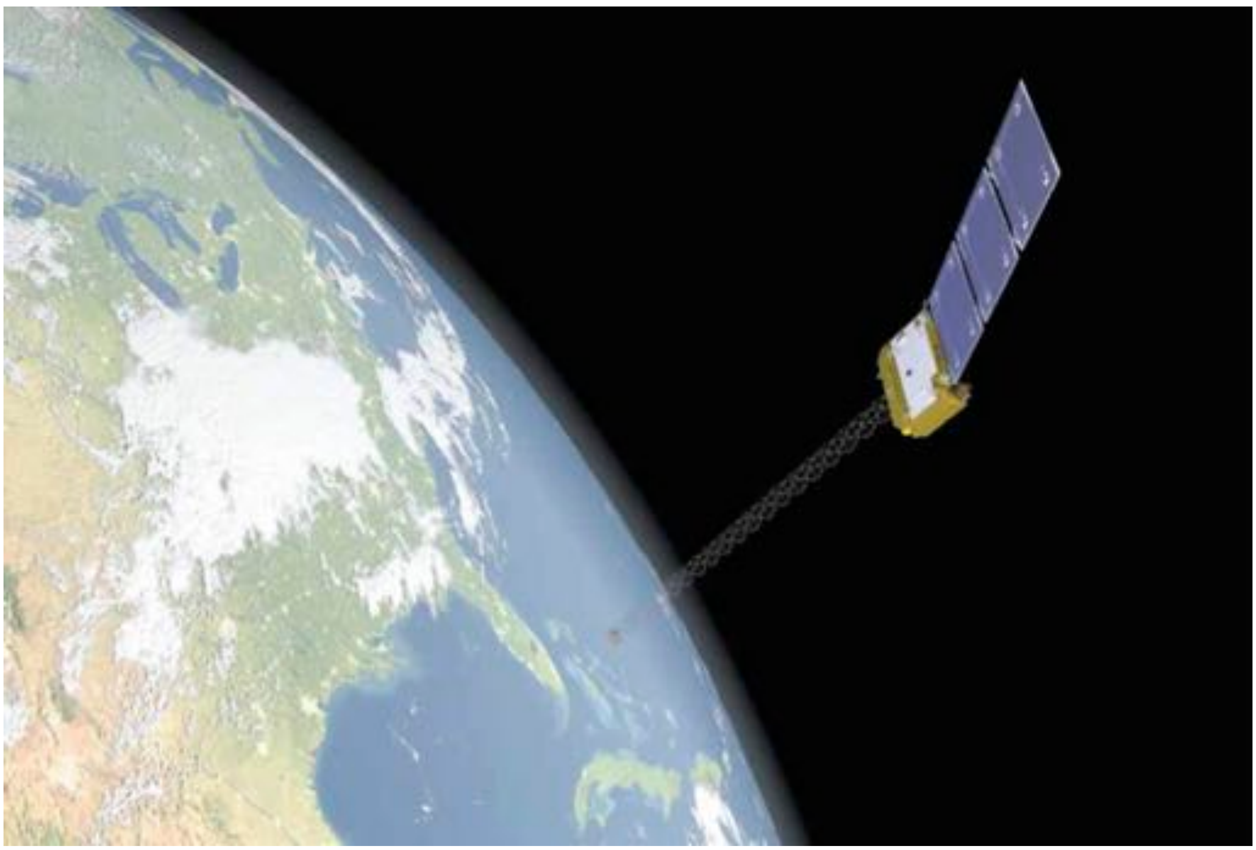



Then, Now, and Beyond



We were there 1960-2019

A book of essays about how the world has changed
written by members of the MIT Class of 1964

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Preface

"Then" is the late 50's early 60's. You took exams with your "slip stick" and often you could bring anything into an exam except another person. Telecommunications was often teletype and computer input was punched cards and tape. Computers were big and not very powerful – such as the IBM 709, 7090, 7094, TX-0, or PDP-1. You waited your turn for the main frame much as a supplicant to the gods. Then there was Project MAC (MIT Project on

Mathematics and Computation) which introduced timesharing – no not shares in a vacation home or jet.

"Now" is well NOW. Computers abound – they wait on our wanting to use them and applications get written with stuff you don't need to prove you need an update and a faster machine. More power in a tiny device than existed in a room full in 1964. Wi-Fi antennas abound. Calculators have solar cells in part because the batteries are more expensive than the electronics. The Internet has a lot of information including stuff about our undergraduate days, where we live, what we do, meetings we go to, etc. etc. Would George Orwell have recognized the "New privacy?"

And **"Beyond"** is well BEYOND. Its in the offing - much like what a landlubber sees when she stares toward the horizon and see the ships going to far off places. Its where predictions of the future don't necessarily come true. But hardly a reason not to predict.

Introduction

The members of the MIT Class of 1964, look at a 59-year period in time through a lens shaped by being brought together to experience "Tech is Hell" and then at graduation, with beaver rings turned around, being ejected into the world. The essays that make up this book are a blend of history and biography written by those who led, participated, and observed the unfolding events in many disciplines, not just science and engineering. Some are about professional life, others about hobbies and interests. Many also share their author's view of what the future might hold.

When we arrived in August of 1960 Dwight Eisenhower was President, the Cold War was still alive and well, the Soviet launch of Sputnik was still fresh in memory, and ROTC was popular on campus. MIT was a bit smaller than today – signs in Kendall Square (now enveloped in MIT) directed us to campus. International students were few, women (aka coeds) fewer and black students even fewer. Academic disciplines were more likely to live in their silos than be housed together, and many biology related disciplines were yet to emerge. Most freshman wanted to go into physics, but that changed. Lasers were new enough to be the subject of a demonstration in physics class. Computer programming was learned on our own to solve a billiard table problem. Computer time was something you stood in line for. $1,500 tuition was a bit lower than now – there was even a "$1,700 is too damn much" campus protest to a tuition increase ($14,426 in 2018 dollars).

While we were holed up at the Tute a number of major and less-major events took place with ripples into the 21st Century. The following selection is taken from a list prepared by Leon Kaatz for our class website.

1960 September to December

- USS Enterprise – the first nuclear powered aircraft carrier is launched
- Nikita Kruschev shoe pounding incident at the United Nations
- Discovery XVII shot into orbit
- John F. Kennedy elected President

1961

- Chimpanzee Ham completes one day flight in Mercury space capsule
- Leakeys unearth bones of earliest Australopithecus
- Yuri Gagarin becomes first man in space
- Alan Shephard becomes first US man in space with suborbital flight
- White mob attacks Integration Freedom Riders at Birmingham, Alabama bus station
- Great Britain applies to join European Common Market
- The Twist by Chubby Checkers is No. 1 on the pop charts
- James Davis becomes first American killed in the Viet Nam conflict

1962

- Decca, major British recording studio, rejects Beatles, convinced they would never make it on the music charts
- U.S. Rocket Ranger strays off path, misses Moon by 20,000 miles
- Cuba sentences Bay of Pigs invaders to 30 years in prison
- First live worldwide television show broadcasts with Telestar communications satellite
- House of Representative passes bill mandating equal pay regardless of sex
- World population exceeds 3 billion
- Maiden flight of Boeing 727
- Mariner 2 spacecraft sends close up photography of Venus

1963

- Viet Cong down 5 U.S. helicopters in the Mo Key Delta in Viet Nam
- France opposes entry of Great Britain in the European Common Market
- Robert Oppenheimer wins Fermi prize for research in nuclear energy
- Boston Celtics win 5th straight NBA title
- Dr. No, first James Bond movie, premieres
- Martin Luther King “I Have a Dream” speech at the Lincoln Memorial
- Los Angles Dodgers sweep New York Yankees in World Series
- President Kennedy assassinated

1964

- President Johnson pledges war against poverty
- Beatles arrive in America for Ed Sullivan Show appearance
- First US Gemini test flight orbits earth 3 times
- MIT Class of 1964 Receives their diplomas

Essay Authors Explore changes in a variety of areas:

- We’ve been to the moon and many of the planets; and sent objects out of the solar system.
- With on line researching, lawyers’ shelves full of law books are for show only.
- At MIT women now make up about half of undergraduates, but the percentage of women faculty in the School of Engineering still lags.
- Equal pay for equal work – disparities continue to exist.
- Freon boat horns have been replaced by a concern for global warming, at least in many circles.
- Global Positioning System (GPS) lets you know where you are with incredible precision, except perhaps for jamming and massive solar flares.
- Britain is now trying to exit from the European Union, which it joined in the 1960s.

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Arts and Culture

Left, Senior photograph being taken of one of the 22 woman, who along with 914 men, entered MIT in 1960, as part of the class of 1964. During the early 60s the total number of women (graduate and under graduate) increased significantly from a tiny base, reaching about 280 by 1964.

Below, 2010, graduates, including many women, moving towards the stage to receive their diplomas. The MIT Class of 2022 had 49% women and 50% men entering, quite a change in 58 years. In 2012, 45% of undergraduates were woman, 32% of graduate students, 22% of faculty, and only 18% of the science and engineering faculty. Still a way to go, especially remembering in 1964 the House of Representative passed a bill mandating equal pay regardless of sex.

Then and Now - Did our world get better? Maybe yes.

David Sheena

Period of Awareness

All of us have heard the story about the inventor of chess, who presented his gift to the King of India, and asked only for a grain of rice on the first square, two on the second, and doubled to complete the board. We all know the power of the exponent, but as anyone who has tried doubling at roulette, quickly discovers that what is initially manageable takes a sharp corner and escapes into the impossible. In the story of the rice, the king can manage a couple of rows of the chessboard's grains of rice, putting them into his equivalent of a truck, and then he is crushed.

I feel like the grain of rice, and time is the chessboard. At some point near the end of my undergraduate tenure, I heard the Dean of Engineering warn us that the half-life of an engineer is a mere five years. For my fellow engineers and me, who are fortunate to be able to commemorate our 55th milestone, we have passed this half-life mark more times than I care to know. I have felt the sharp curve of the exponential change in technology and history — and in the social order — speed past my ability to believe that I can even *try* to keep pace.

Our assignment for this essay was to look at our 59 years since we entered MIT. I want to stretch that. If I take what I call our "period of awareness" — that is the field of view of our personal experience of technological and historical events beginning with the stories and histories of our parents and grandparents till this day — that easily covers more than a century. And, in my particular case, the extent is even greater. I was born in Baghdad which was about 20 to 30 years behind the US, so my personal calipers encompass even earlier.

Then and Now-Personal Examples

So, I recollect from telegram to Instagram; science fiction (think Dick Tracy) wrist phone to real Apple watch; photographs to virtual reality; electronic circuits to genetic circuits; a reading machine at RLE that took up a full lab to your smartphone; IBM 7090 computer that we marveled at, as we passed by its whole wing in Building 26, to multiple computers in our pockets. Libraries that can no longer remain current with the volume and speed of information in the globe's knowledgebase; and access to marketplaces right in our hands. Unreachable stellar objects are no longer the stuff of science dreams and have had their distances conquered; and, landing to the moon is 50 years old this year; few or no photographs of our grandparents, to the entire recorded history of the life of children today, in living color and sound.

And, in my native Iraq, horse carriages were plentiful, and they were not for tourists. Even within the city, it was common to see a camel caravan arriving. Milk was delivered to our house via the cow itself, being milked as we watched. Now I would never recognize the place of my birth.

In all the history of humankind, knowing, let alone controlling, the sex of an unborn child was the domain of fortune tellers, and in the present, we talk of designer babies. In the span of our period of awareness, deadly Infectious diseases first became treatable, and then eradicated. And now we witness the irony that treatments are becoming ineffective and infections have become a grave danger again.

It is not only the technological change that is so overwhelming but the fact that we at MIT, the epicenter of change, were its witnesses.

Flattening the Technology Productivity Curve

Economist Robert Gordon in his book "The Rise and Fall of American Growth," says that we came of age at the flattening of the technology productivity curve and that the drastic change actually occurred at the time of our grandparents and great-grandparents, whom we might have known.

He gives the example that for hundreds of years, men lived with animal power, cooked on an open fire, and had no plumbing. He poses that this was still so in the America of 1870. If a man falls asleep in 1870 and wakes up in 1940; he is in a world that is transformed: the horse is a car, the cooking fire is a kitchen, the outdoor privy is now modern plumbing. There is a telephone, electric light, airplanes, skyscrapers, and a subway. And penicillin is about to come into use. Our sleeper would *not* recognize the world of 1940. But if he takes another nap through to 2019, he *would* understand the world. It is more refined and improved, but eminently recognizable; still cars, airplanes, skyscrapers, and bathrooms. The changes are incremental; only a microwave oven is new in the kitchen; same subway, cars, and skyscrapers. Computers and electronics are new, but still recognizable enough to a person from 1940 — all sourced from electricity and the gasoline engine. Productivity has slowed down in recent decades, and perhaps it is mostly personal convenience that has improved. It is, for example much easier for me to write this now, with all the tools literally at my fingertips.

Steve Hester, Time Travel - We have experienced so much; it is as close to time travel as we can get.

So, apparently I am wrong; the sharp curve of technology came in our grandparents' time and not in the time of our Class of 1964. We were born at the time that our sleeper first awoke. Our "period of awareness spans these two eras in a way that the class of 2019 would never fathom. Perhaps it felt that the historical changes were more drastic in *our* time because we were living them.

When I was in junior high school, we learned about the American Civil War, which was a century earlier. To all the students, it felt like *ancient* history, with no real visceral connection to the present. Now, students learn about World War II with the same last century lens, with no association to *their* present. What makes this remarkable is that we are at *both* ends of this timeline, born during WWII and now ready to see it pass into "ancient" history. Then, there were still living veterans of the civil war, and now, there are still living veterans of WWII.

Better Brake than Accelerator

When we were young, we were excited about change. As we matured, I for one, subscribed to historian Will Durant's view that progress is more secure with the brake than the accelerator. Change almost became overwhelming as it started to overload our albums of experiences. What was illegal and unacceptable became the law of the land and inverted the accepted norms, be it marijuana or gender identity. And what was acceptable then, is frowned upon now. From segregated facilities when we were young to having an African-American president. From women being secretaries at MIT to a woman president of MIT; from 25 women in our class to parity for women at MIT now, and women are seeking the presidency of the United States. The MIT song was changed in 1984 from "Arise! ye sons of MIT In loyal brotherhood," to "Arise all ye of MIT In loyal fellowship." All the schools around us with single genders have virtually disappeared. I remember one professor lecturing in 10-250, saying "Gentlemen…" eliciting an "Ahem" from the one female student. We remember that in MIT dormitories, female guests were permitted in the rooms (unusual at that time) until 10 PM; and now, coed dorms.

I try to put all this into the broader human perspective, and perhaps I can. In my school in Baghdad, children with disabilities — "challenges" is the gentler word now – were the objects of ridicule, even by enlightened teachers. I feel very gratified that we have a more caring world. There is more kindness in language and in how individuals with misfortunes and differences are viewed and treated with dignity. Science and caring human intermediaries try to repair or mitigate many of the miseries and pains of life's conditions. When we were born, Fascists were trying to *dispose* of such people.

Respect for the roles of women and minorities is an accepted norm of civil behavior. These wrongs used to be undertaken openly with no excuses needed. Now, they still occur, but the offending party still has to subscribe to the new accepted vocabulary and understanding.

It is not all good. MIT buildings and dorms were unlocked 24 hours a day. Sadly, not so today. Now, we are more apprehensive for our privacy, security, and identity. And, excesses in careful vocabularies and communication have diminished open dialogue.

Perhaps it is the massive amount of historical and social changes that swirl around in our country and our world that makes me dizzy. I knew my grandfather who was conscripted into the Ottoman army in World War I and later ran off to supply the British in southern Iraq. He and my father grew up in the shadow of Pax Britannica. We have grown up in the protection of Pax Americana. And now, we hear talk of Americana possibly being surpassed.

Umberto Boccioni, Dynamism of a Cyclist, 1913 - We are shown the speed of a cyclist or events locked into one frame, and the various movements of the individual and his mechanism are forced into a single two-dimensional glance. Perhaps our personal histories can appear this way.

The political changes we witnessed are close to unbelievable. We sat at MIT watching the nightly news reporting the kill numbers in Vietnam. And now Vietnam is a vacation destination. I used to read before coming to America about the brutality in Communist China, and today so much of our physical lives is manufactured in China. Most of our parents were born before there really was a communist Soviet Union, and its dissolution came before this year's graduates were born. I used to be able to identify countries on the map of the world and name their capitals; now, I would be lucky not to get a failing grade. Europe has been redrawn, to say nothing of post-colonial Africa.

We grew up under the cloud of the Cold War and remember the House Un-American Activities Committee. And now the enemy has evolved to insidious terrorists whom we cannot see or fight, and we live under a different dread. I used to be able to walk up to a plane, and take my son into the cockpit; that has been replaced by a massive cost in lost time for all the passengers, to say nothing of all the security expense.

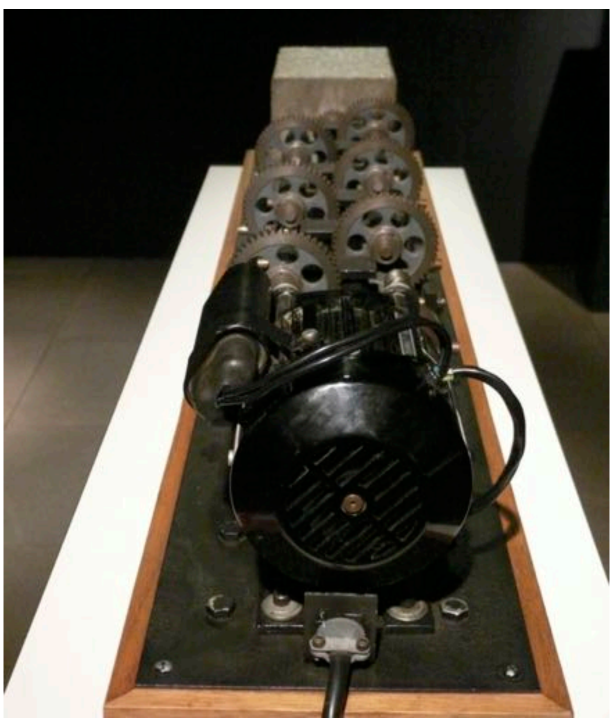
In our time, MIT provided the path for first and second-generation students to enter the American dream. Now the descendants of these students are seeking alternate career path, not necessarily at MIT, and more international students have replaced these original children of immigrants.

Closing Thoughts-Change is Good

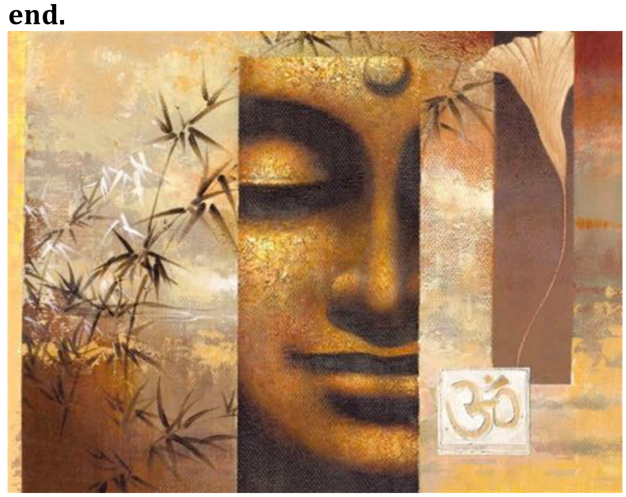
This exercise of jolting the memory is something that could be done by looking at some books and magazines, but the distinction is that we were literally the observers over this span of the time axis. I often see features in periodicals that look back at 50, 75, or 100 years ago, and I remember them or about them. Besides stirring up bittersweet nostalgia, is there a point to this trip along the rabbit holes of memory? Did the world change? Are things better or worse? Can we tell? My personal perspective tells me that there was fear in the Baghdad of my childhood. There was fear in America with the news of megaton nuclear bombs and the drills for them in school. Then all this dissipated and life felt good. Then we started to worry about terrorists, hijackings, school shootings. More so, poor distribution of wealth, polarization, and renewed racism and anti-Semitism leeching into our public discourse.

When we entered MIT, a look at the globe showed few democracies around the world, primarily the US and Canada in the western hemisphere, the nations of Western Europe and a few in Asia. I dared to hope that it was getting better. Harvard professor Steven Pinker, an astute observer of the human condition, makes a scientific and compelling case that it is. He shows, by the data, that life spans, safety, peace, health, sustenance, literacy, and yes the number of democracies, the world *is* getting better. For example, life expectancy is 70-80 years, whereas it was 30 for most of human history; child mortality has been brought down a hundredfold; famine no longer decimates populations. Peace which, throughout history used to be only an interlude between wars, is now a fortunate state. This progress, he demonstrates, is historical as well as recent. Families are defined differently; demographics are different, and the rules of behavior are different. What was acceptable and legal is now not necessarily so, and vice-versa. Heroes have become villains, and some villains have been rehabilitated. We have seen both the rise of religious fundamentalism and secularism at the same time.

We were born in the time when manual labor was still part of the engine of production, and now humans are working on their own replacement. Even though I find it hard to be comfortable with the speed of all this change — that may be mostly a matter of my getting older and preferring the brake over the accelerator — but I am happy that my historical optimism is justified.



Arthur Ganson, Machine with Concrete, 2009 - I saw this in Building 10, and it was later in the MIT Museum. The motor turning very quickly and yet the output shaft is embedded in concrete. Perhaps an allegory for how fast our time goes and how little we get at the end.



Wei Wing-Wu, Time for Reflections

We are unique as historical observers. Our" period of awareness" is perhaps the widest if measured by total change. We all had our particular observations tucked into thick portfolios of memories, and I would like to believe that we of MIT have contributed our share to the rise in human happiness. And, I wish us all the good fortune to experience it for many years to come.

David Sheena '64, Ph.D. '69. David was born in Baghdad, Iraq. He immigrated to America in 1955, as all the Jewish communities left the Middle East. After MIT, he worked on pupilometry and eye movement measurement technology for psychological and brain research. Having cut his teeth on General Radio equipment at MIT laboratories, David co-founded IET Labs which became heir to General Radio to design and manufacture calibration and test instruments, and where he still works. He is a columnist for a weekly newspaper. He is married to Marlene, and they have four children and eight grandchildren. Their oldest son Jonathan is having his 25thMIT reunion this year also. He co-founded a genetics company. David and Marlene are working hard to avoid obsolescence

It Was Different Then—Especially for Women

Lita Nelsen

Twenty-Two young women entered MIT as freshmen in 1960. The class size was limited, since there was no women's dorm on campus, and the very thought of a co-educational dormitory was shocking. The extreme selectivity for women undergraduates resulted in "All Women's Grade Point Average" exceeding "All Men's" for many years.

Considering Eliminating Woman's Admissions - 1956

A few years before we entered MIT, the faculty of the Institute seriously considered ending women's enrollment, even though MIT had been admitting women (in very small numbers) almost since its beginning (and the first female graduate, Ellen Swallow Richards, became an Instructor at the Institute). At the time that eliminating women's admission was proposed (1956), most of the Ivy universities along with most other private universities admitted only men, although some of the Ivies had sister school and some of their classes were coed. Fortunately, the women's alumnae group (now called AMITA) got wind of the faculty proposal and fought back successfully.

The Early 1960s

McCormick Hall opened in 1963 as a woman's dorm.

Seventeen of the freshman women were housed in 120 Bay State Road in Boston, a three-story town house now used as an annex for Beta Theta Pi fraternity. (Two others of the women were commuters, and three others were housed in a Boston college's women's dormitory.) It was a long, cold walk across the Harvard bridge in winter. Cheney Room, an endowed room for women in Building 3, just above the President's office, was a refuge from the weather and from an overwhelmingly male environment; a place to sleep when labs (or bridge games) were running late; and a place to form lifelong friendships with women from other classes.

Those were the days when women in other colleges had 10 pm curfews (a little later on weekends), so the easily-ignored curfews at "120" meant that MIT women were often the only ones left at late parties. After freshman year, most women lived off-campus in apartments, or in Bexley Hall (no curfews) if there was room. McCormick Hall (still strictly for women) was finished for our junior year, and some of the class moved in. Katherine Dexter McCormick (1904 grad) donated the funds for the hall, soon leading to a massive increase in women undergraduates. McCormick Hall has remained single sex to this day, in deference to Mrs. McCormick's wishes.

Outside forces were also very different. It was illegal in Massachusetts to provide birth control products to unmarried people, for example. Of course, men quickly identified the drug stores where a wink would get what was needed. And when the pill came along (Mrs. McCormick was a major donor to the Rock Clinic which did the major research leading to the pill), women passed around information as to which doctors would prescribe it without asking for a marriage license.

Within MIT, differences for women were both subtle and blatant. Women's rest rooms were notoriously scarce (although they were furnished with the same waxy paper that the men endured.) "Coed jokes" were rampant and some of the fraternity men who dated MIT women were subject to harassment by their brothers. Women in engineering were repeatedly told "You'll never get a job; why are you doing this?" although I found the faculty always supportive.

The outside world was not so kind. Although I had the highest grade point average in Course X at graduation, I was not elected to either Tau Beta Pi (the engineering honor society), nor to Pi Lambda Upsilon (chemistry honor society) because neither admitted women. And at the time, laws against discrimination in the workforce did not exist, so in job hunting, I was told "We don't hire women in engineering," or was asked "Will you be able to travel? Even with a man?". Where I finally landed, I was told "The last woman we hired didn't work out, but your academic record is good." They also told me that "We are paying you ONLY 10% under the male starting salaries."

Having been raised in the 40's and 50's, I had been taught to be ladylike, so I just smiled and said that such things didn't bother me. How times have changed!

Times Have Changed

And times have changed. When my daughter went to MIT, her class was 33% women, and she lived in a co-ed fraternity. If my granddaughter were to go (entering class of 2020), her class will be close to, if not above, 50% women. There are many more women's bathrooms, most of the dormitories and several of the fraternities are co-ed. The honor societies have reformed, there are many more women faculty members, and the opportunities for women at work have increased considerably, although still lagging at the highest levels. May the next half century continue the progress—both for women and minorities—with MIT helping to lead the way.

Lita Nelsen '64 Course 10, SM Chemical Engineering '66, SM Sloan Fellow '79. She spent her career first in chemical engineering/medical devices and then spent 30 years in the MIT Technology Licensing Office, 25 as director. She is married to Don Nelsen ('61, Course 6) and has two children: Katrina Nelsen Saba ('91 Course 9) and Dan Nelsen.

Coeducation at MIT

Robert M. Gray

Abstract

MIT was founded in 1861 and admitted its first woman as a "special student" in 1871, the first of a minuscule number of women to be admitted through the following century. In the 1950s, women made up 1 to 3% of the MIT student body, less than half that of 1897. In 1955, President James Killian asked Chancellor Julius Stratton to convene a committee to study the status of women students at MIT and make recommendations for the future. Over a year later, the committee chair Professor Leicester Hamilton wrote to the President recommending that MIT cease admitting women — at least at the undergraduate level. Killian rejected the recommendation and instead made a commitment to increasing the number of women students and improving their quality of life. This article is the story of the infamous Hamilton committee "report" and the sea change that began in the 1950s and 1960s and eventually led to women constituting roughly half of the undergraduate MIT population. Historical context of women at MIT is provided along with comments on persistent problems for women in academic engineering, especially in the areas of electrical engineering and computer science.

Introduction: Women at MIT

This photo of Harriet Fell, '64, from the MIT Museum archives was published in the March 14, 2014, issue of Science in a review by Maria Klawe of Girls Coming to Tech by Amy Sue Bix [30]. The photo caption reads "On the leading edge of a wave. The 25 women who entered MIT's class of 1964 matched the graduation rate of their 874 male classmates."

The pivotal nature of 1960 in the history of MIT had been noted over four decades earlier by MIT Professor Emily L. Wick in her "Proposal for a new policy for admission of women undergraduate students at MIT" [18]:

"Until the Institute could commit itself to educating women in significant numbers, and could provide suitable living conditions, coeds were not overly 'successful'. . . . Before 1960 women entered MIT at their own risk. If they succeeded — fine! If they failed — well, no one had ex-

> ***pected them to succeed. In 1960 the Institute committed itself to the education of women as well as men ...The class of 1964 entered in 1960 knowing that MIT believed in women students. It was the first class in which coeds, as a group, matched the proportion of B.S. degrees earned by their male classmates!" Emily L Wick [18]***

I first became interested in the history of coeducation at MIT in 2012 when Bob Popadic, then President of the MIT Class of '64 (and now Class Historian), decided to renovate the class Web pages for our 50th reunion and include pages on the history on specific living groups, sports, activities, and student organizations. I had written our original HTML crude Web pages years earlier, so he had me elected a Class Officer with a title of Class Webmaster. We tried to find members or participants to write the blurbs, but we often ended up writing pages on groups we wanted to be described, but for which we could not find volunteer authors. I took on the pages on the Association for Women Students, mostly because I am an amateur historian and because I had been actively involved in diversity issues during my academic years, especially with diversity (or lack thereof) of women faculty in engineering. In addition, early on I discovered the important role in the history played by Emily Wick, who was a neighbor in Rockport, where I was living as a seasonal trial run for imminent retirement and where she was a sailing legend. Her sailing days were long over, but at the time I occasionally met Emily at the Sandy Bay Yacht Club social functions and I crewed for her niece Laura Hallowell in sailboat races in Emily's Herreshoff-designed *Bullseye Beaver II*.

Two years of research on the Web (especially the historical Web pages of the Association of MIT Alumae (AMITA)), burrowing into the MIT Archives and Museum, and reading an excellent article by Amy Sue Bix [28] and Emily Wick's papers in the possession of Emily's niece resulted in the Class of '64 Web pages [2].

In 2017 I was invited to update the article and give a presentation on Coeducation at MIT for a lecture series on Title IX [3] organized by Brandeis Professor Anita Hill (who was then visiting at MIT) and MIT Professor Muriel Medard. In the process of preparing for the lecture, I discovered that many of stories I had reported in the Web pages based on secondary sources were apocryphal and that the actual history revealed in harder-to- find primary sources was deeper and richer, and on occasion still not completely known. That research resulted in a presentation at MIT in October 2017 [9]. That talk ended with my learning more stories from MIT alumnae from the late 1950s and early 1960s and receiving encouragement to continue my amateur historian's interest in the topic. In particular, I began a continuing email discussion (with occasional in-person conversations) with Susan L. Kannenberg, an alumna of my brother Peter's class of 1961, author of *100 Years of Women at MIT* (1973)[22], and long time member and activist in the Association of M.I.T. Alumnae (AMITA), an organization which through its various incarnations has played a key role in the story told here.

Another invitation led to further research and another talk in May 2018, this time at Stanford University with the support of the Stanford Vice Provost for Faculty Development and

Diversity, AMITA, and the MIT Alumni Association (MITAA) [10]. Over half of the 57 attendees at the talk were MIT alumnae.

I have long intended to write up the material in full prose instead of the telegraph language of lecture slides, and Bob Popadic's idea of a book telling stories by classmates with origins during our MIT time and implications through the present seemed an ideal excuse for the exercise. This article is the result of that effort based on the Class of '64 Web article, my talks, further conversations with alumnae, and further attempts to dig up still missing pieces of the story. The MIT Association for Women Students and its ancestors remains a common thread in the story, along with AMITA and its ancestors.

The basic story is not new, it is told in significant detail by Amy Sue Bix in [30]. But it is worthwhile to spread the story and too add several details and differing views that were not included in [30] and her earlier related articles. The story can be put into a more global context with the relevant stories of the struggle for coeducation at private elite universities in the Eastern U.S. and the U.K. In Nancy Weiss Malkiel's outstanding book *Keep the Damned Women Out: The Struggle for Coeducation* (2016)[16]. A basic irony is that MIT seriously considered ceasing to be coeducational a decade before the most famous Ivy League schools moved in the opposite direction.

Prologue — The 1870s through 1951

1861 MIT is founded in Boston, although it does not actually begin classes until 1865. William Barton Rogers becomes President in 1862.

1865 The Lowell Institute begins the Lowell Lectures at MIT with a gift of $250,000 in order to spread science information to the public [15]. The free evening courses are open to qualified candidates, both male and female, over the age of eighteen. The classes are organized by MIT and taught by MIT Professors, but the students are not recognized as MIT students and are not allowed to attend regular MIT classes and laboratories. The classes gain a strong reputation for practical lab work in chemistry and other areas, and give MIT an appearance of having women students.

1867 The possibility of admitting women to MIT arises for the first time when several women attending Professor Charles W. Eliot's course on chemical manipulation as part of the Lowell Free Lectures request to join regular daytime chemistry classes. While short excerpts of the exchange that follows have appeared in many books, it is insightful to quote the actual letters from *Life and Letters of William Barton Rogers: Edited by his Wife* (1896) [17] to detail the origins of coeducation at MIT and Rogers' role in both promoting and stalling the idea. The letters mention the Committee on Instruction, which was founded in 1864 to be responsible for "the supervision of the School of Industrial Science, both as to its organization and its business-affairs." [5] The School of Industrial Science was the original school within the Institute. President Rogers was the Chairman and the eight other members included Edward H. Atkinson — a founding officer of MIT and member of the Committee of Finance — and Nathaniel H. Thayer, Jr., a major donor to both MIT and Harvard. [17]

TO EDWARD ATKINSON, ESQ
. 58 PINCKNEY STREET, January 30.

DEAR SIR, — I believe that you are one of the Board of Instruction of the Institute of Technology, and in that capacity I want to ask a favour of you. The time of the "Lowell" class in chemical manipulation is drawing to a close, and some of the ladies of the class, who are very much interested in the subject, wish to go on with it. Will it be possible for them and me to join any class now formed in the Institute so as to continue our studies? If so, what would be the conditions as to terms and time? We hear that there is to be a meeting of the Board of Instruction this week. Could you bring the matter before them and so very much oblige,

Yours truly,
A. R. Curtis.

Atkinson forwarded the letter to President Rogers with the note

BOSTON, February 1, 1867.

DEAR SIR, The enclosed note speaks for itself. Can there be any objection to ladies entering as special students except possibly want of room in the laboratory?

Yours very truly,
EDWARD ATKINSON

A separate appeal was made to Committee member Nathaniel Thayer, Jr.

ANITA E. TYNG AND REBECCA K. SHEPARDTO N. THAYER, ESQ.
BOSTON, January 30, 1867.

DEAR SIR, — At our interview this evening we stated to you that four ladies, regular attendants of the present Lowell class in chemical manipulation, wish to continue the study of Chemistry in the Technological Institute.

Relying upon your kindly presenting our wishes before the meeting of the Committee of Instruction, we remain,
Very truly yours,
ANITA E. TYNG.
REBECCA K. SHEPARD.

President Rogers replies with the authorization of the Committee of Instruction:

TO N. THAYER, ESQ.
1 TEMPLE PLACE, BOSTON, February 4, 1867.

DEAR SIR, — In reply to the communication of Misses Tyng and Shepard, please say to them that the Faculty and the Committee of Instruction appreciate the earnestness with which they and their associate lady pupils in the laboratory are

> ***disposed to pursue their scientific studies and would gladly afford them such opportunities of systematic instruction as are compatible with the objects and plans of the Institute, but that we could not comply with their present request without seriously embarrassing the organization of the laboratory and other departments of the school as connected with the regular courses now in progress.***
>
> ***The plan of evening (including afternoon) instruction, forming a department distinct from the so-called regular courses of the school, has been incorporated into the general organization of the Institute for the purpose of enabling lady students, as well as gentlemen, to have the benefit of systematic scientific instruction under the conditions best suited to their convenience and advantage, and to the interests of the school at large.***
>
> ***This department of the Institute, embracing the Lowell free instruction as a part, will, it is hoped, be so organized in another year as to meet the wants of the ladies whom your correspondents represent, and I need hardly add that the Faculty and Committee will gladly welcome them to the classes thus organized.***
> ***I remain, yours truly,***
> ***WILLIAM B. ROGERS.***

It should be noted here that the second and archaic meaning of *embarrass* is given by the *Oxford Dictionary of English* as "hamper or impede (a person or action)" or "make difficult or intricate; complicate."

Although Rogers has promoted equal education for women in his speeches and writings, he is not yet willing to accept the concept further than allowing qualified women to take the evening Lowell Lectures.

The issue arises again with a letter from William P. Atkinson, Professor of English Language and Literature, to President Rogers:

> ***FROM PROFESSOR W. P. ATKINSON.***
> ***CAMBRIDGE, August 18, 1867.***
>
> ***. . . Application has come from one young woman, a rather remarkable teacher, who desires to avail herself of the Institute. I was sorry to have to reply that nothing was open to her save the Lowell courses. There is a large and increasing class of young women who are seeking for something more systematic in the way of a higher education. If we continue a special technical school, ours will not be the place for them; but if we should expand into a modern university, and I am confident there is room for one, by taking the bold step of opening our doors freely to both sexes I believe we should distance all competitors. It is a step sure to be taken somewhere. . . .***

Unfortunately, earlier in August President Rogers falls ill with pneumonia and poor health and Institute matters — including seeking permission from the Massachusetts Legislature to grant degrees for the impending first class to graduate — leave him little time to pursue the issue of coeducation.

1868 In October Rogers suffers an attack of hemiplegia or paralysis on one side of his body (left). His health rapidly deteriorates and he is granted a leave of absence in December. His friend John Daniel Runkle, Professor of Mathematics, takes over as interim president and becomes president in 1870 when Rogers resigns for reasons of poor health. Runkle serves as President until 1978, but regularly consults Rogers as he recovers his health and defers to him on major decisions. Rogers returns to the presidency on a temporary basis in 1878 and is again elected president in 1879 and serves through 1881. Thus it is President Runkle who receives the next application for MIT admission from a woman, this time not from a student in the Lowell Institute Free Lectures.

1870 In June Ellen Henrietta Swallow graduates from Vassar with an Bachelor of Arts degree in chemistry. During her search for employment she contacts Merrick and Gray (J.M. Merrick and Robert S. Gray, Analytical Chemists and Assayers, 50 Broad Street, Boston), requesting a position as apprentice. They reply that they are not in a position to take pupils, but that she might try to enter the Institute of Technology of Boston. On first glance this is a bizarre suggestion to give to a woman at a time when there are no women students at MIT [26], but an advertisement from the firm lists acting President Runkle as a reference, so the firm is well connected with MIT and doubtless aware of the Lowell evening chemistry classes. Regardless, Swallow writes to MIT asking if women can be admitted, giving as references two of her Vassar professors: astronomer Maria Mitchell — a personal friend of MIT President Runkle, and Professor C. A. Farrar, the head of the Department of Natural Sciences and Mathematics. The Faculty of the Institute of Technology formally receives her application on 3 December 1870, Ellen's twenty-eighth birthday, but it decides to "postpone the question of the admission of female students until the next meeting." On 10 December

> ***the question of the admission of Miss Swallow was resumed and after some discussion it was voted that the Faculty recommend to the Corporation the admission of Miss Swallow as a special student in Chemistry. [26]***

There was a catch, however, as the Faculty also

> ***Resolved That the Faculty are of the opinion that the admission of women as special students is as yet in the nature of an experiment, that each application should be acted on upon its own merits, and that no general action or change of the former policy of the Institute is at present expedient. [26]***

The Committee on Instruction agreed and on 14 December 1870 the *Records of the Meetings of the MIT Corporation* included a widely quoted statement: [1]

> ***It was voted to confirm the recommendation of the Committee on the School of Industrial Science that Miss Ellen H. Swallow be admitted as a Special Student in Chemistry — it being understood that her admission did not establish a precedent for the general admission of females.***

I heard the current President of AMITA read this quotation at the annual celebration at MIT of the birthday of Ellen Swallow Richards

President Runkle informed Swallow of the result, writing

> ***Dear Miss Swallow: The Secretary of the Institute, Dr. Kneeland, will notify you of the action of the corporation in your case at a meeting held this day. I congratulate you and every earnest woman upon the result. Can you come to Boston before many days and see me? I will say now that you shall have any and all advantage which the Institute has to offer without charge of any kind. I have the pleasure of knowing both Miss Mitchell and Mr. Farrar of Vassar. Hoping soon to have the pleasure of seeing you, I am***
> ***Faithfully yours,***
> ***J. D. RUNKLE,***
> ***President of the Institute***

Swallow later wrote that when she read that there would be no tuition,

> ***I thought it was out of the goodness of his heart because I was a poor girl with my way to make that he remitted the fee, but I learned later it was because he could say I was not a student, should any of the trustees or students make a fuss about my presence. Had I realized upon what basis I was taken, I would not have gone. [26]***

In other words, unless she succeeds, MIT can simply deny her existence.

1871 Ellen Swallow is the first woman admitted to MIT as an experiment as a "special student." As the only matriculated woman student, she is largely hidden and isolated as is her lab. The faculty votes to not include her in the list of students appearing in the annual catalog, but reconsiders the action at the last minute and lists her [15].

1873 Ellen Swallow is the first woman graduated from MIT (Bachelor of Science in Chemistry). She also submits a thesis to Vassar which results in a Master of Arts degree.

1875-76 Swallow marries MIT Professor Robert Richards, a member of MIT's first graduating class. She raises funds from the Women's Educational Association (WEA) of Boston (founded 1871) for women's facilities, including a reception room and a laboratory. The women's laboratory is opened in an "annex" (occasionally reported as a "garage") to the main MIT building in Boston with the goal of affording "every facility for the study of Chemical Analysis, of Industrial Chemistry, of Mineralogy, and of Chemistry as related to Vegetable and Animal Physiology."[4] MIT changes its admissions policy to admit "special students" for "advanced instruction in Chemistry . . . without distinction of sex."

1879 Women are given the privilege of being examined for a degree under the same conditions as men.

1882 The original women's lab is scheduled for demolition. When a chemical laboratory is approved for the new Walker Building, ESR writes:

The question of space in the new building for the suitable accommodation of women students has been weighing upon my mind for the last two or three weeks, and after consultation with General Walker, Miss Crocker, Miss Abby May, and Miss Florence Gushing, we have made ourselves a self-constituted committee to obtain subscriptions from women interested in the education of women toward a small sum, say eight or ten thousand dollars, which may be put into the hands of the corporation, in order that they may feel justified in including in the plans suitable toilet rooms in connection with each of the laboratories and a reception room somewhere in the building which shall be for their use only. If this can be done, the Institute can then say that it is in a condition to receive women. [26], p. 148

MIT decides to admit women as regular students (in chemistry only), so that the new chemistry laboratories will be for both men and women, but the funds raised with WEA will go to a women's bathroom and a parlor/reception room. It is unfortunately noteworthy that eighty years later students and staff will still complain in *The Tech* of having "to walk a mile to find a ladies room." When the old laboratories are torn down, ESR looses her duties as director of the women's chemistry lab. Her reduced workload does not last long as she is soon appointed as an Instructor, and she is also given the duties of a Dean of Women, without either the title or added compensation.

1884 The women's reception room is renamed the Margaret Cheney Reading Room after Margaret Cheney (1855–1884, '82), one of ESR's students. It provides an "oasis", "refuge", "haven" for women students.

The First Margaret Cheney Room, in the Walker Building

Photo from *MIT Technology Review* (1921), Vol. 23, p. 545. The portrait on the wall behind the couch is of ESR.

Over a century later the enduring nature of the Cheney Room and the MIT environment for women was emphasized when Emily Wick was quoted in the 9/1/2005 Technology Review: “Everybody came there, it was our place. The rest of MIT wasn’t too welcoming.”

1890 Eta Sigma Mu (HΣM) Society founded — the first club for MIT women students. It begins as a secret select social organization patterned on all-male fraternities, but it soon drops secrecy and actively recruits members, eventually inviting all women students to join. ESR is elected an honorary member. In 1895 the name was changed to *The Cleofan*, with its officers and members first published in the 1897 *Technique*. There was a strong overlap with the *Young Women at the Institute* list in same book, so the recruiting seems to have been successful and a few non-students were included in the club. The name *Cleofan* was a popular name for women’s clubs in the MidWest at the time.

The Cleofan would last into spring 1934, with regular Friday afternoon meetings and annual spring meetings. Three years later the Association of Women Students (AWS) would be founded explicitly as a revival of the Cleofan. Beginning around 1973 the name began appearing as a more inclusive Association for Women Students, and by 1990 the "for" dominated reports in *The Tech*. I have not yet found a specific date for the official name change.

1893 MIT Women in the Margaret Cheney Room

The Institute Committee, the undergraduate student governing body, is founded.

1897 Approximately 6.3% of the 1187 MIT undergraduates are women, a percentage not achieved again until 1969. [18].

Tech Alumnæ Association.

The first annual meeting of The Association of the Women of the Massachusetts Institute of Technology was held Saturday afternoon, December 29th in the Margaret Cheney room. The lunch tables were decorated with flowers sent in memory of Miss Marion Cheever. Mrs. Henry S. Pritchett, Mrs. William B. Rogers, Mrs. Edna D. Cheney, Miss Laura B. White and Miss Pike were the guests of honor.

Remarks were made by Mrs. Cheney, Miss White, Miss Pike, Dr. Elizabeth Pickford, Mrs. De Lancey, and Miss Forrest.

The Association was formed last June of the non-graduates or special students, and already numbers eighty members. It was decided to invite the seniors to each annual meeting and also to admit graduates to membership.

The following is the list of officers elected: President, Ellen H. Richards, '73; Vice-Presidents, Mabel W. Sawyer, '94, and C. Belle Kenney, '86; Recording Secretary, Nettie M. Willey, special; Corresponding Secretary, Sarah H. Bovesteele, '94; Treasurer, Isabel F. Hyams, special; Auditor, Matilda A. Fraser, '89; Executive Committee, Alice B. Tyler, Lillie M. Kendal, Mabel D. Clapp, together with the officers of the Association.

It was voted that each Saturday during the year a table should be set apart in the lunch room for the use of the Association.

***The Tech* 1/3/1901**

1900 The MIT Women's Association (MITWA) is founded "to promote greater fellowship among Institute women," specifically for alumnae. ESR fears that MITWA "will never be a success, because we have no dormitory life, no campus, and hence no college spirit" Nonetheless ESR is elected as the first president of MITWA.

1904 Katharine Dexter — a member of Cleofan — graduates (Biology) and marries Stanley McCormick — son of Cyrus McCormick. She will become a major supporter and fundraiser for MIT women — her endowment was valued at $51 million in 1997, then the largest from an individual donor. She also becomes a suffragist and the sponsor and the financial supporter of the development of the birth control pill.

1913 The Institute Committee becomes the Undergraduate Association with INSCOMM as its legislative and executive branch, with responsibility for approving student activities.

1913–14, MIT Technology Matrons is founded as a social service organization for wives of the professors and administrators. In 1975 the name changes to the MIT Women's League. In 1922 Technology Dames is formed for the wives of MIT students. In 1972 the name was changed to Technology Community Wives. In 1986 the organization opened to all women of the MIT community, married or not.

1916 MIT moves from Boston to Cambridge, approximately 1% of the students are women. The Margaret Cheney room moves with MIT.

1920 The New Margaret Cheney Room in Cambridge

1923 MIT appoints Florence Stiles ('23, Architecture) to an unofficial post as adviser to women students. She becomes Librarian of the Arthur Rotch Library of Architecture in 1931, President of MITWA in 1935, and official "advisor to women students" in 1939.

1934 5/5/34 *The Tech* mentions Cleofan activity for the last time. The only MIT organization specifically for women students vanishes from the MIT literature and it is three years before a new organization arises in its place, the MIT Association of Women Students (AWS).

Coeds To Meet Today In Attempt To Revive Dormant Sisterhood

Representation On Inst. Comm. Is Among The Aims Of Group

In an effort to revive Cleofan, a coed organization which thrived several years ago, the Technology coeds will have a meeting Tuesday afternoon at five o'clock in the Emma Rogers Room.

Coed leaders, who include representatives from the architectural students as well as from the science students on this side of the river, are hoping that the plan for the new society will be approved by the general meeting Tuesday. If the new move is adopted, the coeds will be organized in a unit for the first time in more than three years.

Aims of the new organization will include representation on the Institute Committee for the frailer engineers. Thus far, no coed has ever been elected to a seat on the undergraduate governing body. In addition the new society will run dances and other social events for the women students of the Institute and their guests.

This is one more instance of the coeds attempting to strengthen their position in Institute life, the last innovation was the coed fencing team.

Left, 1937 11/16 *The Tech*

Coed's Club Gains Institute Approval

Association Will Try To Obtain Suitable Housing For Girl Students

Elections for officers were held by the newly-formed Association of Women Students at M. I. T. at the last meeting of the club. At the same time the constitution of the club was voted on and accepted.

Officers for the coming term are: Margaret Whitcomb, '39, Pres.; Frances Emery, '40, Vice-Pres.; Ida Rovno, '39, Treas.; Edith Cameron, '40, Sec'y; Phyllis Winter, '42, and Janet Norris, '42, Representative at large.

The club was organized in an effort to have the coeds in the Institute become more closely associated with one another, and to solve mutual problems more quickly and easily through the cooperation of all the women students. The most important problem now facing the Association is the investigation of the matter of co-operative housing for the coeds.

It is hoped that a satisfactory house can be found soon which will be able to accommodate the entire coed group. If such plans mature, the proposed house will be more in the nature of a Girl's dormitory and will not associate itself with any national sorority.

1938 Association of Women Students founded. Constitution approved by INSCOMM (2/11 *The Tech*)

2/15 *The Tech*, Announced in the MIT Handbook

The new AWS Vice President Frances Emery '39 is listed in Bever (1976) [?] as Frances Glenn Emery Wypler, '39.

1945 Margaret Compton, wife of MIT President Karl Taylor Compton, works with MITWA, Technology Matrons, and Florence Stiles to establish the first MIT Women's Dormitory at 120 Bay State Road in Boston — over 1.2 miles from the MIT campus. It provides 14 beds (later 20) and is supervised by a Women's Advisory Board, not the Dean of Students as are all other student living groups. The original Advisory Board is chaired by the wife of the MIT President Karl T. Compton and has one faculty wife — Mrs. Leicester F. (Alma) Hamilton — along with four alumnae and one student. Florence Styles was an ex-officio member. Mrs. Margaret Alvord is appointed as Housemother or Dorm Supervisor, a position she will hold until her retirement in October 1957. Unfortunately with the number of alumnae on the Advisory Board will decrease and be replaced by members of the Matrons (faculty wives). Stiles states that the dormitory should help improve the esprit de corps of the women students, and hence the graduation rate — women performed well in class in comparison with men, but only 1 in 20 typically graduated.

1946 Emily Lippencott Wick comes to MIT as a PhD student in chemistry from Mount Holyoke, where she received her BA in chemistry in 1943 and her MA organic chemistry in 1945. Emily Chooses MIT because it has a good chemistry department, her Dad is an alumnus, and it is near Rockport on Cape Ann, where her family had spent many happy summers. She lives part time at 120 Bay State Road.

1948 Dorothy (Dotty) Leaman Bowe begins work as a secretary to Professor F.H. Norton in the Metallurgy Department. She quickly expands her acquaintances beyond her Department to include students, faculty, and President Compton. Dotty advises students, coaches for exam preparation, connects students with faculty having similar interests, and becomes familiar with the problems facing women students and becomes an advocate. At the time, women students were often ignored or harassed by some faculty, staff, teaching assistants, and male students, both in person and in print.

The Hamilton Committee: 1950s

1951 E. Francis (Frank) Bowditch moves from a position as Headmaster at the Lake Forest Academy in Lake Forest, Illinois, to MIT as the new Dean of Students at the invitation of President Killian. Bowditch replaces Dean Everett Moore Baker, who died in August 1950. The MIT dormitory Baker House was named after Dean Baker. On 31 July 1951 he sends a memorandum to parents of newly admitted students, which begins

> ***As your son becomes a member of the M.I.T. community in September as a member of the Freshman Class, I sincerely hope you will feel yourselves also welcomed as a very real part of your son's experience here. This offices wishes to serve you and your sons in every way possible.***

The letter continues with the assumption that all new students are sons rather than daughters, yet Bowditch will have a critical role to play in the imminent expansion of the women's program at MIT.

In August Bowditch writes Killian that he has talked with Dr. Hardy about "taking care of women students." Dr. Harriet L. Hardy was a physician with the MIT Occupational Medical Service, and Bowditch describes how Dean Baker had talked with her

> ***about working with women students, it was his concept that she should serve primarily as medical consultant and adviser and not act in the role of dean of women students. She has performed in this capacity but has not gone much further, primarily because of a limitation of time. ... I believe we were both in agreement that it might be a good idea to ask my wife, Anna, to serve unofficially as dean of women students, at least the undergraduates, for this year until we could better feel the situation and make recommendations for next year.***

The bizarre suggestion of considering marriage to a faculty member as sufficient qualifications for an unofficial "dean of women" is unfortunately somewhat typical of the approach of MIT at the time of designating responsibility for the women's program to unqualified, unpaid, and effectively powerless individuals. Happily this would soon be rectified the appointment of a paid and qualified — but still largely powerless — staff member, Miss Ruth L. Bean, as an Assistant Dean of Students with specific responsibilities for the women's program. Killian accepted the proposal in a reply on 13 August 1951, in which he went on to inform Bowditch about the existence of the Advisory Board for the Women Students House and named the members, including Mrs. Hamilton as Chair, three members of the Technology Matrons, and two members of MITWA along with ex officio members — the wives of the Chairman of the Corporation, the President, and the Dean of Students. Killian mentioned the existence of problems with regard to the management of the house and that Bowditch might have heard something about them from Mrs. Hamilton.

Emily receives a PhD in Chemistry at MIT and becomes a Research Associate at MIT, then later goes to work at Arthur D. Little.

1952 The seeds of the Hamilton Committee are sown in an often quoted 24 April 1952 memorandum from Bowditch to Killian and Stratton, with copies to Fred Fassett, Mrs Hamilton, and a few others. It reads

> ***As you know, consideration has been given lately to closing the Women's Dormitory and moving the girls to the campus. At a meeting this week, attended by Mr. Snyder, Mr. Kimball, Mr. Fassett and myself, it was unanimously agreed that any such action should be postponed for a year and that we should recommend to you that immediate steps be taken to study carefully the whole question of the place of women students, particularly undergraduates, at M.I.T.***
>
> ***The present Women's Dormitory is inadequate in size (17 girls) and is too far from the Institute. It is the opinion of many that the place, program, and activities of women students has not been adequately worked out and that, in reality, we face one of two alternatives: eliminate women students, at least undergraduates; or decide we really want women students, plan an adequate set-up, and then deliberately go out and get more good girls. Everyone seems to incline to the latter view.***
>
> ***Dean Fassett is currently gathering data on the history of women students at the Institute, their numbers, records, etc.***

Dean Fassett is Associate Dean of Students Frederick G. Fassett, Jr., who is responsible for student residence and later in 1956 will become Dean of Residence. I well remember his erudite presence at the Inter Fraternity Council meetings where he would often provide quotations in Latin that were lost on me. On 21 May 1952 Dean Fassett sends a memorandum to Chancellor Stratton reporting on a dinner hosted by him and his wife Julie for several residents of the Women's Dorm at 120 Bay State which includes a concise statement of the problems at 120 Bay State Rd:

> ***I think there is little question that the Women's Dormitory presents a fairly serious problem. It appears clear that the girls who live there want their dormitory to be taken into the regular residential system of the Institute. That is to say, they with its administration and supervision to be centered in the office of the Dean of Students. This desire presents possible difficulties in view of the fact that the dormitory has been and is the principal concern of a group of faculty and administrative ladies who constitute and Advisory Council. My impression is that it is possible that the zest with which the Advisory Council worked earlier may have***

> ***worn off a bit, that the relationship between the council and the dormitory may perhaps have become routinized. A second basis of serious criticism appears to be the attitude of the house mother, Mrs. Alvord, toward her responsibilities. On this matter the girls spoke with considerable vehemence, although they were courteous about it. I am of the impression that the post has come to be regarded by its occupant as somewhat a sinecure.***

Dean Fassett also reports that the women express the desire that ultimately the women should have a larger dormitory on the Cambridge side of the river, suggesting that it should house at least 100–200 women.

In a December memorandum to All Women Students at MIT, Dean Bowditch announces the approval of

> ***the appointment of Miss Ruth L. Bean as Assistant to the Dean of Students. In this position, Miss Bean will have two functions: 1) To administer the Freshman Advisory Council and 2) To serve as Dean for all women students. Thus women at the Institute will be directly represented in the administrative organization of M.I.T. for the first time.***

Although Miss Bean will "serve as Dean" and be referred to as "Dean Ruth Bean" in internal and external publications, in fact she will be an Assistant Dean, a member of the staff and not a member of the faculty and hence her impact will be limited. At least it is an official and paid position. An Associate Dean who is a faculty member and has genuine authority will not be appointed for over a decade, and she will be an outsider with no experience with women engineering and science majors. Bean, a graduate of Simmons College, does bring a strong administrative experience and will prove to be a strong advocate for the women's program during her time at MIT.

Dean Bowditch concludes his memorandum with a list of issues needing attention including the demand for dormitories on the Cambridge side of the river and housing for a larger number of women students, athletic programs for women, better communications regarding scholarships and financial aid, and improvements in the Margaret Cheney Room.

1953 MITWA begins a survey of alumnae showing a strong success rate; 93% were employed and active in their specialized fields [?].

1954 On 6 January Dean Bowditch sends a memorandum to President Killian to renew and reinforce his request for a study of the women's program and the need to choose between two alternatives. He writes

> ***It has become increasingly apparent since I have been at the Institute that there was need for a complete objective study of the place of women students at the Institute. Since Miss Bean joined the Dean's Office she has had the opportunity to get to know a great many of the women students currently enrolled and to have a first hand feel of many of the problems which we face in connection with women students.***

> ***The Women's Advisory Board for the women's dormitory is so constituted that actually there is only one active person left on the committee and she is slated to retire at the end of this academic year. It therefore seems particularly appropriate we take some steps at the present time to make as comprehensive a study as possible.***
>
> ***Miss Bean and I would therefore like to recommend that you appoint the following ad hoc committee, charge them to make a study of the place of women students at the Institute, and to report to you their recommendations for a long range program.***
>
> ***Mrs. L.F. Hamilton***
> ***Mrs. Nathaniel Sage***
> ***Mrs. Elspeth Rostow***
> ***Mrs. Lockhart B. Rogers***
> ***Mrs. Alfred R. Wypler, Jr.***
> ***Dean Ruth L. Bean***
> ***Prof. John T. Rule, Chairman***

Because this committee plays a central role in his history and in the development of the women's program at MIT, its proposed members merit some introduction. The proposed Chairman is Professor John T. Rule '21 is the Head of the Section on Graphics and Head of Course IX, General Science, General Engineering and Science Teaching. He had served as Chair of the MIT Student-Faculty Committee and as a member of the Undergraduate Policy Committee. In 1956 he will replace Bowditch as Dean of Students. Alma Hamilton (Mrs. Professor L.F. Hamilton) had long served on the Women's Advisory Committee of the Women's Dormitory. Mrs. Nathaniel Sage is Dorothy Blair Sage, the wife of MIT Geology Professor Nathaniel McLean Sage Jr. Mrs. Alfred R. Wypler, Jr. ne Frances Glen Emery is an MIT alumna in architecture, class of 1939 (Course IV). As mentioned earlier, she was elected Vice President of AWS in 1934. Her husband worked for Liberty Mutual Insurance Co. and was not associated with MIT. She was active in AMITA leadership and would have made an excellent member of the committee. Mrs. Elspeth Rostow is an MIT Assistant Professor of History (in 1952 she became the first woman professor at MIT) as well as Mrs Professor W.W. Rostow. She is the only woman faculty member proposed, but she is not an MIT alumna. Mrs. Lockhart B. Rogers is the wife of MIT Chemistry Professor Lockhart B. Rogers. Dean Ruth L. Bean is the Assistant Dean of Student Affairs, but neither a faculty member nor alumna of MIT.

The proposed committee consists mostly of faculty wives (Hamilton, Sage, Rostow, Rogers), of whom one is also an Assistant Professor in humanities and another has experience with the Women's Advisory Committee and the Technology Matrons. None of these proposed committee members is clearly qualified to have the education, training, and experience to make useful contributions to a committee charged to study all aspects of the place of women at MIT. Only one member, Wypler, is an MIT alumna. Dean Bean is clearly experienced, but she is only a staff person without the clout of a faculty member and she is not an MIT alumna. Professor Rule is well qualified and an influential figure at MIT. In 1956 he will replace Bowditch as Dean of Students. Strangely, however, he will not be appointed to the committee.

The Memorandum goes on, recommending that the committee be kept small and listing several names that could be added as possible consultants to the committee. Five of the candidates listed are faculty wives (including the wives of the President and Chair of the Corporation, who is an ardent supporter of the women's program) along with three deans, including Bowditch.

On 9 March President Killian sends a confidential memo to Pietro Belluschi, the Dean of the MIT School of Architecture and Planning, suggesting that his long range campus planning include consideration for meeting the housing need for women students with an entire dormitory adjacent to the President's House, possibly including other women's activities including the Technology Matrons and Technology Dames along with the Emma Rogers, Alice Maclaurin, and Margaret Cheney rooms. The memo is copied to Provost Stratton, Dean Bowditch, and Dean Fassett.

President Killian reacts to Bowditch's memo, writing to Provost Stratton on 18 March:

> ***Frank Bowditch some time ago proposed the appointment of an ad hoc committee to make a study of the place of women students at the Institute and to make recommendations for a long-range program. I enclose a memorandum which he wrote to me about this.***
>
> ***I have talked with him subsequently with the thought that we could best approach this problem through discussions in a group wholly within the Institute, and I ventured the suggestion that you might be willing to bring together a group of representative officers and faculty members to discuss this problem and to provide a background for us to reach some administrative conclusions. The appointment of a committee including alumnae and wives seemed to me to pose difficulties for it would be a committee not to answer many questions about what the Institute can and cannot do. . . .***

Killian's recommendation against faculty wives seems reasonable, the proscription against alumnae is not — they are the ones most intimately aware of the fundamental problems.

1955 In January Chancellor Stratton appoints a committee:

> ***Professor Leicester F. Hamilton '14 (Chair)***
> ***Assistant Dean of Students Ruth L. Bean***
> ***Suzanne Z. Deutsch, Technology Matron's representative on Women's Advisory Board (Mrs. Professor Martin Deutsch)***
> ***Assistant Professor of History Elspeth Davies Rostow (Barnard '38, MA Radcliff '39, Mrs. Professor W.W. Rostow)***
> ***Associate Prof. Kenneth R. Wadleigh '43***

Professor Hamilton, the Chair, has no apparent qualifications for the committee other than he is a faculty member and his wife has volunteered for years for the Matrons and as a member of the Women's Advisory Committee. The committee includes Dean Bean and Professor Rostow as recommended by Bowditch. Deutch's sole qualification seems to be that she is a faculty wife and member of the Women's Advisory Board for the Women's dormitory, most of whom are faculty wives. Stratton's invitation letters to Mrs. Deutch, Professor Rostow, and Dean Bean states that Hamilton had requested that each be invited to be a member. Wadleigh is a faculty member and years later will become Dean of Students. As recommended by Killian, there are no alumnae members. In hindsight, the committee seems ill constituted to accomplish its assigned goals. As will be seen, it fails rather spectacularly to do so. But it is likely not their fault, there is no record that the committee ever actually met.

In April Katherine Hazen '28, the President of MITWA submits the results of the alumnae survey begun in 1953 to Provost Stratton. Over 70% of the living women graduates and 30% of the special students up to 1952 had responded.

Then Vice President and Provost Stratton responds to Hazen:

> ***The survey of former women students comes at a most appropriate time, and it will indeed prove of value.***
>
> ***As I am sure you are aware, the Institute recognizes the need of a new assessment of the place of women students in this academic community, and wishes to make sure that it is meeting its obligations. This has led to the establishment a few months ago of Professor Hamilton's study committee, and your survey will clearly be of great assistance. Stratton to Hazen, 4/14/1955***

The next day Stratton sent a copy of the report to Hamilton, but unfortunately sub- sequent evidence suggests that the Hamilton committee never saw the extensive MITWA survey nor did Hamilton ever mention it or its conclusions in his later "report."

> ***Women students***
>
> ***For some time this office has felt the need of an extensive study of the place of women students at the Institute and for a closer integration of women students into the whole educational program for undergraduates. The special committee appointed by the provost and chaired by Professor Leicester F. Hamilton is now at work, and its recommendations should contribute immeasurably to the general welfare of women students.***
> ***from 1955 President's Report***

Unfortunately President Killian's hopes prove overly optimistic.

1956 John Rule replaces Bowditch as Dean of Students. Strong sentiments against admitting women undergraduates continue to be expressed in publications, classrooms, rumors, letters, and meeetings. Common arguments are the heavy attrition and poor graduation

rate of women students and that "women's education should be left to 'specialists in the field' such as Wellesley and Mount Holyoke" and Radcliffe and Smith, . . .
The Harvard Crimson chimes in:

> ***Coeds, Even***
> ***Few people are aware that M.I.T. is a coeducational institution. Indeed, to Most Harvard students, the idea of a feminine mind concerning itself with electro-chemical engineering or mining and metallurgy seems somewhat revolting.***
> ***from March 2, 1956 Harvard Crimson***

6/21/1956 Margaret Alvord, the Housemother of 120 Bay State Rd, writes to Hamilton, arguing that the women students would receive "a more rounded education under more normal conditions in any of a number of good colleges ...Then if they still are serious about it, they could come to M.I.T. as graduate students." Alvord then asserts that ". . . if, as Dr. Killian asserts in his annual report, we are committed to produce as many active scientists as possible and to maintain the standards of excellence expected of us, then there is little in the records of the girls who have lived in the dormitory in the past ten years to justify their continuance in the undergraduate school." Years later she explains in a 1970 letter to Emily commenting on Emily's 1970 report [18] on women students at MIT:

> ***While I was still at 120 orders came around I suppose from Killian, for us to take a stand on should we or should we not continue to have girls — and I found myself in distinguished company — Elspeth Rostow, Dr Herbert Harris and I opposing undergraduate coeds. We drew such immature lulus now and then that I felt a girl could get her undergrad work or at least 1st or 2 years just as well at Wellesley or Holyoke.***

It should be noted for context that complaints were made to Dean Bowditch regarding Alvord's lack of support for and interest in residents of the Bay State Rd women's dormitory. See also Dean Fassett's memorandum of 1952 to Chancellor Stratton. It is notable that Alvord years after the Hamilton Committee counts Elspeth Rostow among those who opposed the admission of women as undergraduates, yet she was appointed to the Hamilton Committee to help produce a recommendation. She also mentions Dr Herbert Harris. Herbert I. Harris, MD, MIT medical director and psychiatrist wrote the most extreme negative letter in the Archives on the issue of admitting women as undergraduates. In his 7/31/56 letter to Hamilton he wrote:

> ***. . . The business of raising a family takes from five to fourteen years at a minimum. During this time, had a male student had her place, he could have been contributing profitably in his professional capacity. At this time, when there is such a shortage of engineers, one wonders if we are justified in taking positions away from male students for female . . . With so much conflict at an emotional level, it becomes plain that their intellectual efficiency must almost inevitably become impaired . . . I think that the presence of women students in the student body has a definite leavening effect and their presence is almost universally welcomed, I believe, by the faculty and the student body. My concern is for their***

> ***own welfare, however, and not for the pleasure and ornamentation they can contribute to MIT.***

Harris' letter strikes me as poisonous, condescending, arrogant, and misogynous. Alvord's "distinguished company" seems anything but.

Arguments against continuing coeducation are countered by referral to the MITWA alumnae survey of 53–55 [1] and by AWS and others with statistics of successful careers by women MIT graduates in research, teaching, medicine, law, business, and government. Many observe that the graduation and attrition rates would improve if the resources were provided to improve the academic and personal environment for women students. But these points are not mentioned in the archived files relating to the Hamilton committee, only the invited, negative comments directly to Hamilton are included, and one suspects that the so-called report ignores them.

On 18 September 1956 *The Tech* announces that during the summer John T. Rule, Professor of Engineering Graphics and MIT Class of 1921, was made Dean of Students and Mr. E. Francis Bowditch has been appointed as a special advisor to President Killian.

President Killian eventually gets impatient with the lack of any apparent action and prods Stratton to prod the Committee. Stratton writes to Hamilton

> ***There is now a very strong feeling expressed by the President and by Jack Rule that we must come to grips with the problem of women students, and arrive at some early decisions . . . Even though your report may be still incomplete, may I not have whatever is ready . . . I should particularly like to have an expression of the views of the several members of your Committee on what course the Institute should follow. It is not all necessary that these should be unanimous. 10/17/56***

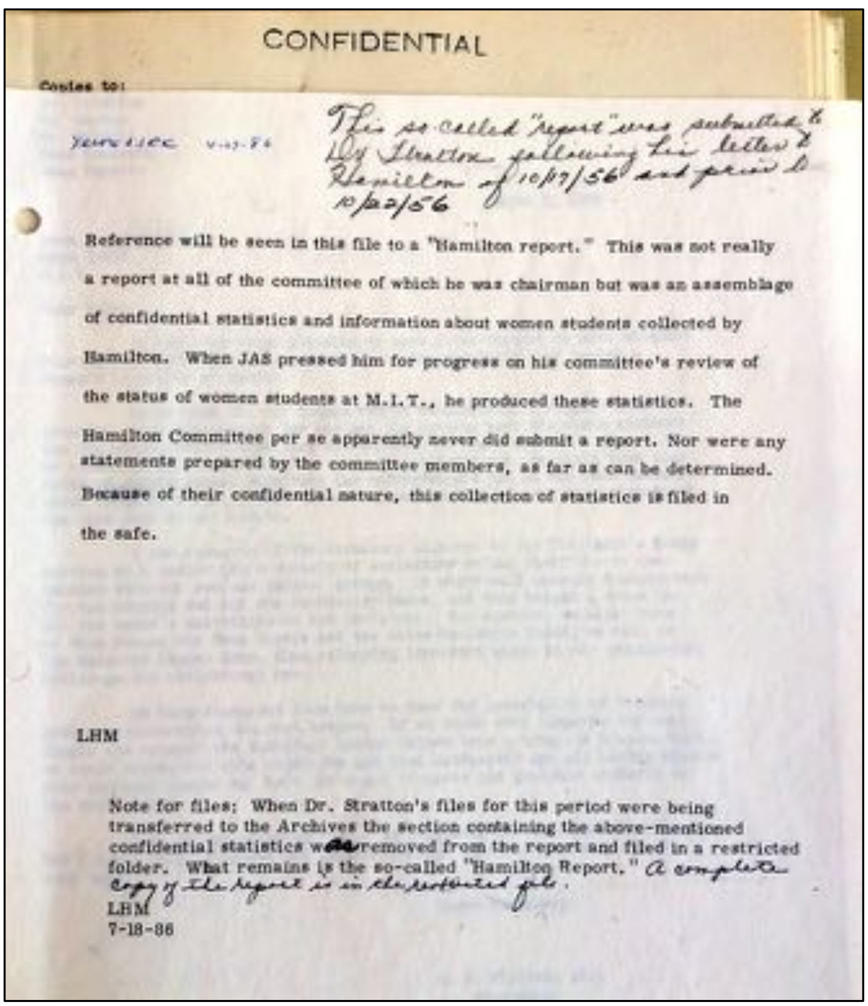
Hamilton submits a confidential memo to the President, which becomes known as the *Hamilton Report*. No copies of this memo are known to exist and much of the understanding of the "report" and its impact follows the excellent (but not easily available) article by Evelyn Fox Keller (1981)[27]:

> ***...The committee's deliberations continued until the early fall of 56, culminating in a report recommending that M.I.T. cease accepting women students as undergraduates. No copy of the final report is available, but some of the correspondence affecting the final recommendation is. ...In retrospect, it appears that the Hamilton Report marked a crisis in the relations between M.I.T. and its women students. The report itself produced a vociferous reaction. Many were disturbed by its conclusions; even more were disturbed by the picture it portrayed. . . The choices were clear: either to discontinue the admittance of women undergraduates or to strive to improve their circumstances. The Record shows that the former alternative was unequivocally rejected, and gradually, efforts were begun to effect the latter.***

By at least one account, the reaction was so acute that all copies of the report were ordered burned.

One wonders if sufficient copies existed to produce a "vociferous reaction," what happened to them all? The story continues.

Keller's story was based on the information available to her at the time, but more details became available in 1986 when the files on women students were transferred from the President's Office to the recently created MIT Archives and another story emerged. *There was no formal committee report*, Hamilton provided his *own* statistics and his own *opinions* arguing that women undergraduates have no place at MIT. Subsequent correspondence between Stratton and committee members suggests that they were unaware of the contents of Hamilton's confidential memo — supposedly representing the committee deliberations. I could find no evidence that there ever were any meetings or deliberations of the committee. These revelations can be found in MIT Archives AC132, Box 18, *Women Students Folder* in notes by Loretta H. Mannix (LHM), Stratton's highly regarded Administrative Assistant:



CONFIDENTIAL

Copies to:

This so-called "report" was submitted to Dr Stratton following his letter to Hamilton of 10/17/56 and prior to 10/22/56

Reference will be seen in this file to a "Hamilton report." This was not really a report at all of the committee of which he was chairman but was an assemblage of confidential statistics and information about women students collected by Hamilton. When JAS pressed him for progress on his committee's review of the status of women students at M.I.T., he produced these statistics. The Hamilton Committee per se apparently never did submit a report. Nor were any statements prepared by the committee members, as far as can be determined. Because of their confidential nature, this collection of statistics is filed in the safe.

LHM

Note for files; When Dr. Stratton's files for this period were being transferred to the Archives the section containing the above-mentioned confidential statistics was removed from the report and filed in a restricted folder. What remains is the so-called "Hamilton Report." A complete copy of the report is in the restricted file.

LHM
7-18-86

I have been unable to get a definitive answer from the archives as to whether or not the "restricted file" exists.
Killian's reaction to Hamilton's memorandum is swift, writing to Stratton on 10/22/56:

Memorandum to Dr. J. A. Stratton:

Dear Jay:

May I venture some suggestions for clarifying policy with respect to women students at the Institute?

Since the Hamilton Committee has failed to come through with anything helpful, I would suggest that we seek to make administrative decisions, first, by reaching some tentative conclusions in our top administrative group, and then reviewing these with the Academic Council. These administrative conclusions should, I suggest, deal with both the long term and the short term problems, and I shall make some observations about each.

Memo. to Dr. Stratton - 3 - October 22, 1956

I would venture the concluding observation that I do not see how the Institute, having admitted women for so long, can now change its policy, nor do I feel that even if such a change were practical we should do it in view of the growing feeling that women should have access to our great universities.

Yours sincerely,

J. R. Killian, Jr.
President

1957 On 4 February Provost Stratton finishes a four page draft of a new policy on undergraduate women that has been approved by the President and the Academic Council. [?] Following a brief history of women at MIT he raises three major questions:

> ***first, whether in view of the very large disparity in numbers it is possible to provide a small group of women undergraduates with a sound environment for study in an institution primarily designed for men; second, whether it will ever be economically feasible to provide women students with facilities for extracurricular activities comparable to those enjoyed by the men; and third, whether means can be found for proper housing of all undergraduate women.***

Shortly thereafter Stratton answers these questions:

> ***After a great deal of thought and discussion a decision has now been made to continue to admit a small number of undergraduates, and to seek to improve their residential environment and to better their opportunities for development in their professional fields.***

The policy admits that improvement will be slow and in the near future the number of women will not be large. The remainder of the policy justifies the policy based on the traditions of the Institute and its duty to make its resources available to all "with qualities of character and intellect equal to the task." Short term housing is described and the supervision of women's dormitories will become the responsibility of the Dean of Residence. In the short term, Bexley Hall will provide housing for women undergraduates in addition to 120 Bay State Road. Stratton summarizes the policy at an informal tea for resident women students 4/24/57. A goal is announced of eventually providing a new residence on campus capable of housing all women undergraduate students and some graduate students.

More Coeds Later, But Fewer In Fall, Sees Stratton At Tea

"Women are here to stay, and it is our hope to make them feel more a part of the MIT community" is the Institute's official policy on Tech coeds as voiced by Dr. J. A. Stratton at an informal tea given at Moore House on April 24 for resident women students.

Dr. Stratton and Dean Fassett explained to the coeds that their place in the MIT community has been under serious consideration for some time and it has now been decided to expand and amplify facilities specifically for women as rapidly as means can be found.

Since it is considered unwise and improper for the Institute to admit Freshmen women beyond its ability to accommodate them, plans have now been made for housing 14 Freshmen in the present Women's Dorm at 120 Bay State Road, with 3 upperclassmen in residence as unofficial advisors. An additional number of women commuters meeting the required academic qualifications may also be admitted to the Freshman class.

Also, a separate section of Bexley Hall will be made available to 33 undergraduate women in September with Prof. and Mrs. William F. Bottiglia as faculty residents.

Girls who would like to live in Bexley next September are asked to sign up in room 7-102 as soon as possible.

The Tech **article 4/26/57**

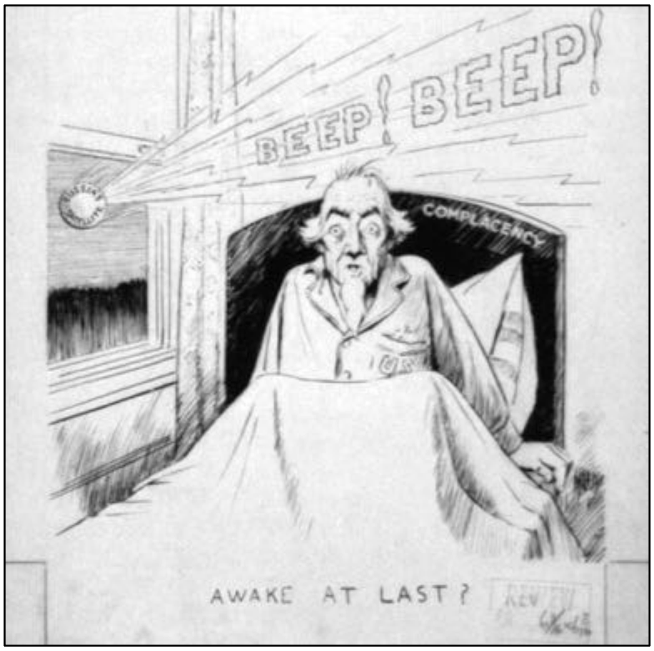
On 5 February Stratton circulates a draft statement of the policy to Dean Bean and Professor Elspeth Rostow, members of the Hamilton Committee, Prof. B. Alden "Bat" Thresher '20 — the director of Admis- sions at MIT from 1936 until his retirement in 1961, Dean Fassett, and Professor Hamilton. In his 5 February letters to Rostow and Thresher Stratton attributes the arguments and statistics in opposition to admitting undergraduate women to Professor Hamilton himself, not to Hamilton's committee.

Bexley Hall is located at 46-52 Massachusetts Avenue in Cambridge. It was purchased by MIT in 1939 and converted to an undergraduate dormitory. The 33 beds in Bexley allotted to upper class undergraduate and graduate women students together with the 18-20 beds for first year students from 1958 onward constrained the number of women admitted as undergraduates to MIT.

Women students faced restrictions called "parietals" on hours and guests in their living quarters, which governed visitors and required signing in and out. The official reason for these requirements was the mollification of concerned parents.

Margaret Alvord writes Dean Ruth Bean on 27 February announcing her intention to retire in November and requests Bean to begin searching for a successor.

Emily Wick returns to MIT as a Research Associate.



4 October Sputnik is launched; the shortage of engineers is noted in the press.

1958 February 25 *The Tech*: "Coeds Fight Expulsion From INSCOMM, Seek Status as a Group"

INSCOMM removes AWS representation claiming that "the number of coeds at MIT is so small as to invalidate any claim of representation" An adjacent article "Tech Coeds: Play A Special Role" concludes with

Last spring, Chancellor Stratton said that, 'Women are here to stay, and it is our hope to make them feel more a part of the MIT community.' To many, it would seem that the latest Institute Committee action lacks the ring of hospitality.

1959 Emily Wick is appointed Assistant Professor in the Department of Nutrition and Food Science at MIT. 20 women reside in the 120 Bay State Women's Dorm. MIT releases document The Woman at MIT [33] arguing the need for additional housing for women students.
Julius Stratton becomes MIT President.

1960 The class of 1964 arrives, along with a few transfers from other schools, including Judith Selvidge '62, the author of *I Didn't Know They Had Girls at MIT* (2014), a fascinating book providing a sage viewpoint of a world-traveled young woman transferring to MIT as a Junior from the University of Geneva.

Emily is the *only* woman faculty member at MIT outside of Humanities. Emily's formal responsibilities for MIT women lay in the future, but by default she is a role model and is actively talking with women students about the Institute and careers. Leaders of MITWA convince their fellow alumna of the need and Katharine Dexter McCormick '04 pledges $1.5M for a women's dormitory.

> ***[the dormitory is] an unprecedented opportunity to advance the professional development of our women students. Women have made substantial contributions to scientific and technical progress in the past . . . Women's potential for achievement in these fields represents one of the great latent resources of the country.***
>
> ***from the 1960 President's Report***

1961 Kenneth R. Wadleigh becomes Dean of Students in July. The title changes to Dean of Student Affairs in 1962.

1962 Sailing and fencing are approved as women's club sports, but women had very low priority in using MIT athletic facilities.

1963 Stanley McCormick Hall opens, attracting national publicity. Many people believe that McCormick Hall is named after Katharine, but even today *no* building at MIT is named in her honor.

Left: Dedication of Stanley McCormick Hall Right: Mrs. McCormick's reminiscent remarks being applauded. From left: Mrs. McCormick, Dr. Killian, President Stratton, Mrs. Killian, Mrs. Stratton, Margaret McVicar '64, Mrs. Compton

The first tower of McCormick Hall houses about 125 women, significantly increasing the number of women admitted. 120 Bay State Road and Bexley cease to be women's residences. Undergraduate women are required to live in McCormick or with parents or close relatives.

Dean Wadleigh hires Radcliffe Associate Dean Jacquelyn Mattfeld as Associate Dean of Student Affairs, responsible for the women's program. For the first time, a faculty member rather than a staff member is responsible for women students, which now number about 248. *The MIT Catalog* mentions "up front" that MIT is a coeducational school, even though it has been accepting women since 1871, albeit in small numbers.

Emily becomes the first tenured female professor at MIT when she is promoted to tenured Associate Professor.

Left: Emily in her office, Right: Talking with students in McCormick Hall

1964 Emily decides to learn more about other aspects of MIT and signs up for the Committee on Student Environment, where she meets Dean Wadleigh.

Dotty Bowe is appointed secretary to Dean Mattfeld when Prof Norton retires and she moves into the Dean's office.

The AWS, headed by Margaret MacVicar '65 (BS '64), sponsors a national symposium "American Women in Science and Engineering" with Carol Gustafsen Van Aken '65 as chairman. MITWA, faculty members, and Dean Mattfeld provide support.

MITWA becomes the Association of MIT Alumnae (AMITA).

1965 "...from 1965 when it was an earth shattering first occasion to have *fifty* women enrolled in the first year class" (Emily Wick, *Tech Talk*, 3/28/1973)

The Academic Council again takes up question of women's future at the institute, with some faculty and administrators still regarding training women undergraduates as a risky venture. After much argument, the Council finally endorses raising the number of women undergraduates to 400, raising the percentage from 3% almost to 9% (but it takes years to happen).

Mattfeld leaves MIT in the spring for Sarah Lawrence to become Provost and Dean of the Faculty, later moving to Brown University and then to be President of Barnard.

After discussions with Dotty, Wadleigh chooses Emily Wick as the new Associate Dean of Students with responsibilities for women's programs.

Emily joins another new Associate Dean of Student Affairs, future Chancellor, President, and strong supporter of diversity — Paul Gray '54

Emily joins Dotty in Room 5-108 with the intent of making it a Dean's office which welcomes students at any time. The office is said to always be full of students.

"Between 1963 and 1972, Dotty with Emily Wick were the women's program at MIT." [14]

Dotty's "goal was to know every woman student, and she and Emily had an office with an open door in the corridor between the Main Lobby and the Hart Nautical area, an excellent place to pop in for a brief talk, especially when coming from McCormick on a rainy day, and entering the building at 55 Mass Ave (with the anchors)." [14]

1966 A woman interviewed for an article reports that MIT is very "expensive, it will cost her $1,700 for tuition and $1,130 more for room and board in McCormick."

1967 Women are finally admitted to the MIT Athletic Association, but not to the Varsity Club. Later in the year women's sailing and crew are designated "varsity teams" retroactive to 1963, all other women's sports considered "club sports."

Undergraduate women are finally permitted to live off campus without the requirement that they live with family, provided they were over 21, or secured parental permission. Some women were not able to live in MIT housing because of lack of space, and so their living off campus was necessity rather than choice.

1968 McCormick Hall East opens. Mildred Dresselhaus moves to MIT from Lincoln Labs with an appointment as the first woman tenured Full Professor following a year as a visiting professor. "Millie" becomes involved with women students and begins discussions with Emily and Dotty on admissions policy and other issues.

Emily Wick is promoted to Full Professor. Emily is the first woman at MIT promoted to Full Professor from within the ranks. She is the second female tenured Full Professor after Mildred Dresselhaus.

1969 Senior House becomes first coed living group with 6 women. The residence requirements for men and women become the same — only freshmen are required to live in Institute houses. All other students may elect to live on or off campus. [18]

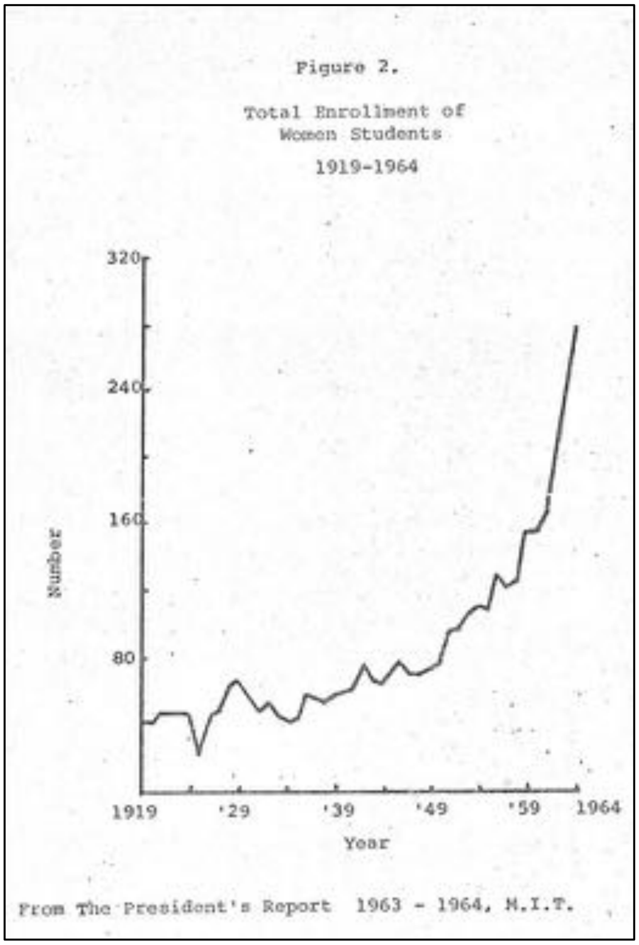
Professor Daniel Nyhart, an expert on finance in the MIT Sloan School of Management, replaces Wadleigh as Dean of Student Affairs. Dean Nyhart decides an Associate Dean focused on women's affairs is no longer necessary and informs Emily and Dotty of his intention to dissolve their office and to not replace Emily and Dotty.

Epilogue: The 1970s and Beyond

1970 In March Emily Wick submits *Proposal for a new policy for admission of women undergraduate students at MIT* [18] arguing that admissions requirements should be made the same for women as for men — in particular that MIT should no longer limit the number of undergraduate women by the number of on- campus beds. The report includes a history of women at MIT backed by extensive statistics on performance, housing, activities, athletics, and contributions. Two striking examples are given by the figure showing enrollment the table showing graduation and attrition data.

The recommendation is adopted by MIT in 1971, at a time when 249 women students were housed on campus.

In September Wick releases a shorter report *Women Students at M.I.T.* including many of the same ideas [19].



Left, Total Enrollment of Woman Students 1919-1964. Source MIT President's Report 1963-64

Below, Graduation and Attrition Rates for Men and Woman, MIT Classes 1960-1969

Table II. Graduation and Attrition Data for Men and Women in the M.I.T. Classes of 1960-1969

Class	Number Entering Class[1]		Percent Graduated (BS)[2,3]		Percent Disqualified (O_1)[2,4]		Percent Withdrawn[6]	
	Women	Men	Women	Men	Women	Men	Women	Men
1960	22	914	36	89	27	*	36	*
1961	16	893	56	87	12	*	31	*
1962	18	923	66	85	22	*	11	*
1963	21	915	62	90	9	*	28	*
1964	25	874	84	86	4	*	12	*
1965	23	885	87	90	0	*	13	*
1966	23	869	91	92	0	11	9	0
1967	39	889	92	94	0	10	8	0
1968	46	861	87	86	0	11	13	3
1969	50	918	100	82	2	8[5]	0	10

*Unknown

[1]From Presidents Reports. Women Students Classified by Years; Classification of Students 1956-69.
[2]From Records in Office of Dean for Student Affairs. Transfer students included.
[3]From Presidents Reports, Degrees Awarded 1959-1969. Transfer students included.
[4]From Committee on Academic Performance, Policies and Procedures, May 1969.
[5]From Committee on Academic Performance, February 1973.
[6]Calculated by difference.

1971 Emily steps down as Associate Dean. Room 5-108 closed. Dotty is promoted to a staff position and moves to Financial Aid. Emily recommends that someone be appointed to continue her work. Wadleigh writes to Killian 10/20/1971 that "Emily played the key leadership role in the successful development of a strong identity and character for undergraduate and graduate women at M.I.T. during her tenure on the administration."

Emily's resigning as Associate Dean and the administration's decision to not replace her results in a strong student reaction articulately expressed by excerpts from 12/7/71 Letter from Carol L. Epstein '72 and Paula F. Stone, '72, to MIT community. Copies to*The Tech*, President Weisner, Provost Gray, Dean Nyhardt, . . .

> ***To Members of the Institute Community:***
> ***We are writing this letter in response to the retirement of Emily Wick from the Deans' Office and the circumstances and issues surrounding her decision. With the demise of Dean Wick's office as of January 1, 1972, the women students of M.I.T. will lose an integral, personal representative in the higher echelons of the Institute as well as a congenial, intimate friend who is sensitive to the problems that we, as women, must cope with in a male-run, male-oriented environment.***
>
> ***To our knowledge, after consulting several faculty and members of the administration, no definitive action is being taken to replace Dean Wick. The needs and position of women at the Institute have apparently failed to generate a serious commitment. We are concerned that unofficial policies will remain the same; that they will perhaps be re-examined and discussed, but that nothing will be done; that the urgency for our full recognition as members of the M.I.T. community will be ignored, and the entire white-washed, appeased, and silenced.***
>
> ***A standard argument used against the establishment of a separate office for women at M.I.T. is that women and men are equal, therefore there is no need for such an office. We argue that we are indeed equal, but that we have not been granted equality; although we are intellectually equal, there are parts of the Institute in which we (and our friends) have experienced personal harassment and discrimination. . . .***
>
> ***As of January 1, 1972, the office of Dean of Women Students will be empty, and will de facto have been abolished . . . We would also like to set up an Institute Committee on Women's Affairs at M.I.T. as an investigatory body to look into areas of concern to women, especially in response to input from the community. . . .***

The reference to "personal harassment and discrimination" resonates with current events and *Sexual Harassment of Women: Climate, Culture, and Consequences in Academic Sciences, Engineering, and Medicine,* the recently published Consensus Study Re- port by the National Academies of Science, Engineering, and Medicine. [35]

The MIT administration reacts to strong outcry, decides to appoint another Ad Hoc Committee, this time an Ad Hoc Committee on the Role of Women Students at MIT.

Meanwhile, Emily, Mildred Dresselhaus, and Paula Stone organize a meeting for women students in January to discuss issues of common interest, but they forget to put "students" in the title of the flyer and draw a much larger audience than intended.

1972 Title IX of the Education Amendments Act of 1972 reads:

> ***No person in the United States shall, on the basis of sex, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any education program or activity receiving Federal financial assistance.***

The first meeting called and chaired by Dresselhaus and Stone draws over 100 women (and two men). The meeting includes women from all aspects of MIT life and raises awareness of the needs and frustrations of women at MIT. The group takes as a name the *Women's Forum* and begins regular meetings. Part of this group is appointed as the official Ad Hoc Committee on the Role of Women Students at MIT.

The committee produces a report on the *Role of women students at MIT* by the end of spring [25], converging at a speed almost incredible for Academia. Its key conclusions and recommendations are indicated by a few excerpts:

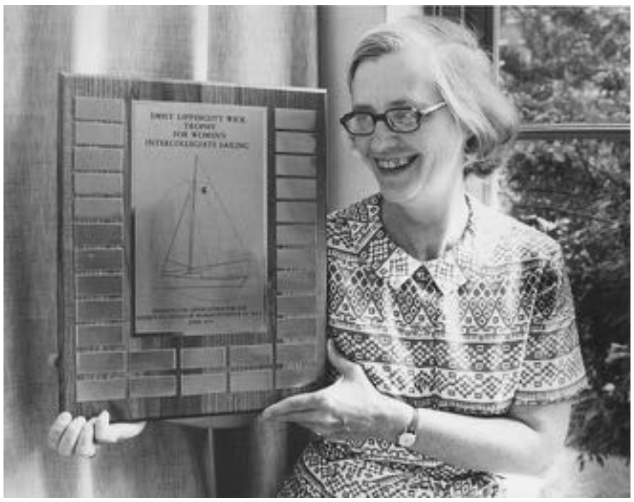
> ***"A discriminatory attitude against women is so institutionalized in American universities as to be out of the awareness of many of those contributing to it. Decisions may indeed be made with no deliberate effort to exclude women — at least at times — but policy must be judged by outcome, not by pronouncement. And here we find inadequate numbers of women at all levels, most significantly so at senior levels."***
>
> ***Recommendations:***
> ***• active recruitment of women***
> ***• publicity about women at MIT***
> ***• alumnae Educational Councilors interviewing applicants***
> ***• department awareness to admit more women***
> ***• a system of women advisors • more women graduate students***
> ***• Emily Wick's position should be filled***

Dean Nyhart hires Anne E. Ellison as an Assistant Dean of Student Affairs in response to a recommendation of the Ad Hoc Committee, but the position is only a staff appointment rather than the previous position of Associate Dean held by Emily. Ellison still holds the post in 1974–5, when she writes in the annual President's Report:

> ***Women's Program*** ***I was a member of the Committee on Educational Policy (C. E. P.) subgroup on women students, which met second term. There was an increasing number of requests from women students to review the report of the Ad Hoc Committee on the Role of Women Students at M.I. T. of spring, 1972, to see how extensively the recommendations had been followed, and to examine some areas in depth that required more work or were not examined in the original report.***

> ***The advisability of a new ad hoc committee was considered; however, it was learned that Professor Lisa Steiner of the Department of Biology had been asked to chair a four-person subgroup of the C. E. P. to review the position of women students at M. I. T. That subgroup, enlarged to include women students, myself, and others, met several times in the spring to identify issues and will recommend whether an ad hoc committee is needed.***

In other words, not much has happened since the 1972 report except consideration of yet another ad hoc committee. On the bright side, the students on the Ad Hoc Committee win a Karl Taylor Compton Prize.



Award pictures Emily's Bullseye *Beaver II*.

Emily Wick receives a Bronze Beaver Award from the MIT Alumni Association, cited as an "advocate and model for a generation of women students at MIT from a handful to an abiding presence."

1973 Emily leaves MIT to become Dean of the Faculty at her undergraduate alma mater, Mt. Holyoke College.

The Ad Hoc Committee Compton Prize is used to fund a women's intercollegiate sailing trophy in Emily's name. A plaque is "Presented in appreciation for her efforts on behalf of women students" to Emily at MIT in June 1973 by Paula Stone on behalf of the AWS.

Note: Emily becomes the first female Commodore of the Sandy Bay Yacht Club in Rockport, Massachusetts, in 1988.

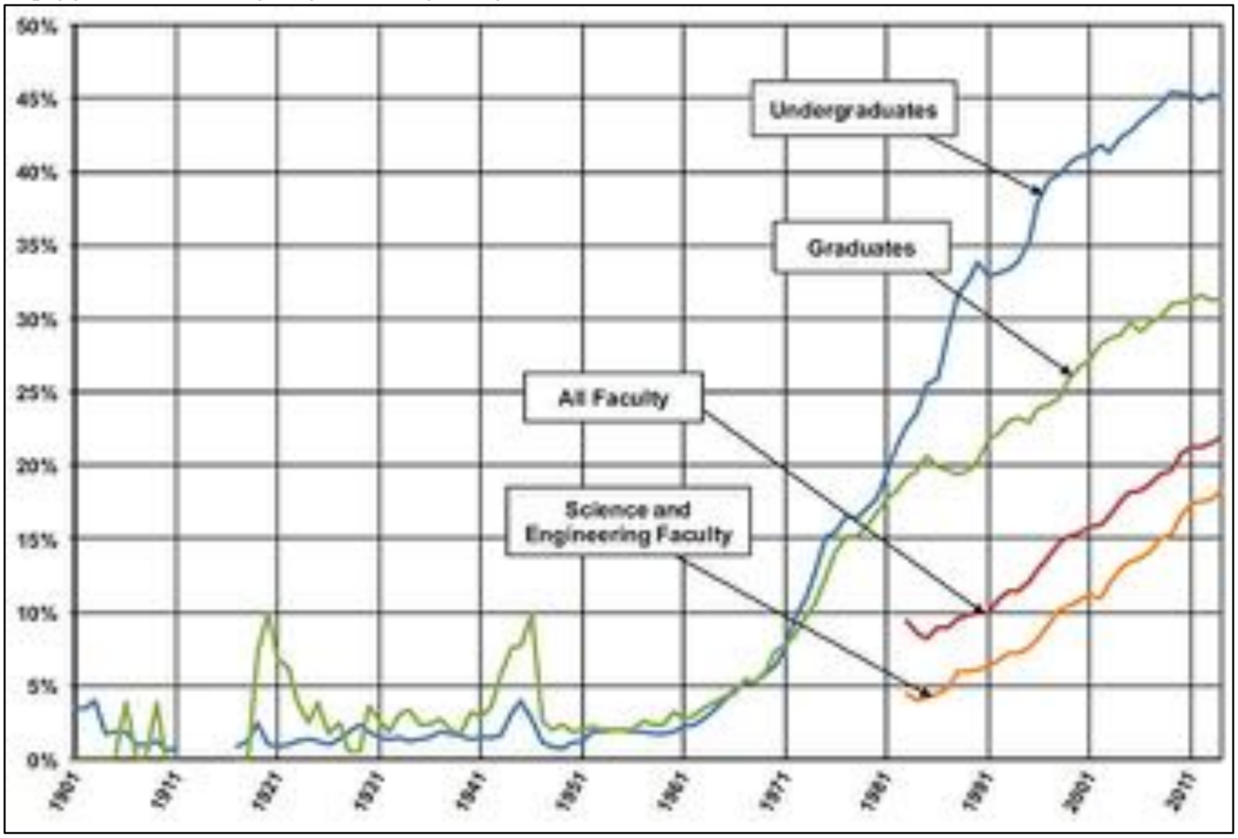
Mary Rowe is appointed as special assistant to the president and chancellor for women and work.

In *A Century of Women Students at M.I.T.* (1973) ([20], Emily describes the accomplishments and progress during her time as Associate Dean of Students. While noting the progress of recent years, she emphasizes several remaining tasks:

> ***First, there must be more women faculty at both junior and senior levels. Women students need to observe and to communicate with women who have been successful in their field of study. . . . Such role-models are necessary if women are to be encouraged to seek careers. . . .***
> ***Second, there must be more women students. M.I.T. — as a leading university in our society — has a responsibility to educate those people whose talents can best be met by the Institute's resources. . . . "***

1978–1983 Emily serves as a term member of the MIT Corporation.

2014 Women at MIT from MIT web site
http://web.mit.edu/fnl/volume/264/numbers.html



Note the large discrepancy from undergraduates to faculty! A major problem in growing the number of women students in engineering is the small number of women faculty of engineering. Too few women faculty, role models, counselors, advisors!

Parting Thoughts: The Bottleneck Facing Women in Academic Engineering

Much of my academic career after 1980 was devoted to the issue emphasized by Emily in her 1973 article regarding the need for more women faculty as role models. Granted the greater problem is the lack of diversity in many professions, including engineering academia. The recent National Academies report [35] provides extensive evidence of the problems caused by and the damage done by this failure, especially in the case of women. My interest began with my first experience supervising a woman PhD student in electrical engineering at Stanford beginning around 1980, and increased as over the next decade and a half my research group grew from 0% women to about half. In 2002 several of my students successfully nominated me for a Presidential Award for Excellence in Science, Medicine, and Engineering Mentoring (PAESMEM), which brought with it a Grant from the National Science Foundation which was explicitly constrained fund work in the area of the award title. This led to two workshops in 2004 and 2007 organized by my students, former students, and me on mentoring for academic careers, which in turn resulted in two coedited books [36, 6] based on the presentations and discussions at the workshops. The workshops and books emphasized faculty diversity at all levels. In later years I gave several talks on the subject to both tiny and large audiences, including talks as a distinguished lecturer of the IEEE Signal Processing Society (2006–2007), at conferences, and at faculty meetings. I close this article on the history of coeducation at MIT with a few global observations on the statistics of women in electrical engineering and computer science gathered during my research on the topic. The data proved difficult to obtain, and even when I retired there were few reliable reports available. The first table is from 2002, and it was used for my presentation at the workshop associated with the PAESMEM award ceremony and at the two workshops that resulted from the award.

Percentage of Women in a few EE/ECE/EECS Faculties in 2002

University of Delaware	0%	UC Berkeley	11%
UCSD	2%	Penn State	11%
USC	4%	Stanford	11%
Cal Tech	5%	Cornell	13%
UT Austin	5%	University of Washington	20%
Princeton	7%	Duke	30%
University of Michigan	7%		

MIT was not included because I did not have reliable numbers at the time. The numbers came from trusted colleagues, who had access to internal data. The intent was to count only genuine regular faculty appointments and not visiting and non-tenure-track appointments, which often inflated the claims of percentages on university websites. Two points stand out. The first is that many of the numbers are abysmally low. Many excuses were offered at the time, which usually boiled down to the candidates being unavailable or the institution had tried hard but failed to entice minority candidates. The numbers also pointed out that there were exceptions, major research universities who did significantly better, usually by a combination of active recruiting and institutional requirements for fair and open searches. The University of Washington was high on the list, largely because of the efforts of Denise Denton MIT ’82 during her time as Dean and the rules for search committees that she compiled end enforced. There were no quotas for appointments, but their were requirements for search committees to demonstrate diversity in the short lists compiled for interviews and visits or explain why. The litany of lame excuses common at the time for recommending only clones of the male faculty were not acceptable and could result in the failure of the search recommendations to proceed. Denton wrote the book (actually, a manual) on fair and open searches, which is well summarized by

> ***It’s a search committee, not an envelope-opening committee.***
> ***Denice Denton***

Years later I updated the numbers. Again I used insider information I trusted to get regular faculty numbers without amplification by non-tenure-track positions and soft-money visiting hires. By this time there had been a thorough study of engineering faculty by gender [Nelson and Brammer (2010) [34]] for the top 50 research universities with a breakdown by fields, so the average was known to be slightly below 10% women in EECS. The significant rise of Cal Tech (perhaps made easier by the small number of individuals involved) was remarkable, and showed the influence of a dedicated university President promoting active searches rather than simply lip service. MIT did relatively well, which reflects both the institutional policy and the fact that it draws on its own graduates, and its percentage of women graduates has been steadily increasing. I often used this table to remind Stanford that in spite of its constant claims of superiority, on this measure it was clearly below average. The addition of a single woman late in the year (increasing total faculty to 42.5) pushed them above average (8.6% shown in the table below became 10.5%), which is a reminder of how small some of the numbers are and the large impact of a few appointments.

2010 Data

Institution	% Women	Total Faculty
CalTech	19.2%	13
Duke	18.5	27
University of Washington	17.5	40
UCLA	13.0	46
U Wisconsin	13.0	38.5
RPI	12.8	39
MIT	12.0%	151
Georgia Tech	11.4	114
Texas A&M	11.1	72
Princeton	10.9	27.5
Purdue	10.8	83
Rice	10.0	20
U Michigan	9.8	71
UC Berkley	9.8	40.5
Top 50 Average (2007)	**9.7%**	
Cornell	8.8	34
Stanford	8.6	41.5
Carnegie-Mellon	8.2	49
U Illinois	8.2	85
Northwestern	7.8	51
NC State	7.4	54
U Maryland	6.8	62
UT Austin	5.0	68
USC	4.9	61
USCD	3.8	52

There have been and there remain serious problems of pipeline and pool, but the numbers of women Ph.D.'s have been steadily increasing, while the percentages of women faculty have not reflected those increases. Worse, the number of women Deans, Provosts, and Presidents remains minuscule. It is notable that even small increases can result in a significant percentage increase when the numbers are small, and that percentage increase can have an impact with more role models, more diverse experience, and more effective faculty, which in turn will draw more students. While MIT has achieved balance in the overall student body, it is not there yet in engineering and in several specific engineering fields, including electrical engineering and computer science.

Are things any better now? I don't know, I retired in 2013, but for a final talk at Stanford in 2017 I noticed that the published Stanford statics were:

School of Engineering
Department of Electrical Engineering
Faculty Demographics by Gender
September 1, 2015

School of Engineering

School	Rank (broad)	Female	Male	Total
Engineering	Assistant Professors	11 22%	40 78%	51 100%
	Associate Professors	9 18%	41 82%	50 100%
	Professors	18 11%	139 89%	157 100%
Total		38 15%	220 85%	258 100%

Department of Electrical Engineering

Department	Rank	Female	Male	Total
Electrical Engineering	Assistant Professor	3 38%	5 63%	8 100%
	Associate Professor		5 100%	5 100%
	Professor	2 5%	36 95%	38 100%
Total		5 10%	46 90%	51 100%

Stanford School of Engineering Compared to:

UCSD
5/52=9.6% ↑

Caltech
3/19=15.8% ↓

U Washington
17% ↓

Stanford Department of Electrical Engineering (actually it's 5/51=9.8% ↓)

So my own former institution seems pretty much stuck at around 10%, although they at least now have women as Dean of Engineering and Provost. Faculty change seems to come much more slowly than student body change.

So how is progress to be made in diversity in faculty at all levels, including the upper echelons? Much has been said and written on the topic during this millennium, but it is worth mentioning a few recurring themes that have been effectively developed by a few institutions:

- ***Active faculty recruiting across a wide spectrum. In particular, fair and open and active searches. A basic principle of optimization teaches that the richer the pool discovered in a search, the better the final candidates.***
- ***Leadership must deal with residual and often unconscious bias, which often means educating search committees (who too often see no problem in reproducing them- selves).***

The schools with the best records had activist Presidents and Provosts!

Creating a respectful, productive, and fulfilling environment. (Another leadership challenge.)
Lip service is not enough.

Acknowledgements

The material draws heavily from the papers of Emily L. Wick in the possession of her niece, Laura Hallowell (Wellesley '64), *The Technique, The Tech, Technology Review, The MIT Handbook,* and the MIT Museum and MIT Archives, the articles and book of Amy Sue Bix, the biography of William Barton Rogers by his wife, the biography of Ellen Swallow Richards by Caroline L. Hunt, and the old Web pages of the Association of MIT Alumnae (AMITA) beginning at http://alumweb.mit.edu/groups/amita.old/esr/swallow.html

Extensive discussions with Susan Kannenberg, MIT '61, have been invaluable regarding the "Hamilton Report" and the environment for women students at MIT in the 1950s–60s. Many of the comments herein have been improved by (or replaced by) her suggestions.

Thanks to classmate Emma Root '64 for email conversations in the earliest stages of this project.

Most of the photos are courtesy of the MIT Museum and *Technique*, and many of the documents quoted or reproduced are from the MIT Archives. Special thanks to Laura Hallowell, to Denise Wernikoff, former Project Archivist at the MIT Museum, and to former Class of 1964 President and *Technique* Photo Editor and Editor, Bob Popadic.

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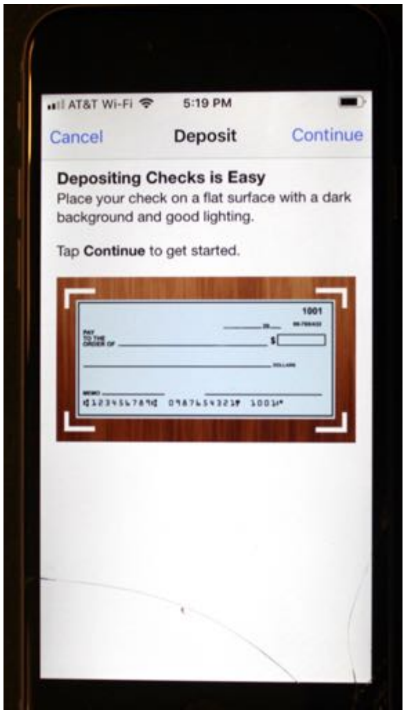
Business



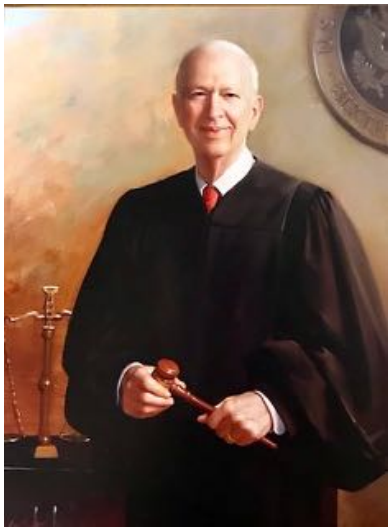
Left, Cell phone application for depositing checks, checking balances, transferring funds and making payments. Today checks after being received, exist largely as images. Payment methods abound, people shop on line, video conferencing has replaced some business travel, and customer service is often a voice response unit or an artificial intelligence bot.

Big Data is king. For some George Orwell's "1984", looks like a primer on the loss of privacy - except perhaps the loss is more to business than government.

Below, Cash was king. Paper checks weren't far behind and human interaction dominated how people shopped, were served by financial institutions and conducted business. This IBM 3890 check sorter introduced in 1973 could process 2400 6" checks per minute.

How Technology Has Changed The Law

Ronald Lee Gilman



The steady advance in technology since our class entered MIT in the fall of 1960 has had a great impact on the practice of law and the art of judging. This impact has manifested itself in two primary ways: (1) by increasing productivity, and (2) by raising new technology-related legal issues.

Increased Productivity

When I began my law practice with a small law firm in Memphis, Tennessee in 1967 after graduation from Harvard Law School, the IBM Selectric typewriter was the technological marvel of the day. Introduced by IBM in July of 1961, the Selectric substituted a "type ball" for the old "basket" of individual type bars that swung up to strike the ribbon on the traditional typewriter of old. Copies were made by inserting carbon paper between multiple sheets of regular paper.

There was no computerized word processing because desktop computers did not yet exist (they were first introduced in the mid-1970s). Nor was there a plain-paper copier on the premises, even though Xerox introduced its first commercial model in 1959.

The most inefficient legal process, however, was the old-fashioned method of finding cases on point. In a legal system based on precedent, the research required (1) finding relevant cases by manually reviewing treatises on specific topics and/ or searching through massive legal encyclopedias, and then (2) laboriously checking the monthly supplements to a series of books called "Shepard's Citations" to find any subsequent cases that cited the cases initially found by the researcher.

All of this has changed in the world of today. With desktop (or laptop) word processing, plain-paper copying, scanning, computerized legal research, email, and the internet, the speed of legal research and communication has gone into hyper drive as compared to the non-digitized world of yesteryear.

Legal research, for example, no longer requires the use of the roughly 2,000 volumes of case law and statutes in my chambers law library. The books are now solely for show. With online access to the latest update of these materials, there is simply no need for me or my law clerks to "go to the books." Moreover, the cumulative cost savings of not having to maintain fully stocked individual law libraries for hundreds of federal judges across the country is substantial. In my four-state circuit alone (which is one of 12 geographic circuits in the country), over one million dollars per year is being saved by eliminating paper publications (your tax dollars!).

The pervasive use of email has had an equally dramatic effect on productivity with regard to communication between judges. As an appellate judge, I sit on three-judge panels to hear cases. The other panel members are typically based in different cities within my circuit and beyond. Although we periodically assemble at a designated courthouse to hear oral arguments and then confer among ourselves, the vast majority of our time is spent in our individual chambers preparing for the cases beforehand and writing opinions afterwards. We now communicate by instantaneous email as opposed to old-fashioned "snail mail," which greatly accelerates the decision-making process.

Now if only this clear advance in legal productivity could be matched with a comparable advance in every lawyer's advocacy and every judge's decision-making ability! Unfortunately, the pace of human evolution pales in the face of the technological revolution.

New Technology-Related Legal Issues

The other major effect of new technology on the development of the law is reflected in the type of cases coming before the courts. Yes, there are still plenty of drug busts, bank robberies, employment-discrimination claims, and deportation proceedings. But who in 1960 could have imagined lawsuits arising out of electronic hacking, GPS tracking, or Facebook data mining?

In fact, a whole host of new terms have emerged in the English lexicon, including "phishing" (a scam by which an internet user is duped into revealing confidential information) and "malware" (malicious software designed to disrupt, damage, or gain unauthorized access to a user's computer). Then there are the regulatory issues and social conflicts related to the new-fangled development of 3D printing (plastic guns, anyone?), crypto currencies, drones, facial recognition software, automated license-plate readers (how about 60 license plates per second?), Pod cameras (police observation devices), social media, and general purpose programmable robots. All of this will keep lawyers, judges, and our legislators quite busy in the coming years as they grapple with how to fit the inevitable conflicts caused by this new technology into traditional concepts of constitutional law, patent and copyright law, criminal law, and the civil law of torts and contracts.

In my own experience as a judge, I was involved in a case where the drug dealer objected to the police secretly installing a GPS tracker on his vehicle without a search warrant (the U.S. Supreme Court has declared this practice a no-no!). I was on the panel in another case where attorneys and journalists challenged the Terrorist Surveillance Program set up by the National Security Agency to conduct warrantless intercepts of telephone and email communications that it believed were connected to al Qaeda (over my dissent, the panel majority dismissed the claim on the basis that the plaintiffs lacked "standing to sue" because they had no proof that they themselves were targeted). These are just two examples of how modern technology has raised public policy issues that did not exist just a few decades ago.

Hopefully, a rational legal framework to accommodate these recent developments will have emerged by the time the Class of 1964 holds its 75th Reunion in 2039!

Ron Gilman '64, Harvard Law '67, has been a judge on the United States Court of Appeals for the Sixth Circuit since he was nominated by President Bill Clinton and confirmed by the Senate in 1997.

Technology Comes to Shopping

Conrad Grundlehner

Prologue

It's 2019 and a baby boomer is searching for the perfect wedding gift for her niece. Using her smart phone, she searches for suggestions as to what that might be. Once having made her selection, she orders the item with her credit card, specifies that it is to be gift-wrapped with a personalized message enclosed and sent to the bride-to-be's address with expedited delivery, and receives an email confirmation with a tracking number for the shipment. It wasn't always this easy.

Shopping for consumer goods when we went off to MIT in 1960 was quite different. People went to stores, picked out what they wanted, often with helpful clerks, paid for their purchases with cash and then carried them home. Special orders were available, but were 'special'. Credit purchases were generally unavailable and few merchants accepted checks, especially those drawn on out of town banks. Some department stores and high-end merchants allowed their good customers to buy on credit. But credit availability was tied to a specific, local store and only granted if the customer's name and payment record were good. The merchants in each city exchanged credit information among themselves through the local retail merchants' associations. They kept information on consumers which sometimes included subjective judgments on a person's character and associations.

Behind the efficient shopping of 2019 was a new construct which brought together many elements. First, vendors operating nationwide needed the means to reach their prospective customers. Next, it had to be easy for the customers to place orders. Then, those orders had to be delivered to anywhere in the US. And finally, there had to be a risk-free way to pay for the transaction. This last capability – payment – was the area in which I made a modest contribution.

The Winds of Change

The Merc**hants.** Sam Walton looked at main street USA and saw not an idyllic picture of small-town life, but shops with narrow selections selling overpriced goods with uneven service. The Wal-Mart stores he started brought about a radical change in merchandising. He located his stores far outside of town centers with ample parking. He worked directly with manufacturers – many foreign, especially Chinese to stock his stores with a huge variety of goods at appealing prices. He was soon copied by other 'big box' merchants selling consumer electronics, office supplies, athletic equipment and a host of other goods not generally available in small-town America.

The societal changes catalyzed by the First World War and the increase of spending power catalyzed by the Second World War created greater demand for goods. This demand created a related increase in the demand, use, and popularity of mail-order catalogs. In addition to mail-order catalogs retail brick-and-mortar shops were becoming more common and some of the first shopping malls in North America were built. Later, the internet tied together all three ways of shopping.

The Golden-Era of Mail Order. The 1980's were a catalog golden era. Companies such as Sears, J. Crew, Lands' End, Talbots, and L.L Bean were all banking in cash with the success of their retail catalog business. As retail stores began popping up with more fervor and the shopping experience in these stores became better, buying through mail-order catalogs became more of a complimentary activity. This did not mean that the power of mail-order catalogs diminished.

In the 1990's the retail landscape began to change. The catalog businesses slowly transitioned away from a catalog heavy business model. Sears published its last general catalog in 1993. However, they published seasonal catalogs and continue to do so today. You might think this change in landscape was due to a decrease in mail-order sales. Not true. Sales couldn't be higher. From 1990 to 1996 mail-order sales grew at a rapid rate—?9.9% per year. To put it in context this was about 2 time the average growth of in-store sales.

The Future of Catalogs. There is a common misconception that mail-order has been phased out given what appears to be a high cost and poor return on investment. Many companies pulled their catalogs after the 2007 Great Recession to save money, only to notice a dramatic fall in sales independent of the decrease in general consumption at the time. But some created extremely successful business exclusively around mail-orders, essentially leveraging a channel that everyone had abandoned because it was "uncool". Undeniably, the catalog has now become a highly undervalued distribution channel and is here to stay. Why?

Take a moment to consider the data on conversion and cost. Analysis done by the Direct Marketing Association on direct mail (i.e. catalogs and flyers) have a 1.1 to 1.4% response rate in 2012, considerably higher than response rates to email (0.03%), banner ads (0.04%), or paid search (0.22%). This difference is significant. In 2013 the Direct Mail Association found that 65% of consumers of all ages have a made a purchase as a result of direct mail. Cost per conversion is cheaper. With catalogs you need to spend $47.61 U.S. to land an order. You have to spend $53.85 for email and $99.47 for paid search. Furthermore, direct mail is uncluttered. Direct mail is free from the noise and uncomfortable competition for attention, especially when compared to the bombardment of email and digital ads users currently experience online.

The catalog has a profound history and holds a valuable place in our history. However, its effectiveness extends beyond its narrative and makes it a potent tool for the future of marketing.

Package Delivery. The small package delivery business was well established early on. By law, the Post Office Department could not carry parcels weighing more than four pounds at the beginning of the 20th century. Private express companies, which had begun to flourish in the mid-1800s, delivered large packages. The establishment of rural free delivery had provided a heady taste of life for rural Americans. Soon the demand increased for the delivery of packages containing food, dry goods, drugs, and other commodities not easily available to farmers.

When Congress considered enacting a law to allow Parcel Post service, express companies and country merchants fought long and hard against it. Rural residents, who represented 54 percent of the country's population in 1910, were equally emphatic in wanting Parcel Post. In 1912, Parcel Post was established by an act of Congress. The ability to deliver packages insured the success of catalog sales firms Sears, Roebuck & Co. and Montgomery Ward.

United Parcel Service began in 1907 as an alternative to Parcel Post. These two shared the small parcel delivery business until the establishment of Federal Express in 1971. Federal Express' focus was on delivery by air; it later acquired a ground delivery company it renamed FedEx Ground.

Toll-Free Calling. In 1967 AT&T began offering 1-800 toll-free service. Prior to that, merchants who wanted their customers to be able to contact them without paying long-distance charges were offered Enterprise numbers. These were, in effect, collect calls and had to be placed through an operator. 1-800 offered an easier way to contact a merchant. It even offered 800 directory service (1-800-555-1212).

Credit Reports

The 1960s and subsequent decades saw the growth of credit reporting companies. Equifax, in particular, grew by acquiring the credit reporting operation of the merchant's associations in the Southeast Atlantic region of the US. Trans Union and TRW also grew through expansion, Trans Union by concentrating on services to merchants in the Midwest and TRW by servicing the financial industry. In the process credit records were automated. These three organizations, in their early days were not always careful about the accuracy of the data they kept on individuals. As a result of several high-profile lawsuits and growing public awareness, in 1970 the US congress passed the Fair Credit Reporting Act (FCRA). The Act protected consumers from the willful or negligent inclusion of inaccurate data in consumer credit reports.

The three credit reporting companies received magnetic tapes containing 'trade lines', i.e. the payment history of each of their customers who had mortgages, car loans, personal loans from a financial institution or revolving credit from a merchant. They then had to aggregate the trade lines from each credit grantor to a given consumer. This was not as simple as it may seem; many names are similar and all to frequently trade lines were assigned to the wrong consumer.

There was one element in credit reports which was not easily available to the credit bureaus and that was legal data. Legal data consisted of tax liens, default judgments and bankruptcies. The only way to get this information was from the court record rooms in each county, and from the federal bankruptcy courts in each state.

The local credit bureaus would hire workers on a contract basis to visit each court house and manually copy the details of each kind of legal record. They would be paid on a piece rate basis. After returning the sheets to the local bureau the bureau's staff would access the company's mainframe remotely by terminal and pull up that individual's credit record. The details of the legal record would then be added to the credit file for that individual.

There were two serious problems with this activity. First, as many names are similar the matching process was up to the individual operator, who had to make judgments resulting in type I or type II errors. Second, entering legal data was a low priority activity for the office staff resulting in huge backlogs of legal data waiting to be entered.

The credit reporting companies were very interested in receiving legal data on magnetic tape so that it could be processed in a manner similar to the tapes they were receiving from the credit granters. The matching algorithms would be similar and under their control. And, they could monitor the flow of legal data more easily than if it came from the local bureaus.

Banks. With more knowledge about the credit worthiness of their customer, banks became more secure about issuing credit cards. They could now observe the Federal Reserve rule that required them to 'know your customer.' There still was a 'chicken-and-egg' problem in that merchants did not want to accept a card that was not widely used and consumers did not want to carry a card that few merchants accepted. The Bank of America broke the logjam by mailing out 60,000 credit cards to their customers in Fresno, California in 1958.

But there was a downside to credit cards initially. Banks mass mailed them indiscriminately to bank customers who were thought to be good credit risks. They were mailed off to unemployables, drunks, narcotics addicts and to compulsive debtors. These mass mailings were known as "drops" in banking terminology, and were outlawed in 1970 due to the financial chaos they caused. However, by the time the law came into effect, approximately 100 million credit cards had been dropped into the U.S. population. After 1970, only credit card applications could be sent in unsolicited in mass mailings.

Enter the Personal Computers and My Activities

Since graduating from MIT, I tried a variety of activities of an entrepreneurial nature, most of which were not successful. But along the way I learned to program in Cobol, Basic and Fortran as well as picking up a lot of practical business information. My partner and I were looking for a data-based business to enter and we learned that TRW was unhappy with their legal records vendor. We made a proposal and were invited to make a test tape. At this point I became involved.

IBM had introduced the personal computer in 1980. Buyers were intrigued, but little software was available. I saw that by supplying a data entry program that would run on the PC, I could use the installed base of the machines to allow a home-based data entry activity. Many homemakers with access to a PC were interested in working part time at home on their own schedule. I paid them a piece rate that would allow a profit to me, as the credit bureaus paid me by piece rate. I was thus assured of a profit regardless of volume. Since I worked from my house my overhead expenses were minimal. I gradually increased the sophistication of the data entry program to reject erroneous data (bad addresses, impossible judgment amounts, wrong status dates, etc.)

The first portable computer used to collect credit data: an NEC PC8201a. This allowed a data collectors to enter data directly at the court record rooms for credit reports.

I then moved my data entry program to a NEC PC 8201a, a notebook-sized computer with an LCD display of 80 characters by 8 lines. This allowed data collectors to enter data directly at the court record rooms, eliminating the keying from handwritten forms. By eliminating the keying charge I further increased the profit margin.

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About this time (mid 1980s) I was approached by the credit bureau operation of Trans Union, a Chicago-based bureau which served customers in the Midwest. They wanted to expand into the mid- Atlantic states and need a full seven-year backlog of legal data from Virginia and North Carolina. The volume was huge. I had a big recruitment job ahead of me as well as getting permission to get the data from the court record rooms.

All the data was public, so there was no way the clerks could exclude me, except by arguing that the presence of my collectors would disrupt their operation. One local credit bureau sued to be let in; the judge denied them entry. Obviously, I had to win the clerks over.

My approach was straightforward. I told them that I needed not a case or two but seven years back data. Usually my request was met with bug-eyed incredulity. After they got over their shock I asked casually if they knew of anyone who would be interested in entering data for me. After thinking it over it would usually come down to they had a relative who needed to make some extra money. My 'outlandish' request meant that cousin would be sitting quietly in a corner keying data into a portable computer. Everyone was happy.

My operation produced some interesting stories. A collector in a Virginia court had to go to an auxiliary storage room to get old records. The room was in a dingy, ill-lit basement of one of the city buildings filled with all sorts of odd stuff. While opening drawers in an old file cabinet, she came across evidence from an past murder trial – glossies of a gruesome corpse, vials of blood, etc. Just then the strange man whose job it was to carry records between the courthouse and the storage room suddenly appeared. When she recounted this story, I was expecting her to quit, but instead she said "I was so scared I went back to my car and got my gun!"

In a case in Maryland, I rented a copier machine to photocopy records from a courthouse and asked the firm manager if he knew of anyone who wanted part-time work. He said his teenage son was interested and so I hired him. This kid could only be described as a callow youth. A few weeks later I returned to see how things were going. The boy said to me about the thirty-some married women in the record room, "Do you know what the women talk about all day?" He got an education along with a job.

The Internet

The internet has made a difference in the payment process. Credit cards can be validated online during the checkout process leading to a seamless shopping experience. The internet has made possible purely internet based payment systems such as PayPal and Apple Pay. It has also made charitable donations more easy through such sites as GoFundMe. The internet further let to the growth of online merchants – Amazon being the first but then 'brick and mortar' retailers adding online offerings of their own. The internet did not replace catalog sales; there are more catalogs being produced now than ever before. Truth is, the two media complement each other. Furthermore, one sees print media (newspapers, magazines) advertising websites.

Final Comments

All these changes – the malls, catalog and internet shopping led to the death of the downtown main street merchants. In my legal data collection business, I would occasionally visit some small town that it seemed that time forgot. There would be individually owned stores and diners, not chains. The first time I experienced this I thought I had gone through some time warp and was transported back to a small town like the one I grew up in some seventy years ago.

In the 55 years since we graduated each of us has, in some way, contributed to the vast changes that have occurred in our lives. It is easy to see the progress; it is less easy to see what we have lost.

Conrad Grundlehner '64, M.A. in Applied Economics from the University of Pennsylvania, is the retired president and owner of Conrad Grundlehner, Inc. a firm engaged in legal records collection and sale. After graduate school he conducted work measurement studies for the Department of the Army at Frankford Arsenal. Then he was the co-developer of a trading model utilizing mutual funds. After several positions with the consulting firms of Hay Associates and Strategic Planning Associates, he founded his current firm. He is married to the former Marietta Guidon, a retired nephrologist.

Checks are Going Away and Have Been for a Long Time

Bob Popadic

Banking 1960's Style

Technique 1964 Business Staff in front of Bursar's Office – Trying to cash a check after hours?

Banking at the MIT Bursar's Office

The business staff of the 1964 Technique, the MIT Yearbook, is pictured above visiting the Bursars Office – probably couldn't do that today. As Editor in Chief I was introduced to high finance, being one of the folks who could sign checks that required two signatures. Believing systems should be checked, a pun intended, we wrote some checks and signed them Donald Duck and Mickey Mouse. Interestingly the bank happily paid them. I would learn later that while it might have been neglect, it was more likely a conscious trade off of the potential cost of a loss versus the certain cost of checking signatures on every small check. If you made a purchase at a store, yes the bricks and mortar kind, you paid with cash, a check, or charged it to a store-specific credit account. If you ordered something by mail you likely mailed a check as payment. If you placed the order by phone you might have it delivered COD (cash on delivery). If the shipper was not local to you the package came by USPS (United States Postal Service) or Railway Express. UPS, DHL and FEDEX were all in the future. I can remember the excitement of getting a postcard saying the set of dishes I ordered for my parents and paid for with a postal money order had arrived by Railway Express and to come pick it up.

Cash Was King and You Didn't Get it from an ATM

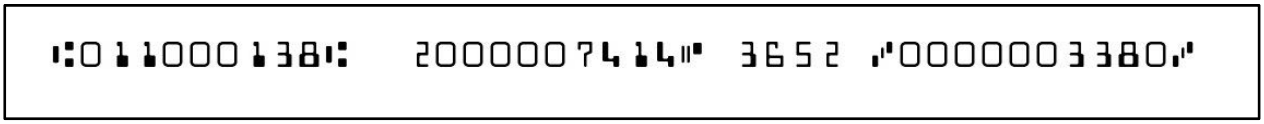
In my personal life as a student I returned to the world of cash, no checking account, the Bursar's Office was where I'd cash checks. These were the days when $10,000 bills were still in circulation – if inflation applied, a value of over $81,000 in 2018 dollars. They were taken out of circulation along with $5,000 and $1,000 bills starting in 1969.

If you made a purchase at a store, yes the bricks and mortar kind, you paid with cash, a check, or charged it to a store specific credit account. If you ordered something by mail you likely mailed a check as payment. If you placed the order by phone you might have it delivered COD (cash on delivery). If the shipper was not local to you the package came by USPS (United States Postal Service) or Railway Express. UPS, DHL and FEDEX were all in the future. I can remember the excitement of getting a postcard saying the set of dishes I ordered for my parents and paid for with a postal money order had arrived by Railway Express and to come pick it up.

Times moved a bit slower them. No online ordering because there was no online; and therefore no need for suitable online payment mechanisms. Since for the consumer it was a largely cash based world, how do you get cash from bank tellers that keep bankers hours? With difficulty, since bankers hours were 35 hours a week 9-5 and branches closed even earlier. Bankers needed to get to the country club to play golf, didn't they? Checks need to get to the processing center. Partly the bank access problem was addressed by paying people in cash and businesses often cashing checks for employees.

If cash is king, why not dispense it from a machine? – No need to change banker's hours. Enter the **ATM** (automated teller machine, not asynchronous transmission method). The first ATM in the US was installed by Chemical Bank in 1969. In 1970, there were 151 ATMs in the US. The number grew over the decades dispensing cash and reinforcing "Cash is King." By 2009 there were 425,010 ATMs, dispensing cash and occasionally accepting deposits, but cash was no longer king. Those magnetic striped ATM cards did not become true debit cards suitable for store purchase or use online until the 1990s as point of sale networks became available. By 2013 about 30% of consumer purchase transactions were made by debit cards, more than cash.

General Purpose Credit Cards did not exist in 1960. There were store and gas cards (not necessarily plastic), which identified you to a specific merchant. There were special purpose credit cards like Diner's Card (started 1950). Bank of America started offering a regional general-purpose card in 1958; and started licensing other banks in 1966 – remember Captain Americard, their marketing mascot? By 2013 about 22% of consumer purchase transactions were made with credit cards. The share having declined from 28% in 2000 as the use of debit cards grew.



The MICR line at the bottom of the check as it has been since the 1960s: Preprinted bank routing number, customer account number, and check number; and amount of check encoded by bank of first deposit.

In 1960, if cash were king, **Checks** were not far behind and decidedly the dominant form of non-cash payment and business payment mechanism. In 1960 about 13 billion checks were written. As a student, I didn't have a checking account, which probably was the norm at that time. While we were at Tech, check processing was still shifting from manual processing machines to computers. MICR (magnetic ink character recognition) encoded checks were introduced in 1959. These are the characters, then and now, printed at the bottom of the check which identify: the paying bank, the customer's account number, check amount, sometimes the check number. The first three are applied by the check printer, while the check amount is added (encoded) by the first bank receiving the paper check. The MICR character set has 14 characters, ten numeric plus control characters. The funny characters printed in magnetic ink were read by magnetic sensors, which produced a different waveform for each character. High tech in1959.

By 2013 the once dominant check was only 8% of consumer transactions, down from 53% in 2000. Checks written by businesses and consumers peaked at 49.5 billion in 1995. The use of checks started to decline as a percentage of transactions long before that. Checks are still around, however having survived - although in much smaller numbers - the onslaught of credit cards, debit cards, ACH (automated clearing house, a bank network for exchanging debits and credits to customer accounts) items, check conversions, on line shopping, and other indignities. Today there is even a RDC (remote deposit capture) app for depositing checks within many online banking cell phone apps.

Besides the ever present march of technology, the slow demise, but not death of checks has been aided by changes in the structure and concentration of the banking industry. In 1960 there were no banks with a national presence. The "national" in their name indicated they held a Federal not a state charter. Bank branches of both federally and state chartered banks were limited by state laws to: the state (e.g. New Jersey), the county or other instate geography (e.g. Massachusetts), or a single location (a unit bank, e.g. Illinois). Who would have believed in 1960 that a major US bank (Bank of America) would be headquartered in North Carolina? The rest of this essay explores the journey of checks as they Keep Going Away, but are not yet gone.

An Accidental Banker

After MIT I went up the river to Harvard for two years of grad school and then on active duty with the Navy. I was stationed at the government contracting office in Newport News Virginia. We were the pilot for development for a program to determine percentage of completion of a ship and consequently the payment to the contractor. Naval construction was in transition. Traditionally you ordered a ship at prices that were almost quoted in dollars per ton and came back to pick it up when done. A bit of an exaggeration, but Naval ship construction was becoming more like the aircraft industry with weapons systems and other changes being made during construction. As a consequence there was design work, materials ordered, and construction done that was no longer needed and might have to be removed. Neither the government nor the contractor were happy with the determined percentage of completion and the payment derived from it. I was the local day-to-day liaison person.

It was 1968 and my active duty time was ending, and I wasn't interested in the job offer from the project contractor (legal in those days), so asked the HBS alumni office to set up some appointments from me on a trip to Boston. Had one with State Street Bank, not sure why I wanted to talk to a bank, but it was too late to cancel. Turned out George Rockwell convinced me to join the bank in the Data Processing Division, which he headed. I was responsible for all admin except human resources and the management sciences department. Part of the orientation for new officers was to spend time on all shifts in all departments. That included a evening watching checks being processed. Back in those days, paper checks stayed paper throughout their life – from deposit to return to writer. Over the years, that was to change dramatically, as paper checks: were no longer returned to the writer, were transformed into ACH items, and converted in images by customers.

Checks received by tellers were transported to the operations center, mostly by truck. The amount was encoded, key entered, and printed in MICR font in magnetic ink, then checks were sorted based on if they were "on us," drawn on the bank of first deposit doing the processing, or needed to be shipped someplace else. Some place else could be: the local Federal Reserve Bank for either delivery to local banks or movement to other Feds via the Fed's private air network; a local clearing house where couriers from different banks exchanged bags of checks; or a correspondent bank (often by air) for further sorting and delivery to their local correspondent banks. At State Street, at the time we processed checks and did account processing for many New England banks.

The IBM 3890 check sorter was introduced in 1973 and could process 2400 6" checks per minute. This is a later model than the one I was introduced to in 1968.

One night I was introduced to the check sorters, which microfilmed the checks; put them in pockets by destination; and updated the records associated with the pockets, including capturing data for posting to our customers' accounts. The sorters were driven by IBM 1401 computers, with 16 to 32,000 word of memory (enough to hold a company logo today). One memorable event was having the bottom of the sorter opened to show shredded checks. The percentage was not insignificant, but later decreased with improvements in technology. Today most checks never see a sorter - more about that later when we talk about remote deposit capture.

The "on us checks" which were received by tellers or sent to us by other banks were stored, sorted by account number and then paired with printed statements to be mailed to the account holder. It was quite a trick to get the right pile of checks in the envelope with the right statement.

The 1970s

While working at the bank in the 1970s I was first told checks are going away, an event repeated many times over the next decades. The number of checks written were still increasing, but credit cards were increasing their share of non-cash payments. Checks are indeed going away, but at a glacial speed, as new technology has kept them alive.

Clearing Houses, Networks and Devices Change

The seeds of change planted in the 1960s started to mature and new seeds were planted in the 1970s. During the decade there was an increase in clearing houses, networks and devices where transactions could be initiated.

Clearing Houses are needed when a system extends outside the boundaries of a single entity and settlement is needed. American Express was an example of a single entity system where one provider has both all merchants and all cardholders. Check clearing houses are need to enable multiple banks to work together, since only a fraction of the checks bank customers deposit to their accounts are drawn on other customers of their bank. The first Automated Clearing House for electronic items was formed in 1972, and by 1977 there were 32 serving banks, thrifts and companies. The volume continues to grow.

Networks Proprietary electronic networks already existed for ATMs. Multi party networks enabling clearing and settlement can include delivery of checks and other financial documents by foot, truck and plane; but usually in the banking world it means something electronic. The grand daddy is Fed Wire, which goes back to 1918 and its leased line telegraph network. Shared networks emerged for ATMs, credit cards and debit cards.

Devices The number of ATMs reached 20,000 by 1980. Telephone had been used for credit card authorizations in the 1960s. Non-voice authorization terminals emerged in the 1970s. Early POS (point of sale) terminals designed to replace submission of paper credit card slips emerged, but by the end of the decade the number of POS transactions was still not significant. At the end of the decade some home bank offerings were starting to emerge using cable TV and computers.

The stage was set for expansion in the decades to come.

During the 1970s credit card usage increased dramatically with general-purpose cards replacing dedicated merchant cards for many. ATMs proliferated dispensing cash and accepting deposits in envelopes. Telephone bill paying was introduced in 1973. In 1975, the Federal government started offering Direct Deposit (an ACH service). These offerings reduced the need to visit a branch and use a teller. During this period cards displaced cash and checks for many purchases. At the same time, many employers and benefit providers switched from checks to the use of Direct Deposit, which created ACH (automated clearing house) items.

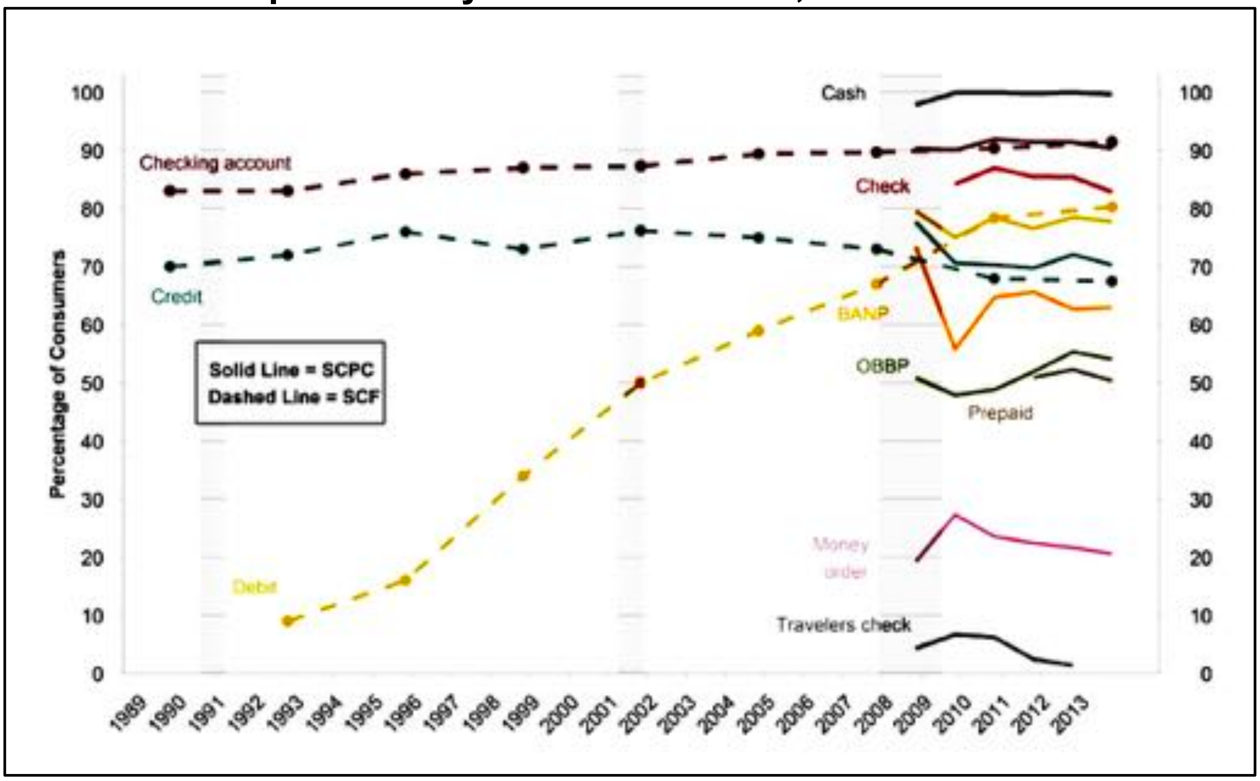
In 1980, checks dominated non-cash payments with 34.0 billion checks written, compared to 1.3 billion credit card transactions and 239 million ACH items.

The 1980s and 1990s

The 1980s and 1990s were decades where consumer adoption of payments instruments that emerged in the 1970s increased. The figure below shows for the period from 1989 to 2013, the percentage of consumers who had various payment instruments. In 1989 about 85% of consumers had checking accounts and 70% credit cards. By 1999 there were modest increases in the percentage of consumers with checking accounts and credit cards. On the other hand there was a dramatic increase in the number of consumers with debit cards (over 30%).

Looking ahead, by 2009 access to debit cards would over take credit cards. And a number of new ways to make payments would emerge.

Consumer Adoption of Payment Instruments, 1989–2013



Source of graph: Consumer Payments Research Center. Source: 2008–2013 Survey of Consumer Payment Choice (SCPC); 1989–2013 Survey of Consumer Finances (SCF). BANP – Bank Account Number Payments, OBBP – Online Banking Bill Payments. Vertical shading shows recessions.

By 2000 with strong consumer adoption of debit cards, debit transaction volume was well on its way to challenging both that of checks and credit cards.

Consumer Initiated - Non-Cash Transaction Volume - 2000

	Number (Billions)	Percent
Checks	28.3	53%
ACH	2.2	4
Offline Debit	5.3	10
Online Debit	3.0	6
Credit Card	15.0	28

Changes in Check Processing

Up until the early 2000s couriers rushing to meet operational deadlines was the norm. Checks were picked up from branches and ATMs and delivered to the operations center, where they were processed to meet deadlines for presentment to the Fed and other institutions. During the day customer accounts were updated. The cycle repeated itself every business day.

Over the years, check processing changed in a number of small ways. Imaging was added to the encoding machines, so that instead of the operator keying the amount having to look down into a mechanism that transported the individual checks, the operator saw the check enlarged on a screen and from that key entered the amount. Next came power encoding, where OCR (optical character recognition) was used to encode the amounts. Even with a significant percentage of checks unable to be processed automatically, banks experienced processing savings.

The first change to the "lives" of paper checks came in the 1970s when some financial institutions started offering "check safekeeping", where rather than returning the checks the customer received a listing of the checks paid. Safe keeping meant that if you needed a copy of the check, the bank would provide one. As a result banks offering it experienced significant processing and postage savings.

Not all customers appreciated the lack of returned checks. Banks responded with image statements, which included copies of the fronts of checks (and also backs for commercial accounts). Paper checks were still being moved about until they reached the check writer's bank.

By 2002 businesses were allowed to convert a retail customer's check to an ACH item at the point of purchase (POP), and convert checks to ACH items at lockboxes (ARC), subject to some restrictions. These checks traveled no more and the customer did not receive the check or a check image with their monthly statement, only an item listed on the statement, which when conversion was first introduced often lacked a check number. ACH items are subject to their own set of regulations, which are not the same as those for checks.

For some time, the Fed had been looking at moving images of checks rather than the checks themselves. While I was at Arthur D Little we looked at a number of alternatives for the Fed. One of the issues hindering replacing checks with images in the collection process was whether an image was a negotiable instrument, subject to the rules and regulations that apply to checks. This issue did not arise with image statements since the images were of checks already paid. Another issue was how to migrate many banks and processors from the current paper environment to the electronic.

2000s Poised for a New Set of Changes

Phone, catalogue and Internet shopping was beginning to impact in person shopping. Over time the number of establishments accepting only cash had declined. The Post Office and fast food chains were now accepting debit and credit cards. Cards were being accepted at mobile and temporary sales locations. Of 29.5 billion electronic payments in 2000, 5.3 billion were off line debits, predominantly signature based; and 3.0 billion were online debits. ATM cash withdrawal transactions had declined.

Lowered communications and terminal device cost were driving increased traffic on existing network infrastructures. In 2001, total ACH transactions reached 8.0 billion, up 16.2% from 2000, largely the result of business-to-business transactions. Poised to grow from small numbers were onetime ACH transactions: Point of purchase check conversion (POP), account receivable conversion (ARC) at lockboxes, as well as web and phone initiated ones. The total number of checks written increased from 32 billion in 1979 to 49.6 billion in 2000, but checks share of non-cash payments declined from 85% to 60%.

Check Image Capture – Paper Becomes Electronic

The Fed proposed the Check Truncation Act in 2001, which the Fed Vice Chair said "would remove existing legal barriers to the use of new technology in check processing and holds the promise of a more efficient check collection system."
The Act died in the aftermath of 911. In 2003 the Check 21 Act was proposed and passed taking effect in 2004.

The Act provided for: the equivalency of images to physical checks; the creation from image data of substitute checks for presentment to banks not yet ready to receive images; and provided for check image guarantees from banks to other banks later in the processing, including the paying (check writer's) bank. Unlike checks converted to ACH items, check images were subject to the same check regulations as paper checks.

Example of a substitute check – front of check.

The stage was now set for paper checks to cease to exist at the first point someone could convert it into an image. And over time the list of ways someone could do that grew. Conversion of paper checks to images began at check sorters at processing centers, in part because many sorters were already imaging checks electronically for image statements. The Fed eliminated its private airline that moved paper checks between their processing centers. Imaging reduced the time it took for checks to be collected, and thus reduced float (value from the time a check was written until it hit the customer's account for payment).

If you could convert a paper check to an image at a processing center, why not elsewhere? Even before the Check 21 Act passed Zions Bank subsidiary Net Deposit was working with the bank's customers to pilot capture check images at business locations. The hardware involved was fairly expensive. It was a dedicated check scanner, attached to a PC, capable of imaging both side of a check while maintaining physical control of the check. This assured that images of front and back of the check were kept together, and thus satisfying the legal definition of a check.

Medium speed check scanner used to create front and back images of checks.

With passage of the Check 21 Act only businesses with substantial volume could justify the equipment expense. At the same time banks were looking to placing scanners in branch back rooms, that could send images to the processing center and thus save money by eliminating the costly courier routes that were designed to meet processing center deadlines. As demand for dedicated check scanners increased, new lower cost models were introduced. This enabled placing scanners at teller stations and allowing businesses with lower check volumes to deposit checks from their offices. The benefits to businesses were the ability to make deposits later in the day and avoid the cost of personnel going to the bank.

In June of 2005, Bank of America launched a pilot check image capture program in Charlotte using ATMs; and rolled the program out nationally in 2006. The ATMs had dedicated check scanners built in. Offering the service provided benefits to both the bank and its customers. Previously deposits were made at ATMs with checks or cash placed in envelopes that were picked up, usually daily, and transported to the processing center where they were opened by two people to confirm the deposit amount, particularly cash, entered by the customer. Customers felt more comfortable with imaging than with paper envelopes because they could confirm that the amount read from the check image matched what they had entered. Banks no longer had to stick to strict daily schedules to pick up deposited checks for transport to the operations center to meet processing deadlines. ATM servicing could be more flexible based on when the ATMs were likely to run out of cash.

In 2003 my company, Lighthouse Consulting Group, developed a conceptual design for a check deposit appliance, much like a postage meter, that could image checks and deposit them without the need for a PC. In 2005, we filed a patent application titled Ubiquitous Imaging Device Based Check Image Capture, which described how already owned commonly available single sided imaging devices, such as fax machines and flat bed scanners, could be used for check image capture. We believe our patents apply to ubiquitous devices not in existence at the time of our patent filing, such as cell phones. Cell phones would become the dominant method for consumers to deposit checks remotely.

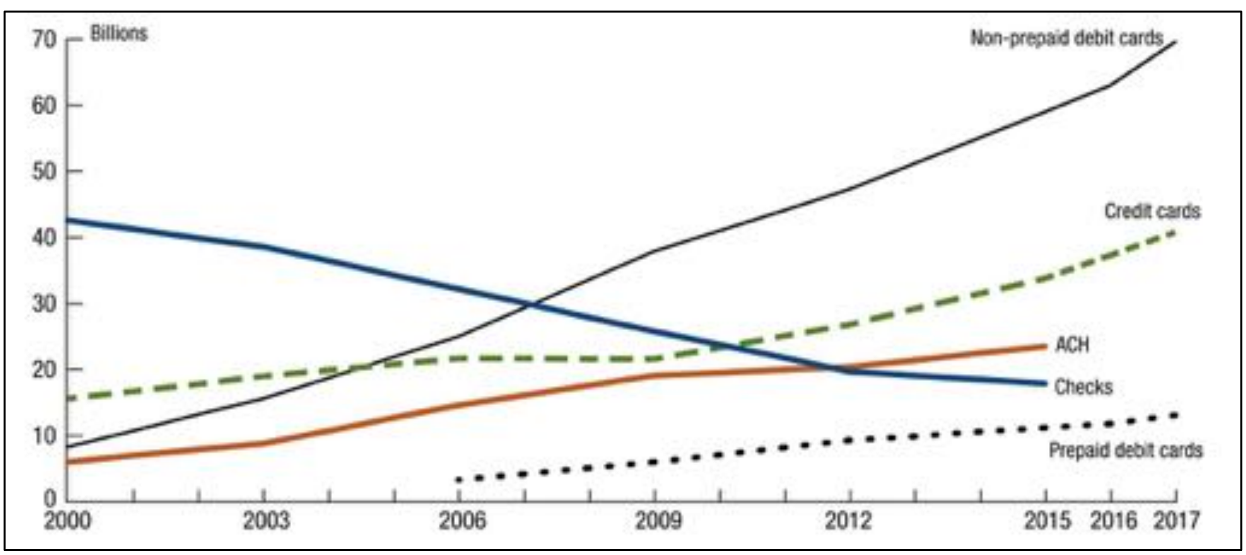
USAA (United Services Automobile Association) started offering a flat bed scanner solution in 2006 to their active and retired military members. It was a natural choice for an organization that had few branches and served members all over the world. Earlier they had pioneered having deposits dropped off at convenience stores from where they were overnight shipped to the processing center. USAA also became a leader in the use of cell phones for RDC (remote deposit capture), the new name for remote check imaging. They introduced making deposits from member cell phones in 2009 using software they developed or jointly developed with Mitek Technologies.

Key to the USAA RDC offering was the iPhone. The iPhone introduced millions of people to apps, made touchscreen interfaces the norm, and had the most attractive design of any mobile released to that date. By 2008 they were capable of capturing and transmitting check images. In 2010 Chase began to offer RDC and the rush was on for banks to offer this capability to their individual and small business customers.

Bank of America's current remote deposit capture application shown here ready to take an image of the front of a check. A separate step takes an image of the back of the check. The separately transmitted images are paired at bank's site to form a complete check.

Today nearly every bank offers their consumer and small business customers a cell phone based RDC solution. Millions of bank customers use their cell phones to deposit billions of checks per year.

2010s Checks Continue Decline



Trends in Non-Cash Payments, by Number 2000-17 Source: the 2018 Federal Reserve Payments Study

The graph above shows that by 2005 debit cards transaction numbers had overtaken credit cards and by 2007 they exceeded checks. With the bottom of the recession past in 2009, credit and debit card volume grew, while check transactions continued to decline.

Summary

In the 1960s checks had very little competition for non-cash payments and stayed in paper form throughout their life. Checks were transported by foot, truck and plane, from the writer's hand, through the banking system, to be returned to the writer in its original paper form covered with endorsements acquired in its travels. The first processing change was the elimination of returning paper checks by "safekeeping," by some banks. The bigger change came when many banks implemented image statements.

Credit cards and then debit cards nibbled away and then consumed the check as a payment vehicle. ACH items replaced some checks used for: direct deposit, consumer payments for reoccurring bills; and for business to business transactions. The decline of checks was further helped by the growth of online shopping, where checks could not be accepted. However, the data on the bottom of the check could be used to create an ACH item. Paper checks could be converted to ACH items at point of sale or at lock boxes. So a payment that started out as a paper check would be something else by the time it reached the customers checking account. Today paper checks are converted to an image by the first person who can, including the consumer using her or his cell phone.

Paper checks are still printed, but hardly any are returned in paper form to the original writer. I first heard, about 45 or so years ago, that "checks are going away" and indeed they are … going. Sometime in the future all that will remain of checks is the name they gave to an account type – Checking Account; and children will ask their patents where did that funny name come from.

Bob Popadic '64 Course 6, Harvard MBA, spent his career in the financial services industry as a bank executive and consultant, including VP Computer Services, General Manager/EVP Leasing, VP Corporate Planning, and Consulting Practice Leader.

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Science and Technology

Left, Gordon Brown, head of MIT's Electrical Engineering Department uses a take home lab kit – often referred to as tooth pick engineering. The kit contained discrete components – transistors, resistors, capacitors etc. – no integrated circuits which while were available, but quite expensive.

Bottom, Apple Watch. In the 1950s and 60s Dick Tracy, a comic book detective used a watch to communicate. The Apple Watch makes it real and reflects the massive shrinking in size of computers and increase in processing speed.

Hard to believe, today you can accidently throw out your laptop with a pile of magazines.

Moonshot

David Saul

Introduction

Moonshot. The word evokes not only traveling to Earth's neighboring satellite, but also has evolved into a dictionary definition of "an extremely ambitious and innovative project". Comparisons to the Moonshot for seemingly intractable projects have become part of our culture. People say "If we could fly to the Moon, why can't we (*insert big project name*)?" For this essay, I will attempt to draw parallels between my own personal career and MIT's contributions to the US space program.

MIT's involvement with NASA and the space program goes back to the early days of aviation and is inextricably linked to the success of the Moon landing. I believe that describing the Moon landing as a "mission" is important because it highlights how having a difficult goal, which many consider impossible, can lead to a glorious result. We should not underestimate the tremendous problems in propulsion, navigation and life support that had to be solved. As alumni, we should be justifiably proud of the role that MIT played in the success of mankind's first Moonshot. One would have to go back to the Manhattan Project, where MIT was also instrumental, to find a historical analogy of such proportion.

The Apollo 11 mission that landed men on the Moon and returned them to Earth celebrates its fiftieth anniversary in 2019. We all probably remember where we were in July 1969 when that occurred. My wife, Susan, and I were inches away from our black-and-white Westinghouse television for that first "small step" and "giant leap". In this essay, I highlight how the Apollo program could not have succeeded without MIT's contribution. In the process, I will also document my personal history leading up to my involvement in the program before, during and after MIT. I don't intend this to be a scholarly document, but I will provide popular culture references to books and movies, where appropriate, if you would like to branch out from what I have written.

My Early Interests

I first became interested in Astronomy and the planets while still in elementary school. We had an out-of-date encyclopedia at home where I could not get enough of reading about them, Mars and the Moon in particular. Fortunately, planetary information was not changing very much in the 1950s. We still considered Pluto as a planet. In Junior High School, I discovered Science Fiction literature, a behavior I suspect I share with many of you, my fellow classmates. It was a classic age for Science Fiction with authors like Robert Heinlein, Isaac Asimov, Arthur C. Clarke and Ray Bradbury as well as a number of others who bridged across to hard science, like Willy Ley. I became a multiple times a week visitor to our local public library in Brooklyn, New York, where I took a direct path to the Science Fiction shelves. When I could afford it from my allowance, I would buy a copy of Popular Science magazine and devour their imaginative articles about space stations orbiting the Earth or interplanetary travel. I read everything I could about the nascent rocket program under Werner Von Braun in the White Sands Proving Ground and the technology that had been transferred from Germany.

One of the classic toys when we were growing up was an inexpensive metallic gyroscope. You would wind a piece of string around it and pull to start the gyroscope spinning. The gyroscope would maintain its orientation, when tilted, based on the principle that angular momentum changes in the direction of torque. Who would have thought at the time that a children's toy would be the scientific basis that made interplanetary navigation possible?

I was accepted into Stuyvesant High School in New York City, but attended for only one week before my Father's business relocated to St. Thomas in the Virgin Islands. It was quite a culture shock to move into an isolated environment without television and a library sorely lacking in Science Fiction books. I truly believe that led me to focus on studying and creating the academic record that helped me get admitted to MIT.

My Path to MIT

The launch of Sputnik in October, 1957, solidified my commitment to study aeronautical engineering. How the Russians could have leapfrogged USA technology was a shock to me, as well as to the US Government. It clearly helped provide focus and funding for the first US satellites and a year later to the establishment of Project Mercury. The names of those first "astronauts", Shepard, Glenn, Grissom, *et al*, are well known. Tom Wolfe's book, *The Right Stuff*, is an excellent non-fiction novel from 1979 about them and was adapted as a movie in 1983. Later, while at MIT, we had newer astronauts in our classes and I could still see some of their maverick characteristics that had been captured in *The Right Stuff*. In 2001, the MIT News Office published a full list of the thirty-one astronauts who had been educated at the Institute, including the second human to set foot on the Moon, Buzz Aldrin. http://news.mit.edu/2001/commnasalist-0606.

My college search was narrowly focused on schools with leading technology programs. MIT topped the list. I still had family in New York City and they wanted me somewhere closer, but my mind was set. When I received my MIT acceptance I could not wait to reply. I had not visited any colleges before applying due to my distant location. The first time I saw MIT was in 1960 from my taxi traveling from Back Bay train station to Baker House. Not surprisingly, the taxi driver had trouble finding Baker House's rear entrance, knowing only its Memorial Drive address. Future generations, confident in their GPS devices, don't have that problem.

At MIT, for the first time, I was with others who enjoyed the same interests I did and who reveled in being science and engineering geeks. That is not to say that the pace of learning at MIT was not a shock. The phrase "drinking from a fire hose" became reality. But I knew I was at the right place.

At MIT

After freshman year, I selected Course 16, renamed Aeronautics and Astronautics from Aeronautical Engineering, as my major. The department was transitioning from analog to digital technology, providing my first exposure to computers. I did not realize at the time how digital technology would come to dominate not just my studies but create an industry and revolutionize the world's economy. Simultaneously, in 1961, Alan Shepard became the first Mercury astronaut to fly. Many of us became devotees of the Baker House TV room to watch those launches. In 1962, John Glenn became the first astronaut to orbit the Earth, although Russian cosmonaut Yuri Gagarin had accomplished this milestone first, ten months earlier. In May 1961, shortly after John Glenn's single orbit of the Earth, President John F. Kennedy announced the mission in a speech to a Joint Session of Congress: "First, I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the Earth". It is safe to say that most of the technical problems needed to complete this goal were still unsolved. The Apollo program had been born and MIT would be critical to its success, particularly to solve the navigation problem. Navigation at the degree of accuracy and precision required had never been attempted before and historical methods (compass, sextant, *etc*.) clearly could not be used beyond the Earth's surface. Inertial navigation, which MIT pioneered, was the only solution.

My Father came to visit MIT for the first time during my sophomore year. As I remember, it was a day designed for parents. After my classes I met up with my Dad and asked him what he had thought of the day. He had been impressed by the facilities in Building 33 and the various presentations by the faculty. But he did comment on a crazy man wearing a bow tie who had talked about flying a man to the Moon. It had been our department head, Charles Stark Draper, who everyone referred to as "Doc Draper". Clearly my Father was reflecting the common beliefs of his generation, born shortly after the Wright Brothers first flight, that interplanetary travel was science fiction. Many MIT faculty, staff and students contributed to the Moonshot, but Doc Draper is the single most important individual. Without his vision and leadership MIT's role in providing the navigation systems would not have happened. Doc Draper was a pilot himself who pioneered inertial navigation with airplanes. I remember seeing a grainy black and white film of an early instrument landing using his inertial navigation equipment where the cockpit had a canvas cover drawn over it to block out the pilot's view. In 2016 MIT did a short video tribute to Doc Draper at: https://www.youtube.com/watch?v=do2vBKe20GQ.

Technology Developed for the Moon Landing

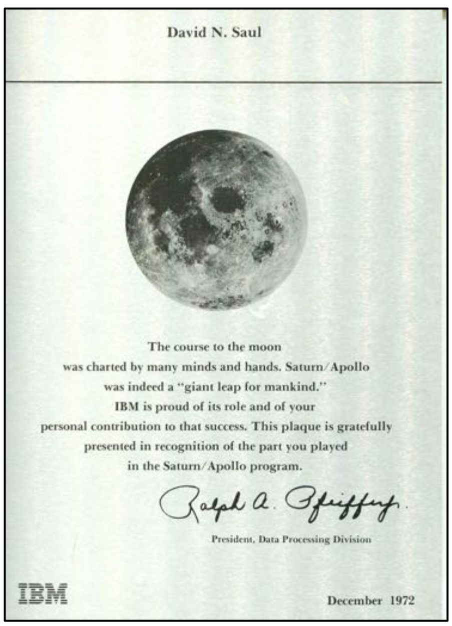
With the Gemini program, NASA started to build the capabilities necessary to sustain a Moon mission. We needed to discover the effects of prolonged weightlessness on the human body and whether astronauts could work outside in space, leading to the first "space walks". Mercury and Gemini were both based on military rockets, whereas a moon mission would require a propulsion vehicle far more powerful than anything ever built before. While I was a graduate student at MIT, the Aero department arranged a trip to Cape Canaveral for one of our classes. We flew down on a military flight from Hanscom AFB and were taken on a tour of the facility. We got to see the building which housed the Saturn V rocket that would eventually lift Apollo off into space and were awed by its sheer size. That night, we got to witness a rocket launch from the control room. Even though we were indoors, I still remember it as one of the loudest sounds I have ever heard.

In 1961, MIT Aero alumnus, Professor and then NASA Deputy Administrator, Robert Seamans, awarded to MIT the contract to design the Apollo guidance, navigation and control system. This included the Apollo Guidance Computer. By today's standards, the Apollo Guidance Computer was primitive. It was a 16-bit word computer that limited its precision to less than that of the 24-bit scientific computers then in use. But memory constraints were its biggest handicap. The original design had only 4K words of core rope memory, a variation on more common magnetic core memory. As NASA continued to add functions for the computer to perform memory eventually grew to 36K, still tiny by modern standards. Raytheon was chosen to manufacture the Apollo Guidance Computer based on their prior Polaris missile experience. That effort had been much less complex and left Raytheon with a big challenge to meet. There were two computers on board, one each in the Command Module (CM) and Lunar Module (LM). The user interface keypad and display were minimal due to size and weight constraints.

I had the opportunity to work on one of the ground-based guidance projects at MIT's Instrumentation Lab during my senior year. Instrumentation Lab has since been renamed Draper Labs in honor of Doc Draper and continues as a major government contractor.

Biennially since 1989, the US National Academy of Engineering awards one of the world's preeminent awards for engineering achievement, open to all engineering disciplines, the **Charles StarkDraper Prize**. It honors an engineer whose accomplishment has significantly impacted society by improving the quality of life, providing the ability to live freely and comfortably, and/or permitting the access to information. The recipient receives a $500,000 cash award and is one of three prizes that constitute the "Nobel Prizes of Engineering". In 2007 it was awarded to Sir Tim Berners-Lee, now at MIT, for inventing the World Wide Web, which is having its thirtieth anniversary this year.

I am sure that MIT contributed to manned space flight in many other disciplines in which I did not participate. These include materials science, human biology and the management sciences of running a massive, distributed development effort.



After Graduation

My first job after MIT was at IBM in Cambridge, just two Red Line stops away. That IBM office supported US Federal government customers and my first assignment was at MITRE in Bedford. Soon after that project, I was back in Cambridge working with the NASA Center in Technology Square. As part of the IBM support team, my experience at MIT's Instrumentation Lab had well prepared me for my small contribution, programming a portion of the Apollo ground controller computer. I even got to go back to their Cambridge Parkway location where people were surprised to see me return.

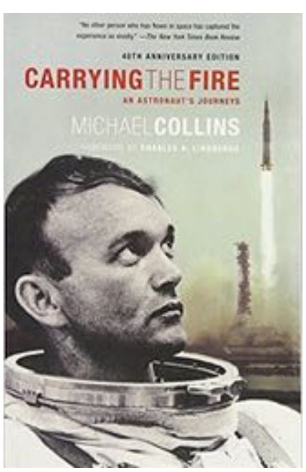
Ambitious projects show their true mettle in how they respond to setbacks. For the Moon mission, the tragic Apollo 1 fire in 1967 was the biggest test. The ways in which NASA responded and corrected the faults that had led to the accident were truly remarkable. Design changes to move away from a pure Oxygen environment that had accelerated the fire were accompanied by process changes in manufacturing and quality control. That Apollo 7 was able to validate "man rating" in 1968 was proof of the changes positive effect. The ambitious acceleration of the program would result in a risky but awe inspiring result when Apollo 8 flew before year-end 1968.

Apollo

NASA showed they were truly back on course when Apollo 8 circumnavigated the Moon at Christmastime 1968. Apollo 8 was the first manned spacecraft to leave Earth's gravitational field and orbit the Moon. The photographs that astronauts Borman, Lovell and Anders took changed our perception of the Earth. When they read from Genesis on Christmas Eve it was impossible not to be moved emotionally.

Apollo 8 and Earthrise

The successful Moon landing in July 1969 has been well documented including a Neil Armstrong focused movie last year, *First Man*, available from Amazon. It did a good job of highlighting just how risky the venture was and that astronauts still needed "the right stuff". The actor portraying Neil Armstrong, Ryan Gosling, managed to capture the concerns and conflicts going through Armstrong's mind with a minimum of dialog.



My personal favorite recollection of Apollo 11 is Michael Collins' book, *Carrying the Fire*, released in 1974. Collins was the Command Module pilot who orbited the Moon while Armstrong and Aldrin landed. Collins is a skilled writer, and he manages to convey what it was like to fly to the Moon and yet not be able to land and walk on it. He was also the first person to wonder how it would feel if his companions had not been able to return to the Command Module and he had to return alone to Earth, leaving them behind.

Exhibitions

In 2019, two major museum exhibitions will open to celebrate the fiftieth anniversary of Apollo 11. The National Gallery in Washington will be showing *By the Light of the Silvery Moon: A Century of Lunar Photographs from the 1850s to Apollo 11* from July until next January.
https://www.nga.gov/exhibitions/2019/century-of-lunar-photographs-1850s-apollo-11.html

The Metropolitan Museum in New York City will exhibit A*pollo's Muse: The Moon in the Age of Photography* between July and September.
https://www.metmuseum.org/exhibitions/listings/2019/apollos-muse-moon-photography

I cannot recommend highly enough the film, *Apollo 11*, released in March 2019. It contains much high definition material with views never before seen in public. The Apollo Guidance Computer memory overflow during the landing brought back memories. The movie particularly celebrates everyone who contributed to the Moon landing.
https://www.imdb.com/title/tt8760684/

A documentary, *In the Shadow of the Moon,* does an excellent job of capturing the entire scope of the Apollo program, from 1968 through 1972. It is available on Amazon Prime Video or DVD, as well as in a book edition. On July 8th PBS is premiering a three part documentary on the moon landing and the world in 1969, Chasing the Moon, along with a companion book. Information on the series is available at #ChasingTheMoonPBS.

The accident that nearly doomed Apollo 13 is well documented in the docudrama of the same name. One of the film's stars, Tom Hanks, has shown his continued interest in the space program with his excellent twelve episode HBO miniseries, *From the Earth to the*

Moon, which is available on DVD from Amazon.

After Apollo 11

The final lunar mission, Apollo 17, was in 1972 and was the last of the six successful Moonshots. By this time public interest in and support for lunar exploration had declined. NASA shifted its emphasis to the Space Shuttle and concentrated efforts on experiments in Earth orbit. When would we return to our Moon?

In 2017, NASA announced its new Moon mission. "We are going to the Moon," NASA Administrator Jim Bridenstine told an industry conference in May 2018. "To do so sustainably, we are going to expand partnerships with industry, to deliver payloads to the surface of the Moon. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization." If history is any guide, it seems impossible that MIT will not have a role in this latest Moonshot.

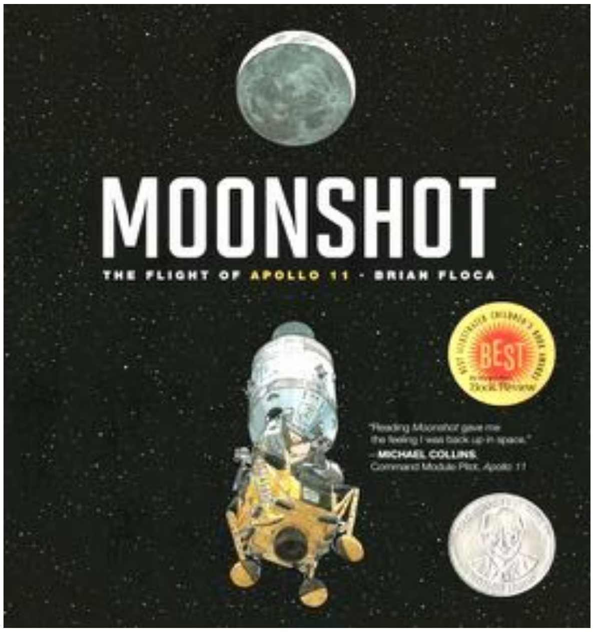
The smartphone that we all commonly carry today has orders of magnitude capability and a far better user interface than the Apollo Guidance Computer. Many of those advances in hardware and software technology are products of MIT research and companies started by MIT entrepreneurs. To further reinforce how far we have come in fifty years, Verizon's latest advertising for 5G technology begins with the phrase "50 years ago, engineers helped us reach the moon with technology less advanced than the average smartphone".

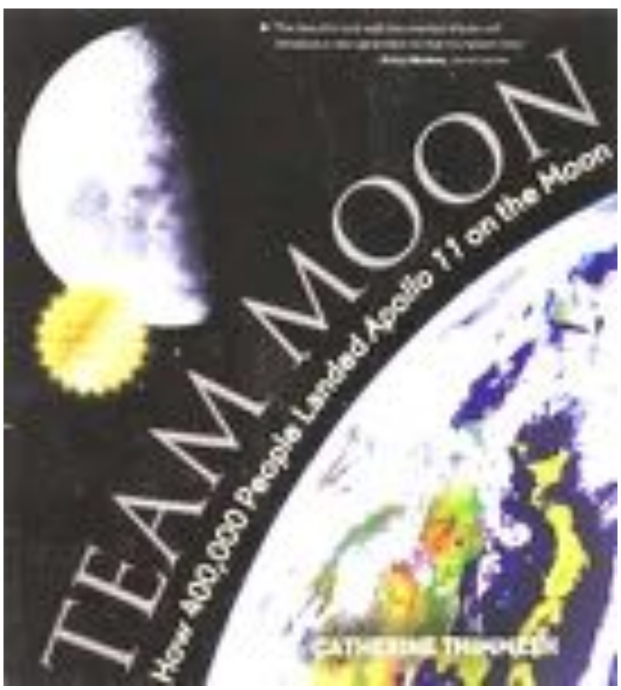
As I write this essay, a new book about Apollo 11 by James Donovan entitled *Shoot for the Moon* has just been published. In its publicity is the following quote from Apollo 11 Command Module Pilot Michael Collins: "This is the best book on Apollo that I have read. Extensively researched and meticulously accurate, it successfully traces not only the technical highlights of the program but also the contributions of the extraordinary people who made it possible".

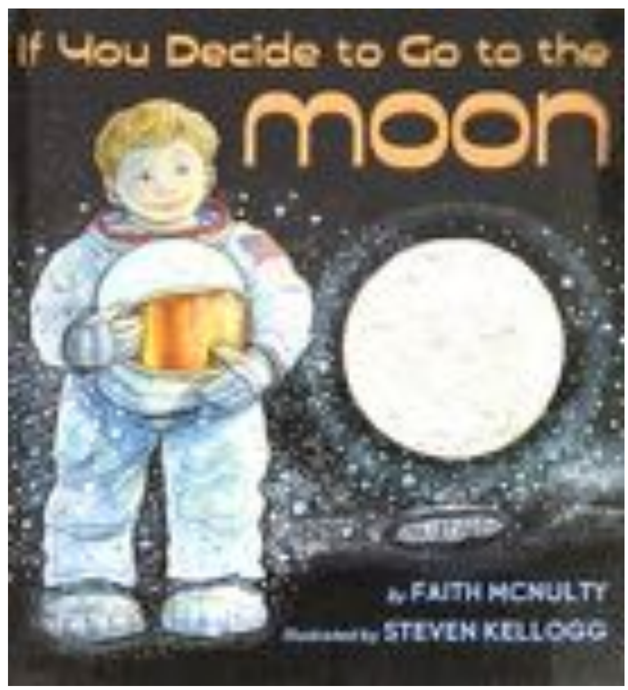
Concluding Remarks

In conclusion, I would like to end on a personal note. As the years pass, I think more and more about our grandchildren and the world we should be leaving to them. There are many lessons from history about injustice, intolerance and bigotry that we want them to disavow. The Moonshot is a lesson in cooperation and humility that we want them to emulate. It is estimated that 400,000 people worked in collaboration on the Apollo project, including NASA, contractors and universities, like MIT. I was struck by a recent column in The New York Times written by Bret Stephens entitled *How Neil Armstrong Stayed Humble*. Stephens wrote the article after he watched the current *Apollo 11* film twice and reflected on the character of the contributors to the mission. One quote from the article stayed with me: "And there lies the greatest marvel of the Apollo program: Not so much the size of the endeavor, or the machines that were built to accomplish it, but rather the quality of self-effacement among the men most associated with its success."

Here are several books, for different age groups, about the moon landing exploits that we can share with our grandchildren to help them understand its historical importance.







David Saul '64, his first job after graduating from MIT in 1965 was with IBM's Federal Systems office in Cambridge, as earlier described. His first management position was with IBM's Cambridge Scientific Center, where he oversaw advanced technology computer projects in virtualization, multiprocessing and networking. In 1981, his group developed IBM's first software product that allowed the IBM Personal Computer to communicate over telephone lines to mainframes. In 1993, he joined State Street and applied his computer skills to financial services. Today, he is State Street's Chief Scientist, where he focuses on applying innovation to their business.

The Journey of an Aeronomer

John Meriwether

Beginning an Aeronomy Career

My journey as an Aeronomer (a specialist in the physics and chemistry of the upper atmosphere) began in Winchester, KY, one early 5th of October 1957, as I got ready to deliver my morning round of the Louisville Courier Journal. When I rolled my papers for delivery, I saw the major headline was on the surprising Soviet launch of Sputnik. The word aeronomy was coined in the mid-50s to refer to the physics and chemistry of the upper atmosphere, which started as a new discipline as an outgrowth of the Space Age. Now that so much time has passed, I thought my classmates might find interesting a description of my career with a focus upon the Space Age, where so much progress and development have taken place during our lives, what with the Apollo 11 journey to the Moon in 1969, the development of the International Space Station in the 90s and later, and all the space probes sent out to explore the planets, inner and outer. I started doing aeronomy research as a University of Maryland (UMD) graduate student in the late 60s, just ten years after the launch of Explorer I by Van Allen that led to the discovery of the plasma belts in outer space – these are now known as the Van Allen belts. This interdisciplinary area became the primary thrust of what I did over the next five decades since I started in 1967 doing research as part of my dissertation in the UMD chemical physics program.

Three other threads also led me to my aeronomy career. A few weeks after the launch of Sputnik when I set out once again to deliver my papers, I saw the whole northern sky was lit up with a red color. It took me a while to figure out that this must be the aurora borealis, which was an exceptional event because it was taking place so far south. While riding my bike that morning I suddenly remembered reading about the aurora in the Norse fairy tales that I had read a few years earlier during the fourth and fifth grades. The second thread came later in 1960, when my family had moved to Louisville. My father and I stopped in Cherokee Park to observe the track of the Echo I satellite that was lit up very vividly by sunlight reflection from the satellite's silvery skin as the spacecraft passed overhead. And of course, my deep interest in science fiction at the time meant that space physics would indeed have a strong attraction for me.

Educating an Aeronomer

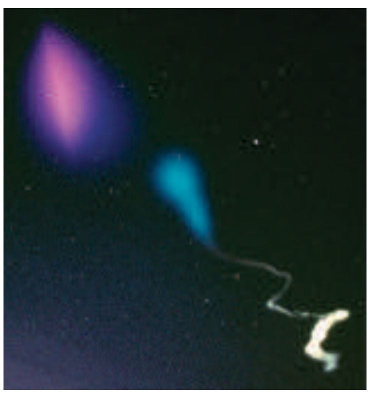
Still though, I had no particular ambition then to do aeronomy research. My pathway to becoming an aeronomer was first started by studying chemistry at MIT. I tell the story of liking very much to hear about atomic orbitals in the 5.01 chemistry class taught by Prof. W. R. Thorson, a quantum chemistry theorist, who had no hesitation to talk about atomic or molecular physics to first year students. He was frustrating for me, though, with my hearing impairment (severely deaf in both ears and eventually, many years later, I was treated with a cochlear implant) to have him walk back and forth while lecturing. Seeing his face just half of the time frustrated my lip reading efforts. Still, all this talk about quantum mechanics sounded rather cool to me. As I moved through the curriculum of the Course V major, my interest in physical chemistry and then chemical physics grew stronger and stronger. It was clear organic chemistry, though interesting, was not a career path I could get excited about – too many cooks and each one having considerable talent. In my junior year I rather enjoyed Prof. Isadur Amdur's physical chemistry class, perhaps because his voice was one that I could hear quite clearly, enabling me to overcome my hearing handicap. It was also at this time that I took the 5.70 statistical thermodynamic class from Prof. Oppenheim, in which I came to enjoy listening to the mathematical intricacies of investigating the implications that might unfold given a starting point of a representative model of the problem at hand. I found Prof. Oppenheim was a patient lecturer who took great pains to make his lectures crystal clear. I have never seen anyone since with his ability to walk into the classroom, pick up a piece of chalk, and write out without reference to any notes his lectures with great clarity and illuminating commentary. It was then that I knew my career direction was toward physics.

For grad school I went to the University of Maryland because it had a graduate chemical physics program, and I was excited to be at a campus near the National Capital. I had not been sure whether a large university such as UMD would suit me, so during the MIT 1964 spring break, I took a bus ride down to Washington and stayed overnight at a hotel outside of Union Station. I then took a train out to College Park and walked over to the UMD campus and found my way to the Institute of Molecular Physics, a small building specially designed to be rugged and stable as a great foundation for high resolution molecular spectroscopy. (For this same reason it was a home for one of Prof. Joe Weber's bar gravitational wave detectors; Dr. Weber was my professor in quantum mechanics. I remember him especially because he often treated his class students with stories involving the leading figures of physics such as Heisenberg, Schroedinger, and Dirac.)

A NASA rocket launch at Poker Flats, AK into aurora. (University of Alaska at Fairbanks).

I found the faculty and staff there at this Institute to be collegial and keen to have me come to UMD, which I did. I was satisfied that UMD would be a good home for me to undertake the studies in both chemistry and physics as prescribed by the terms of their chemical physics program. What I later discovered was that the rigors of a MIT education in chemistry had left me with the equivalent of a five-year curriculum. Thus, I was well prepared to start off my graduate program with just primarily classes in physics. Unknowingly, I was doing the right thing by getting a sound education in the fundamentals of physics and chemistry since this proved to be great preparation for studying aeronomy and space physics later on. It is quite strange to think of those years in contrast to today as aeronomy was such a young science. There were so many questions to investigate and study. It is so different nowadays with young researchers having to face mastering six decades of literature to study.

What proved to be even more of a motivating factor was the experience of going with my advisor to the Churchill Rocket Range located just off the Hudson Bay in February 1967 to do a dissertation project of observing the nitrogen molecular emission spectroscopy in the blue and red spectral regions with a fast filter wheel photometer. What we found as a result of that expedition was that the aurora became redder as it became brighter. To me what was even more exciting began with an arrival in mid-afternoon after a long jet flight up to Ft. Churchill from Winnipeg. Traveling by jet was for me at that time a very new experience that proved to be the first of many flights I would make to go off to some optical observatory for the sake of my research. Shortly after our arrival and after the evening twilight, a bright auroral green arc developed overhead and persisted until after midnight when it became even brighter with great auroral folds and draperies all over the sky. Just after midnight, a rocket was launched, and the trail streaked upward toward the aurora. I found that to be so exciting, I was hooked on aeronomy research from that point forward. The photo on the prior page illustrates an example of the experience of launching such a rocket into a vivid aurora display. A colleague of mine at Clemson University has had a very successful career flying rockets with a streak of at least 100 rocket launches that were all deemed to be successful. Doing rocket science is indeed a special experience in aeronomy but it was not a career path that I ever sought out.



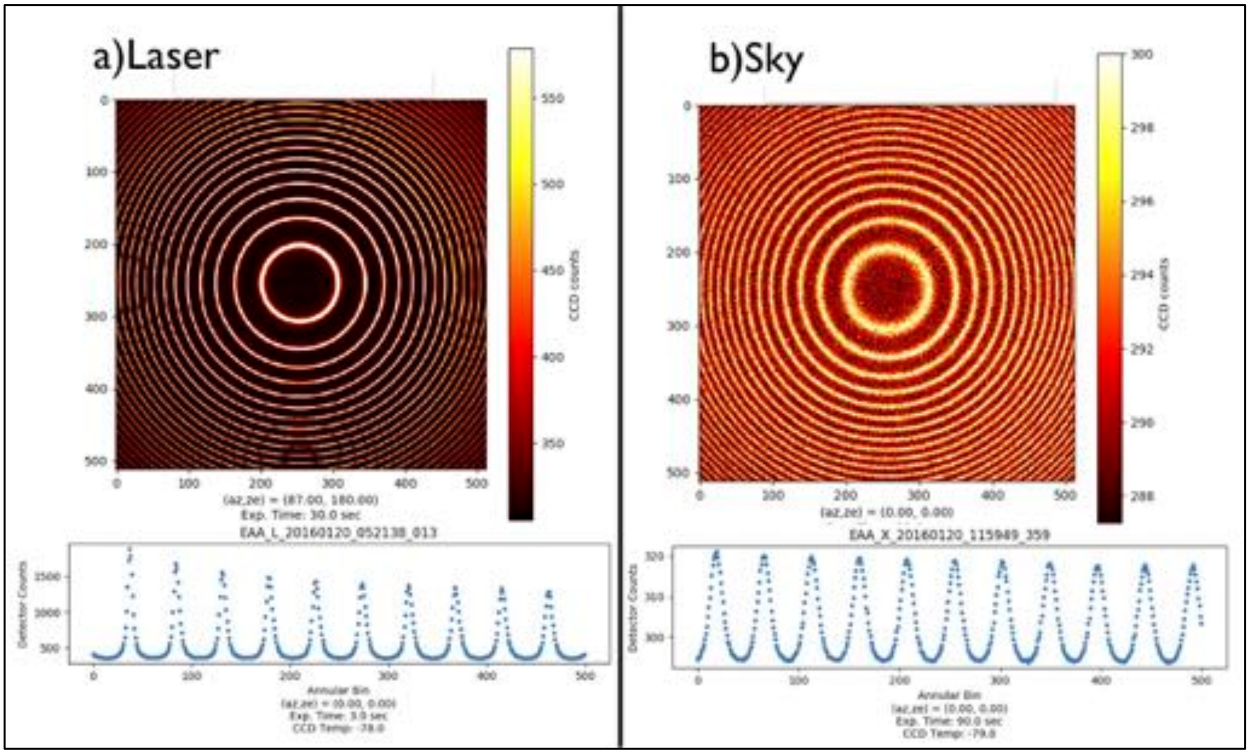
Photograph of a barium ion cloud release (pinkish-reddish color) developing striations along the magnetic field line as a result of the F-layer ionospheric electric field. Also shown in the vicinity of the Ba+ cloud is a neutral Ba/Sr cloud. Drifts of these clouds are measured using photographs obtained simultaneously from two camera stations. Also shown is a TMA (trimethyl-aluminum) cloud illustrating the multiple turns of the neutral wind vector between 90 and 140 km. (NASA attribution)

But Sputnik and the aurora borealis were not the only impacts on my career choice -- good luck put me in the right place at the right time. Toward the end of my graduate studies my advisor urged me to attend an international space physics conference to be held at the State Department in downtown DC. There I heard a talk about the use of barium chemical releases to track upper atmosphere winds (altitudes above 200 km) and plasma drifts. The way the experiment worked is that sunlight ionizes the barium to form ions that will drift in response to any imposed electric field. These ions will fluoresce in the presence of sunlight to form glowing reddish-pink clouds. The remaining barium (and also strontium) that is not ionized would form a neutral barium/strontium cloud that is purple-bluish in color. The photo above illustrates a barium ion cloud developing striated structures, the barium/strontium neutral cloud, and a trimethylaluminum trail all released in the same flight. The idea is that the upper atmosphere plasma drift and the neutral wind at altitudes above 225 km could be measured by photographing the motions of the Ba+ ion cloud (reddish glow) and the neutral Ba/Sr cloud, as these clouds drifted against the background of the "fixed" stars. Triangulation from two or more camera stations would establish successive positions of these clouds, and the ion and neutral velocities could be determined from these tracks.

Later that week I went to a cookout at the Goddard Space Flight Center. By sheer chance the person in front of me, Tom Skillman, in the line for barbecued steaks was an engineer associated with the Goddard research group that did that barium release work. After that conversation with me in which he learned of my strong interest in the experiment, he talked to his boss, Dr. Jim Heppner (the person that gave the talk I found so keen), and I was invited to go in for a visit with him at the Goddard Space Flight Center for an interview that led to a National Research Council (NRC) postdoctoral fellowship. As it turned out, Jim was one of the scientists associated with the Naval Research Laboratory group that sought to launch the Vanguard spacecraft. I heard from him his story of how he and his colleagues had worked feverishly to launch this satellite only to be faced with disaster on the launch pad.

Travels as an Aeronomer

This beginning took me to many places around the world. Part of the work that I did for Jim as a Fellow was to make a trip to Barter Island, Alaska, to help man a camera station to photograph the luminous barium clouds released from the rockets launched from the North Slope at the Bar Main DEW line radar station. What these experiments established for the high latitude locations within the polar region was that the plasma was driven to move in the direction of the Sun. Moreover, contrary to what one would have thought, i.e., air moves from the dayside toward the night across the terminator, the neutral air at these altitudes (above 200 km) within the auroral region moved toward the Sun in the evening twilight and southward during the morning twilight. These were early days in aeronomy research, and understanding of the underlying dynamical forcing physics came slowly as more observations were collected. Caught up with the excitement of being involved in these experiments, little did it bother me that the temperature at the camera station might have been as low as -50 C and the surface wind speed as high as 20 knots. I was well fitted out with Arctic gear and bunny boots and quite happy to be involved in such a project.



Images of the Fabry-Perot two-dimensional interference ring pattern seen for the laser and sky observations. Annular summing of both ring patterns around the ring center provides one dimensional interferogram that can be used to determine Doppler shifts and Doppler broadening. The increase of the full width at half maximum for the sky interferogram relative to the laser illustrates the hot temperatures of the upper atmosphere, which might be as high as 1000 K.

What became clear to me, though, during that period of my postdoctoral studies was that there must be a better way of studying the dynamics of the upper atmosphere than to launch a rocket each time you wanted to know which way the air or the ions at 250 km was moving. It turned out that there was an alternative ground-based approach based upon using a high-resolution Fabry-Perot interferometer (FPI) to measure the Doppler shift and Doppler broadening of the oxygen auroral red line emission at 630-nm. The way this instrument works is that the circular interference ring pattern will shrink if the air along the line of sight is moving away from the FPI. Alternatively, the rings will expand if the air is coming toward the FPI. A typical interference ring pattern obtained by a quality digital camera is shown in the figure above as well as the one-dimensional interferogram derived by summing the signals around the ring center. After having read a journal paper published by Prof. Paul Hays (University of Michigan) that made reference to this FPI application for measuring upper atmosphere winds, I stopped by to see him in Ann Arbor in March 1971 on returning from a series of NASA barium release experiments held in the northern region of the Hudson Bay. I indicated to Paul my enthusiastic interest in becoming a part of his group. I told him I was keen to master the nuances of this instrument's assembly, data collection procedures, and analysis. I also told him that I thought he should move his FPI instrument to Alaska. Little did I know what adventures this immersion with Paul's group would lead into. He liked my spirit and background and offered me a few weeks later a postdoctoral position with him to do exactly this project of running the FPI in Fairbanks, AK. The FPI instrument at that time was in a primitive state of development and as time went on, the advances of technology would improve the FPI sensitivity for the measurement of winds by more than two orders of magnitude as well as allowing for it to be automated for unattended operations using a PC to direct image collections.

As a result of my initiative, I spent the winters of 1971-1972 and 1972-1973 in Fairbanks Alaska operating the Michigan FPI. Back then, this required me to stay up all night to move the mirror periscope system from one look angle to the next and to operate the data collection pressure scanning system which needed at that stage of the FPI instrumental development manual intervention. The Michigan trailer was located on Ester Dome overlooking the town of Fairbanks. Each night was an adventure driving a four-wheel drive vehicle up a mountain gravel road to the site. Since that time, with computers and remote operation capability via the internet, such dedication and manual effort are no longer necessary. At that time, though, I had the satisfaction of being part of a pioneering effort gathering for the first time extended high latitude observations about auroral winds, data that were quite different from prior expectations but in agreement with the results from the chemical release experiments but giving a broader picture of the upper atmosphere dynamics.

After 1973 I continued my journey in aeronomy research with a research associate position at Arecibo Observatory (4 years, 1975-1979), and then as a research scientist for 9 years (1979 to 1988) back at the University of Michigan. At Arecibo my work was aimed at developing an airglow observatory so to supplement the Arecibo ionospheric radar measurements of height profiles of plasma parameters (ion and electron temperature, ion drifts, and electron density) with neutral observations of airglow emission intensity emitted by glowing oxygen atoms. I was able to persuade a colleague to transfer to Arecibo, a 1 m scanning spectrometer from Kitt Peak Observatory that I put this instrument to work at Arecibo to observe not only the oxygen emission lines but also the emissions of hydroxyl (OH) as well as other atomic and molecular species. At Michigan my charge was to take over the Fabry-Perot airglow observatory that I had previously operated in Alaska and do interesting science. Accordingly, I learned to support my research through proposals to the National Science Foundation and other funding agencies. The basic theme of my work during these years and later (since 1992) has been based upon the need to take the FPI instrument to interesting sites to further the science. This led me in the first four decades to now to study the upper atmosphere dynamics for such regions as the geomagnetic high latitudes (Thule Air Base and Sondrestrom Air Base in Greenland), or the geomagnetic equator (Arequipa, Peru; Bahir Dar, Ethiopia; and Campina Grande, Brazil). Mid-latitude regions proved to be of interest as well so I set up FPI observatories in western North Carolina, on the campus of Eastern Kentucky University, and helped colleagues with their FPIs at Urbana, IL and Ann Arbor, MI. These FPI observatories were part of a network that we called NATION. It was a strange feeling to install a FPI instrument at EKU just 20 miles away from where I first saw the red aurora one February morning. Talk about returning to your roots!

A New Aeronomy Career Direction

In 1988 I had decided it was time to shift direction away from the focus on upper atmosphere dynamics. So when I was offered an opportunity to be a research physicist at the Air Force Geophysics Laboratory located in Bedford MA where I would lead a Rayleigh lidar group, I changed directions. Application of the Rayleigh lidar instrument gave me an opportunity to widen my horizons in geophysical research by studying the dynamics of the lower region of the atmosphere through the application of a high power Nd:YAG (neodymium-doped yttrium aluminum garnet) laser that illuminates the column of air up to a peak height of 100 km. By using observations of the back-scattered light from each laser pulse combined with application of data analyses algorithms to the data collected over a collection period of 20 minutes, temperature profiles from 30 to 90 km could be measured with good accuracy. The dynamics of this middle atmosphere region are interesting because there are density fluctuations introduced into the upper atmosphere by gravity waves (GW) launched by the convective wave activity of meteorological weather systems. These waves are not to be confused with the gravitational waves that Prof. Joe Weber (UMD) tried to observe with his bar detectors. Such GW fluctuations are also associated with thunderstorms, tsunamis, solar eclipses and also with an artificial source such as a nuclear blast. In the course of four years I led campaign efforts in January in Sondrestrom Greenland and in Alaska during the 1991 summer. This last activity was aimed at detecting high altitude ice clouds at 83-84 km. This region of the atmosphere becomes very cold due to the upwelling caused by a global circulation pattern, and any water vapor freezes out as ice crystals producing thin clouds that serve as tracers of atmospheric dynamical activity.

Teaching Aeronomy

By 1991 I found myself feeling dissatisfied working in the mission-oriented environment of the Air Force laboratory. I much preferred the challenge of writing a successful proposal. Also I missed the satisfaction of working on a problem and then publishing my findings and conclusions. Fortunately, I was given the opportunity to become a tenure-track associate professor of physics at Clemson University, which has a beautiful campus located in the foothills of the Blue Ridge Mountains in the western end of South Carolina. It is somewhat ironic that I achieved tenure as a physics professor given that I started out as a course V major. I certainly enjoyed teaching the variety of physics classes that I did, and when I taught statistical thermodynamics, I swear that in preparing my lecture notes for my classes, I could hear in my inner ear Prof. Oppenheim making remarks here and there relating to the content that I was preparing to teach. I came to appreciate very much the amount of work he did to achieve such polish for his lectures.

At Clemson University, for my research, eventually I returned to the application of the FPI instrument to study upper atmosphere dynamics, especially with efforts collaborating with Dr. Fred Biondi, a fellow MIT alumnus (Class 1944). He and I journeyed at least once a year to reactivate our FPI instrument located at Arequipa in the southern part of Peru. These observations during the 90s proved to be a pioneering set of equatorial wind observations that really helped to improve our understanding of the plasma instability physics associated with the equatorial region where holes and major wave structures would develop in the F-layer plasma due to the activation of the Rayleigh-Taylor instability.

At this time, I realized the technology of digital cameras had improved greatly so in the first decade of the 21st century, my Clemson students and I worked on developing the FPI instrument to incorporate a good quality CCD camera for the detector in place of a photomultiplier. This version of the FPI design increased the sensitivity of the FPI by a factor of 200 in comparison with the sensitivity of the instruments I had used previously. A whole host of new research questions came to the fore with this technological innovation of the FPI instrument. With the help of quite a few Clemson graduate students during the past 15 years and especially with the help of our classmate Dr. Peter Sherwood who provided invaluable support regarding the various issues of software development needed to implement the new FPI design, I proceeded to extend my work into other locations around the world including Brazil, Ethiopia and also central Alaska. None of this extension was planned as I simply took advantage of opportunities as they came my way whether to propose new instrument installations or whether to collaborate with colleagues in the field. A consequence of this activity was that I deferred retirement for ten years. I just could not bring myself to walk away when my research was becoming so much more interesting due to the high quality data that the FPI was now capable of collecting.

Comparing Aeronomy, Then and Now

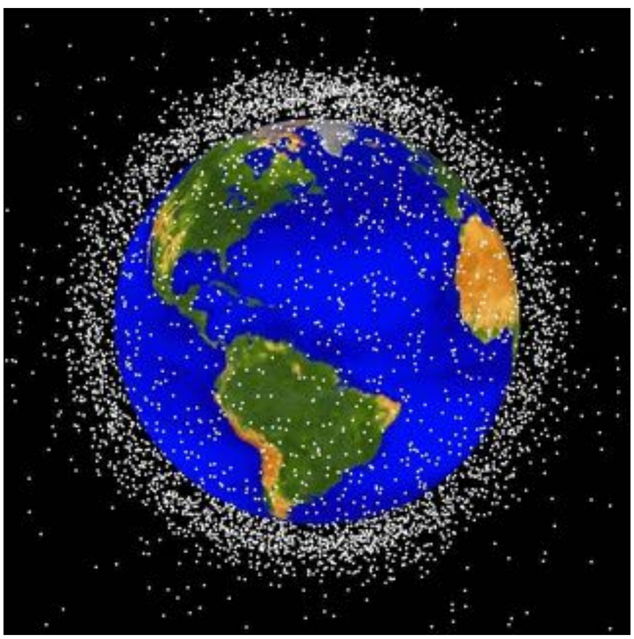
In closing out this essay, I would like to comment about how the discipline of aeronomy has evolved over these five decades. I see quite a number of changes.

1. *Now, there are many more scientists in the field. The American Geophysical Union has a fall meeting every year, normally in San Francisco in mid-December.* When I first started attending these with my first meeting in 1969, the meeting rooms for all of the various disciplines (geology, glaciology, hydrology, space physics, aeronomy…) could be housed in one hotel – the Jack Tarr Hotel which is the one featured in the movie "Conversation" by Coppola. Toward the end of the 70s this venue expanded into two adjacent hotels. Toward the end of the 90s, the San Francisco Moscone Center became the meeting site. And now finally, just last December I and 26,000 other scientists attended the annual meeting held at the Convention Center in downtown Washington, DC. I recall that my experience of presenting my very first paper went badly. The meeting chair, a major figure in aeronomy research, had indicated that anyone running over the allocated time for the paper presentation would be removed bodily from the podium. My paper was the second scheduled for a Monday morning program. I was using lantern slides, that were projected by a separate projector that had not been positioned at the proper separation from the screen. Thus, my first slide overfilled the screen at least four times. The time required to reposition the projector was only several minutes but I was quite rattled by the resulting time delay. Not wanting to face the Chair efforts to bodily remove me by running over my time, I proceeded to give my talk at about three times the normal talking pace. I have given possibly several hundreds of oral papers since but that memory remains still vivid in my mind.

2. *Now the oral presentation at such meetings is much more challenging to achieve without flaws.* Rather than viewgraphs that were customary in the early years, now all papers are done using PowerPoint or Keynote. While one can do a great job of presenting in-

formation with such software with considerable flair and finesse, it also can lead into bad papers with too many graphics or slides that are way too busy for comfortable viewing. I judge that maybe only 15% of the papers I have listened to at various science meetings nowadays are of sufficient quality to do a proper job of communication.

3. *Journal papers are now much more demanding to complete from start to finish.* The process of peer review is truly a wonderful feature of today's science as it ensures that proper scientific practice is followed regarding conventions of scientific writing style. However, sometimes it can be frustrating to deal with the reviewer comments that might come forward. Moreover, I have done perhaps some 200 papers in my career. This productivity would surely not have been possible without word processing to make easier the process of drafting a paper. In addition, the internet has made passing draft versions back and forth among co-authors so much easier. Still, the journals have become more demanding of late with the latest wrinkle the requirement that the raw data be made available for any interested reader. It is sometimes quite onerous to get into all of the details regarding how raw data might be processed.



Illustrating the spatial distribution of satellites and space debris objects relative to the Earth for low Earth orbits (LEO) and geostationary orbits.

4. *Now there are many more satellites that provide an enormous range of data for aeronomy and space physics studies.* Not just the major observatories funded to study aeronomy (the atmospheric Explorers C, D, and E), Dynamics Explorer 1 and II, TIMED and UARS) and space physics of the magnetosphere (LBSPICE and the Van Allen probes) but also CubeSats. The efforts of flying satellites have become greatly simplified and much cheaper as a result of using CubeSat technology that allows miniaturized satellite payloads constructed by academic teams of engineers and scientists to hitch a ride on any rocket that can fly from Cape Canaveral or Vandenberg launch facilities. That one satellite of Sputnik of long ago has now led to space being filled with satellites as illustrated by to the left . In 2017 the UN recorded that there are 4,635; of these, about 1,100 remain functioning with about half (538) being communication satellites located at geo-stationary heights. Space debris is a major serious problem. Eventually, humanity will probably need to clear out all of these junk objects.

5. *Now, computers have become so important both experimentally and theoretically.* The advent of mini-computers in the early 80s made automatic data collection so much easier to achieve. I well remember writing Fortran code for a LSI-11 DEC computer to manage the FPI data collection at the FPI observatory I installed at Sondrestrom, Greenland or in Arequipa, Peru. Moreover, the internet has made possible accessing remote geophysical observatories for both downloading data and passing forward new instructions for data collection. It is strange to access via the internet a FPI observatory located in Ethiopia or in Argentina or in Peru to modify the observing code or to check upon the FPI observing plan or to transfer back to my computer the FPI data collected.

6. *Beyond that, supercomputer operations have now become essential.* These very expensive computers are required to deal with the vast complicated modeling that exists regarding the analysis of many sources of measurements from a vast array of geophysical sensors scattered about the globe. Over the past three decades, scientists the world over have been engaged in wiring up the Earth with many thousands of sensors such as the GPS (Global Positioning Satellite), FPIs, incoherent scatter radars, coherent radars (SuperDARNs), all-sky imaging systems, digital ionosondes, and total electron content monitors. In addition, complex global circulation models developed primarily at the National Center of Atmospheric Research (NCAR) have been developed with extensive modeling code that attempt to simulate the workings of the geospace system all the way from the Sun to mud, i.e., the surface of the Earth. The basis for all this modeling activity is the axiom that the only way to be sure you understand the physics of a complex system is to develop modeling to the degree necessary to be capable of predicting what might happen with some degree of accuracy and fidelity.

7. *Another significant change taking place over the past five decades is how space science has become quite clearly a mature discipline*. I hasten to say that this should not be taken to suggest that such research is not worth the undertaking. Rather, I suggest this to say that aeronomers and space physicists have come to appreciate the geospace system to be extremely complex with significant variability ongoing at multiple temporal and spatial scales. Thus, this fact that the scope of the geospace system that we are trying to study has become so much broader in scale means that single point measurements whether from space or the ground no longer serve to advance the science. It becomes really necessary to utilize networks that have the necessary spatial coverage of the important physical parameters relating to the geospace phenomenon that one wants to study.

8. *I would argue also that the aeronomy and space physics field has become more mature as a consequence of advances in scientific understanding taking place with the passing of time.* I can offer a metaphor to describe the nature of how research activity in almost any field would go. I suggest doing research is like mining gold. As you are following the vein in your research activity, eventually the vein will peter out. Either then, you stop and change the course of your research pathway in the search of a new vein. Alternatively, you make use of technology progress to enhance your re-

search capability so your efforts to mine the gold can continue even if the vein is hardly evident. As the complexities of the geospace system became more apparent, to me it seems quite clear that no longer was it likely for a single researcher or a professor joined by a student or two to make significant breakthroughs. Nowadays, the complexities need to be tackled by teams of researchers that include enough of a range of special talents to have in hand the necessary means of making progress. This trend is also true in regard to modeling efforts that are aimed at incorporating diverse elements across the geospace system whether solar or geomagnetic tail or the near Earth environment. Aeronomers in a way similar to the astronomers have accordingly become engaged in extensive collaboration by forming teams involving many persons. This collaborative activity of course has been greatly facilitated by the internet that make it possible for numerous discussions to take place via emails or Skyping or attending conferences and workshops via a video connection.

9. *The issue of space weather, a term coined in the mid90s, has now become the main focus of all this work becoming much more important in the past two decades to NSF, to NASA, and to NOAA. Why?* One burp from our sun, a major solar flare or a coronal mass ejection (CME) event, can potentially create tremendous damage to our current rather fragile technological state that is now so dependent upon communication through the internet. In aeronomy frequent reference is made to the Carrington Event, which was a massive solar flare in 1859 that produced a CME aimed directly at the Earth. The primitive technology of those times could tolerate the high levels of current that developed on telegraph lines. Moreover, there were no electric transmission lines at that time. And no space-based internet. Not so today. Extreme solar storms would decimate all forms of high technology. The severe space weather effects caused by such an event would start with an explosion, or "solar flare" in the magnetic canopy of a sunspot. X-rays and extreme UV radiation would reach Earth at the speed of light, ionizing the upper layers of our atmosphere. The consequence is the equivalence of an electromagnetic pulse or EMP having a potential to cause radio blackouts, especially at high latitudes, and extensive GPS navigation errors. Minutes to hours later, energetic particles arrive. Moving only slightly slower than light, these electrons and protons can electrify satellites and damage their electronics. Then come the CME clouds of magnetized plasma that can take a day or more to reach Earth that would engulf and squeeze the Earth's protective magnetic shield and as a byproduct creating global auroral displays such as what I experienced that one February morning in 1958.NASA experts say that a direct hit by an extreme CME such as the Carrington Event could cause widespread power blackouts, disabling everything that plugs into a wall socket.

   The damage to our civilization today by the occurrence of such an event would be horrendous. It would require years for recovery. Should such an event happen today, given sufficient advance notice by early warning satellite sensors, mitigation of the severity of the related space weather is possible to some degree by turning satellites off, and perhaps by activating power grid protection devices that are able to absorb the excessive currents that would otherwise occur.

10. *A focus on space weather has other practical implications.* My efforts in measuring the neutral atmosphere winds and temperatures prove to be useful because the data I and my colleagues have generated have been used in the formation of an empirical model predicting upper atmosphere winds based upon input parameters associated with the state of solar flux or geomagnetic activity. These predictions are reasonably accurate and are useful for the calculation of the effects of atmospheric drag upon the orbits of the orbiting satellite objects. A major geomagnetic storm caused by space weather events leads in to major modifications of these trajectories so a process of re-acquisition of the orbital data using sophisticated radar systems is required. Data from the FPI instruments help to speed up this process of new determination of orbital parameters. Beyond that, my work has helped to provide a better understanding of the forcing of the upper atmosphere winds that arise from plasma drifts within the auroral region or by the passage of air from the heated daytime side to the night due to the day-to-night pressure gradient or finally, as a result of atmospheric tides propagating upward from the troposphere.

11. *In the course of these five decades as I attended the various space physics meetings (at least, several hundreds), I became aware of the increasing activity in climate change studies.* In the 70s many wondered what impact the increasing atmospheric content of CO2 would have. This did not really register with me as a big issue until the early 90s when the first IPCC report came out indicating climate change would eventually become a severe problem for future generations. In the 80s I also became aware of the issue of the ozone hole that was so well studied by my friend and colleague, MIT Professor Susan Solomon. These two issues combined with space weather illustrate how basic research in the atmospheric sciences can also relate to major concerns humanity needs to resolve in the coming years. My part may have been only a small one, but I feel satisfied to have been part of a cadre of scientists that has a common goal of serving the interests of humanity in spite of all the pressures out there to deny the force of what Nature is trying to tell us regarding climate change, ozone hole recovery, or space weather.

12. *Finally, a comment regarding the entry of young aeronomers into the discipline nowadays.* My story illustrates how much luck can play a role in regard to how opportunities are made available in life. Speaking for myself I feel I had been quite fortunate though, of course, it is difficult to quantify how much of a difference having a MIT degree might have made. Nowadays, the funding agencies have sought to develop programs designed to attract new young colleagues, both women and men, into the disciplines of aeronomy and space physics. NSF has a two-fold agenda. The first goal, of course, is to fund the best science. Perhaps not so much appreciated is the second goal, which is to achieve a broader selection of young scientists and engineers that are attracted into the discipline. Aeronomy has a strong attraction as I have tried to make clear. The funding climate in Washington has been quite tight for the past two decades, but in spite of this constraint, it has been possible to achieve the reinvigoration of aeronomy and space physics by supporting young scientists in a variety of ways. I have spent the past four years working to help the aeronomy community and the National Science Foundation formulate a path forward in the era of flat

> budgets. In such circumstances of limited funds one comes to appreciate better the idea of a facility life cycle. Once the operations of the facility have looked at the primary science issues and collected the desired measurements, looking at the question of whether continuation of operations can be justified by the expected continued science returns is extremely important. Funding is always limited, and one wants to be sure to achieve the best possible return for the science dollar spent. This is where peer review plays a very important role helping to prioritize the ways that science funding should be expended. As an example, Arecibo Observatory has been active in aeronomy research for nearly six decades. What has kept it continuing to remain vital is the continual infusion of technology that has improved the instrument capabilities thus allowing the continuation of cutting edge research.

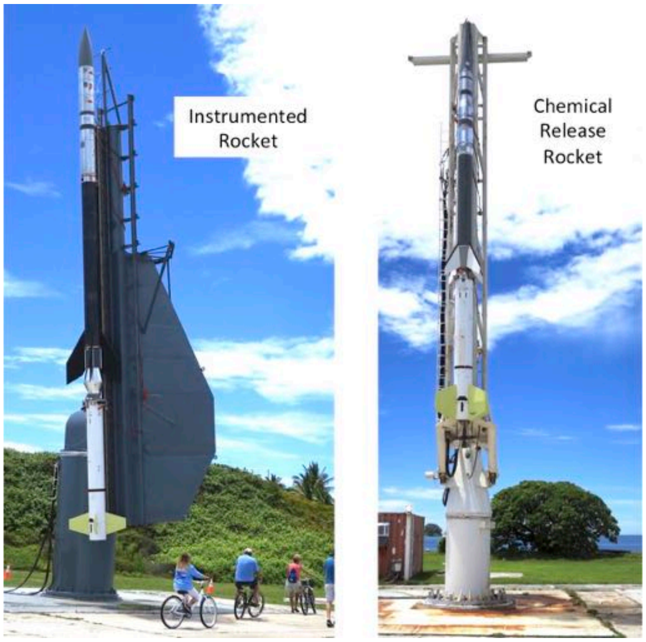
This opportunity of working at NSF also gave me the chance to become aware of the class of younger scientists now entering the field and how much more diverse in gender and nationality that class has become. I am really impressed with how these younger scientists have so much dedication, enthusiasm, tremendous skill sets and training that they bring to their work. All of this reinforces the goal of wanting to be sure to invest science funds in areas that have the greatest potential for positive science outcomes.

I remember in my senior year working in Amdur's laboratory in a room that had a window that faced towards what we now know to be the Green building. As that winter unfolded with the events of the Kennedy assassination and the Johnson inauguration, I watched the Green building being constructed on a day by day basis. Little did I know then how it would unfold that the discipline of aeronomy represented by that building would be my career niche. It has certainly been a great experience and one that is not completely finished.

In closing, aeronomy is a discipline with an international community, and so, as a consequence of this reach and my travels abroad, I find myself somewhat more familiar and acquainted with colleagues on a global scope than I am with my Clemson neighbors. I continue to enjoy my work and hope that I may continue to make contributions to the literature. Right now, though I am at last retired as July 2018, I have returned to FPI research. I am looking again at the vertical wind data associated with Alaskan FPI measurements, results I had never really looked at closely before. The high quality of the more recent data as compared with the results of the early days has revealed an even more dynamical environment than one could have hardly imagined. I hope that I might spend some time again in Fairbanks during the January to April period of 2020 but perhaps more so as a science tourist hoping to see again an exciting rocket launch or two going into the midst of aurora.

Rocket Science is Hard

I close with one more story about a rocket launch that helps illustrate the conduct of rocket science. In August 2017 I traveled to the South Pacific to the island of Roi-Namur near Kwajalein where I had a FPI instrument running to help support a NASA rocket experiment that was designed to study the development of the Rayleigh-Taylor plasma instability that readily occur at equatorial locations where the geomagnetic field lines lie horizontal. My measurements of the winds and temperature supplement the ground-based ionospheric ALTAIR radar observations of the F-region plasma parameters. The process for this instability behavior is not very well understood, and the rocket experiment was designed to get definitive data that could be compared with modeling reconstruction of the event studied.



Two rockets mounted on launch rails on the launch pad at Roi-Namur in September, 2017. The firing angle was set to be 94 degrees elevation westward toward the Pacific Ocean with nominal apogee heights at 400 km.

Two NASA rockets pictured to the left were to be launched – one carrying two trimethylaluminum (TMA) canisters for trail chemical releases on the rocket up leg and down leg portions of the rocket trajectory. Watching these TMA trails move would produce data on the speed and direction of the winds as a function of height. The other rocket carried an electric field experiment combined with a plasma density monitor. Due to the vagaries of the surface cloud cover that was especially variable for this equatorial location, after a dozen successive nights of countdowns, we came down to the last night of the September countdown window, and then down to the last hour, and finally at 35 minutes past midnight, NASA launched both rockets with an interval of 7 minutes. The roar of each rocket was something to behold, and even more spectacular was that surface fog and rain clouds had moved in making for limited visibility. Thus, I could only see an orange-reddish blob of light moving upward into the sky when each rocket was launched. After both launches, I remember biking back to my dormitory in pouring rain and asking myself, how did I ever get into this situation? Unfortunately, both rockets did not perform as expected – the motor on one burned through its sidewall resulting in tumbling of the instrumented payload. The TMA canister on the other did not deploy for the up leg. Thus, unfortunately, no usable data was collected. This illustrates how painful rocket research can be. In spite of all efforts, not everything will go right every time. I well remember the morning afterwards at breakfast trying to console the lead scientist on these failures. I remember also how impressed I was that he took a moment to ask about how did the FPI do. But of course, the rain clouds combined with fog made the FPI data become useless. The bottom line of this story is that rocket science is hard but when everything works, it is truly a thrilling experience – instant gratification.

Success at Last - 21st Century Aeronomy

On 5 April 2019, my Clemson colleague, Prof. Miguel Larsen, succeeded in carrying out the AZURE (Aurora Zone Upwelling Rocket Experiment) in northern Norway after a frustrating period of dealing with adverse weather activity of high winds and cloudy skies. The photo on the next page shows the three types (Ba ions, neutral BA/Sr, and TMA trails) of chemical releases that were released using mini-rocket canisters that were ejected at separate heights along the up leg and down leg of the rocket trajectory. The two rockets were launched nearly simultaneously (2 minute separation) toward the north with an azimuthal separation of about 25 degrees. The idea was to explore in three dimensions the auroral dynamics involving the neutral wind and ion drift dependence upon altitude in regard to speed and direction by observing the dynamical behavior of multiple chemical releases.

On the ground my colleague from the University of Alaska operated a miniaturized version of the FPI that we called MiniME because it did a great job of measuring the Doppler shift and Doppler broadening in spite of the small size of the instrument. Getting this experiment off was quite dicey because the weather was not very cooperative. Finally, after nearly two weeks of countdowns, the meteorological conditions on the ground were all favorable for the first time, and fortunately, the aurora had been quite active, just the type of complex geophysical dynamics involving the wind and ion drifts that we wanted to study.

This is surely an example of the 21st century aeronomy experiment. I found it quite strange to be observing via the Internet this experiment at home just after dinner time by looking at images produced by an all sky camera located at the Alomar Observatory in Norway. Thus, in real time I could see on my iPhone the launches of the two rockets followed by a long pause of about 4 minutes as the two rockets passed through the lower at-

mosphere. Then lo, about ten chemical puffs and two TMA trails for each rocket appeared though not all the mini-rockets worked. More video details are available at this YouTube web site:
www.youtube.com/watch?v=YD4ghvmREI8&feature=youtu.be

This successful experiment opens a new era of rocket-based aeronomy as many questions will now be possible to address using the results learned from such experiments. I feel quite fortunate to have been a part of such projects over the years.

John Meriwether '64, Doctorate University of Maryland1970, held postdoctoral positions at the NASA Goddard Space Flight Center and the University of Michigan. He married Erika in August 1973; and then held a research associate position at Arecibo Observatory for four years. After 8 years at the Space Physics Research Laboratory at the University of Michigan and four years at the Air Force Geophysics Laboratory in Bedford, MA, in 1992 he became Associate Professor of Physics and Astronomy at Clemson University, South Carolina. He was promoted to Professor and received tenure in 1998. He and Erika have one son, Alexander, who went to Williams College. He is a keen enthusiast of folk music sung by the singers from our generation, Joan Baez, Judy Collins, and Peter, Paul, and Mary. He also has a strong interest in classical music.

Half a Century of Medicine

Robert B. Colvin

Perhaps no field has changed more since we entered MIT in 1960 than medicine. I was fortunate to have a close view of the healthcare revolution from the trenches, as one of the 30 or so in our class to go to medical school after MIT. And what a change medical school was from MIT! Instead of equations and logic, we got endless lists of "facts" to remember. That has improved considerably. Because of the scientific advances since 1960, teaching medicine now is almost like teaching geometry, with mechanisms, molecules and first principles which can be used to explain disease phenomena and select therapy.

So, what has changed in medicine since 1960? The headline news is we are living longer. Life expectancy in 1960 in the US was 66.6 years for men, 73.1 years for women. In 2015 that had increased 8-10 years to 76.9 years for men and 81.6 years for women. Some of the reasons will be discussed in this essay. First the bad news.

New Diseases

Newly discovered organisms have appeared over the last 50 years. Legionnaires' disease is caused by a bacterium discovered in Philadelphia in 1976. Ebola virus was discovered in an epidemic in Africa in 1976. Acquired immunodeficiency disease syndrome (AIDS, HIV) was first detected in 1982 in San Francisco, although in retrospect it could be traced to the Congo where it was transmitted to humans from chimps in the 1920s. HIV, claimed over 600,000 lives in the last 40 years in the US and 1.1 million are living with the infection. In the last 20 years, effective antiretroviral drugs have been developed which greatly reduce the effects of the virus, but do not cure it. Preventive vaccines are yet to be invented. Hepatitis C virus (HCV), was identified in 1989 and infects about 2.2 million people in the US. HCV is now <u>completely</u> curable with direct acting antiviral drugs. The catch is that the drugs are expensive, initially $85,000 for a 12 week course of treatment. Fortunately, competition and further research have brought down costs substantially.

Old Diseases

Some old diseases have become <u>more</u> prevalent, especially those related to lifestyle, such as obesity which now affects about 40% of the US population, up from 13% in 1960, with the attendant increased risk of type 2 diabetes. The cost of obesity is estimated to be over $150 billion per year.

Another "disease" which has greatly increased in the last 20 years in the US is opioid addiction, with annual opioid death rates quadrupling since 1999 from 16,849 to 70,237 in 2017. The increase is big enough to affect the overall life expectancy in the USA, which has gone down in the last two years for the first time. While widespread over selling of prescription of opioids (e.g., oxycontin) started the epidemic in the late 1990s, recently more potent black market opioids (e.g., fentanyl) have dominated. Massachusetts is among the top 10 states, with a rate that peaked in 2016 at 2,099/year. Since then, considerable efforts by physicians and government leaders have begun to gradually bring down the rates by about 4% per year.

Now Some Good News

Smoking and lung cancer have diminished remarkably. Cigarette smoking peaked in 1963, with an amazing 4,345 cigarettes per year per adult in the US (down 75% to 1,016 in 2016). 1964 was a good year, not just for us graduating from MIT, but for the world, with the release of the Surgeon General's report on smoking and health. Since then smoking has declined in the US from about 42% of the population to about 18% and it is estimated that 9 million lives have been saved. There was a 30-year delay in the reduction of lung cancer death rates which peaked in 1993 at 59/100,000 people and since has fallen 29% in 2015. However, lung cancer is still the leading cause of cancer death. Each year, more people die of lung cancer (142,000) than of colon, breast, and prostate cancers combined.
Many other causes of death have also gone down dramatically since 1960 when adjusted for population and age: influenza and pneumonia (82%), cerebrovascular disease (79%), heart disease (70%), gastrointestinal diseases (56%), liver disease (48%), motor vehicle accidents (48%), breast cancer (37%, and prostate cancer (33%).

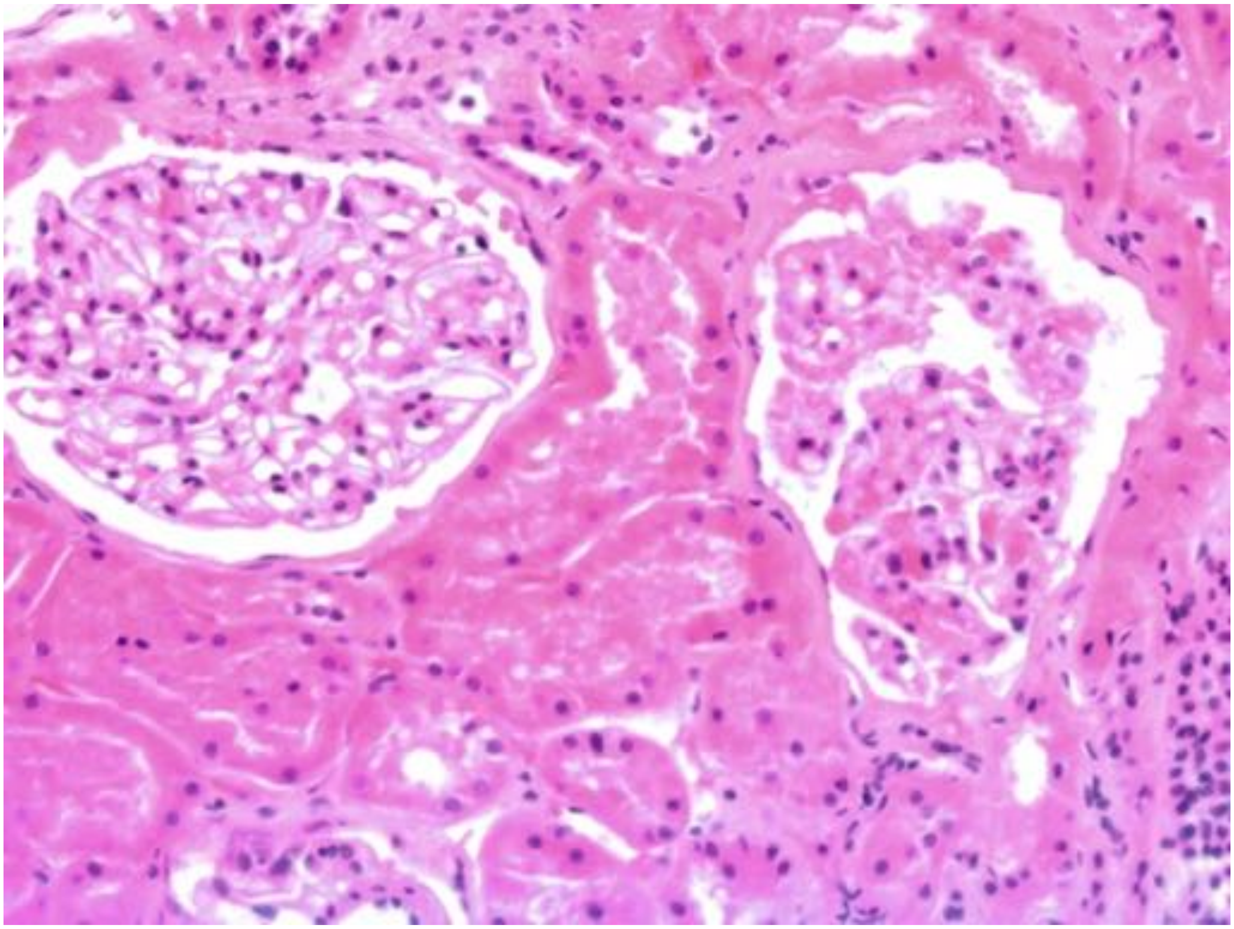
New Drugs

Drug discovery has changed from seeking random natural products with beneficial effects (e.g., penicillin, cyclosporin) to designer drugs intentionally based on knowledge of the function and structure of the target (e.g. anti-HCV and HIV drugs). Immunology has helped with the discovery of monoclonal antibodies, highly specific drugs that target a single molecule and thereby have fewer side effects. Some examples include check point inhibitors used to stimulate the immune response to cancer (Jimmy Carter was cured of a metastatic melanoma by this), anti-inflammatory antibodies such as Entyvio used for inflammatory bowel disease (based on one of our laboratory antibodies from 35 years ago) and anti-B cell antibodies for lymphoma and leukemia.

Practically all the drugs used clinically now were not known when I went to medical school. We lower our cholesterol with statins, cure wet macular degeneration of the eye with anti-VEGF, and alleviate rheumatoid arthritis with tumor necrosis factor inhibitors produced by genetically engineered drugs.

New Treatments

Organ transplantation has become widespread since the first successful kidney transplant was done at the Brigham hospital in Boston in 1954 by Joseph Murray. Improvements in surgery and immunosuppressant drugs have enabled lifesaving transplantation of heart, liver, lung, pancreas, small bowel and bone marrow. Outpatient kidney dialysis started in 1962, which allowed patients to stay alive without kidney function while awaiting a donor. Heart support included the heart-lung machine allowing replacement of artificial heart valves in 1960 and extracorporeal membrane oxygenation in 1976. The current research at Massachusetts General Hospital (MGH) is focused on a clinical trial to induce immunological tolerance to the foreign organs, through the use of donor bone marrow. This would eliminate the need for multiple drugs and their complications. So far, we have had some success in about a dozen recipients, with our first patient now over ten years with a well-functioning kidney allograft and no immunosuppressive drugs.



Biopsy from a patient who received a kidney transplant and bone marrow transplant 8 years previously, using a novel research protocol developed at Massachusetts General Hospital. She is tolerant and does not require immunosuppressive drugs. Achieving tolerance has long been the holy grail of clinical transplantation and progress continues to be made.

Overall, 36,527 organ transplants were performed in the United States in 2018, which set an annual record for the sixth straight year (partly an unfortunate benefit of the opioid crisis). Since 1988 750,000 patients have received an organ transplant. The limiting factor is not medicine, but rather the donor supply. This is the year of the pig! The hope for the future is that organs from pigs (xenotransplants) might fill the void through genetic engineering. A new technology, CRISPR, has boosted the likelihood of that outcome and a startup company in Cambridge, eGenesis, is pursuing this.

CRISPR (clustered regularly interspaced short palindromic repeats) enzymes, combined with a DNA cutting enzyme (Cas9), permits efficient genetic insertions and repairs in living cells. Several companies, including Editas in Cambridge, have been started to develop therapeutic strategies based on this discovery by Jennifer Doudna in 2012 at UC Berkeley and

Feng Zhang at the Broad Institute of MIT in 2011 (both of whom received patents) and clinical trials are underway. Many ethical and scientific issues have been raised, such as the apparent gene editing of a human embryo in China. Much more to come, stay tuned!

A few other notable advances. Knees and hips can be replaced with artificial joints, enabling us bionic oldsters to continue our tennis and golf games. Laparoscopic surgery is widely used. Now you can still where a bikini after your gallbladder operation. Novel imaging techniques are highly dependent on technology and computation (CT scans, positron imaging, functional MRI, Doppler angiography and more). These have improved diagnosis. Genetic sequencing is identifying individual drug targets in cancer for "personalized medicine" and calculation of risk for hereditary diseases. Gene sequencing has become exponentially cheaper and is now less than $1000.

MIT and Medicine

MIT has grown enormously in the fields of biology, biomedical engineering and medicine. As medicine has gotten more scientific and able to engineer therapies, it is predictable that MIT students would be attracted to Biology, Course VII, now the major of 8% of the undergraduates.

MIT started the Health Sciences and Technology (HST) program with Harvard Medical School in 1970. HST admits about 40 students per year to a two-year program strong in science and appealing to scientifically oriented students who then go to Harvard Medical School hospitals for their clinical training. I have had the privilege of teaching some of the classes and the students are outstanding. MIT's Biology department is superb, with three Nobel Prize winners among the current faculty (Robert Horvitz, Phillip Sharp and Susumu Tonegawa).

MIT also has implemented major research institutes in biology and medicine: Whitehead Institute for Biomedical Research (1982), McGovern Institute for Brain Research (2000), Picower Institute for Learning and Memory (2002), Broad Institute (2004), Koch Institute for Integrative Cancer Research (2007). These foster connections and collaboration/shared faculty with MGH and Harvard Medical School and have made Kendall Square the world's epicenter of biological research.

And MIT is not standing still. This year MIT created the Schwarzman College of Computing which will support artificial intelligence (AI) research and applications in all fields, including medicine. I was delighted to attend their inaugural program in March, I was blown away by the energy, power and creativity of this innovation. AI is being used to improve diagnosis of mammograms and tissue biopsies, to assist the radiologist and pathologist. Watson is helping clinicians with tumor diagnosis.

Payment for Healthcare

One year after we graduated, Medicare and Medicaid were created and the so-called Affordable Care Act followed in 2010. Meanwhile the cost of medical care has increased exponentially, from 5% of GDP in 1960 to 17.9% of GDP in 2017, still 8.8% of Americans have no health insurance coverage. The solution- Single payer? More regulation? New technology? Better life styles? Don't ask me, I'm only a doctor and I'm out of space on this essay.

Robert B. Colvin '64, Harvard Medical School '68, is Benjamin Castleman Distinguished Professor of Pathology, Harvard Medical School, and Pathologist-in-Chief, emeritus, Massachusetts General Hospital. He leads a pathology research program in transplantation and kidney disease.

Analog to Digital - Close-Up View

Donald M. Stewart

The House of Analog Horrors

Our lives began in an analog world. By today's standards it was not complex, rather one that captured the advances of the late Victorian era, the inventiveness of the early 20thCentury, and armaments of two world wars. Analog is what you could read on a meter or heard from a loudspeaker, while digital barely existed.

Analog design tended to attract engineers with quirky outlooks. Their view was perfectly reasonable, given the toil needed to achieve an analog design that was low cost to manufacture, with adjustment points that were independent of each other. Signal interactions made analog designs difficult to achieve full accuracy. Perhaps the best-known analog circuit today is the battery performance monitor in the Apple iPhone. Analog circuits always leave me with the sense that they could be further optimized if I only had the time.

I admire analog engineers – both electrical and mechanical - for their important work of softening industry's transition to digital design. The Plan B (back-up) version of a circuit could be complex analog, but within the capabilities of a debugged design and manufacturing process. The digital designers on the design team could be solicitous as they had the enormous leverage of the experience curve to drive down cost.

How did people on the street experience the analog to digital transition? The short answer is that they remained inexperienced as adoption times were measured in decades. The earliest circuit with volumes in the millions was the automotive spark ignition switch that performed the humble role of providing a spark for all cylinders. It replaced mechanical contacts that did not perform consistently. Most people were unaware that the device was in their car.

When you think about analog circuits, consider including humans with our thousands of analog feedback control loops. As we know from personal experience, these electro-chemical circuits function in a wide range of environments.

I experienced the analog to digital transition in a variety of ways:

As a child the coal truck would arrive periodically, but it could not dump its load near our furnace for lack of access. Instead the coal was carried over the shoulder into the coal bin in a bag similar to a rucksack. No one had designed a useful coal unloader, so humans were the beasts of burden.

The furnace had a screw drive that deposited coal lumps in a regular pattern on the burning grate. The drive engaged in notorious behaviors resulting in a cold house at unwanted times. With three young children and a husband with a heavy travel schedule, my mother's choices were meeting the challenge by feeding the drive one lump at a time or signaling defeat to an unknown technological master who won, except the day when it was broken up using sledge hammers. Hers was an analog solution as she adjusted the location of lumps on the grate to compensate for errors in the furnace.

Our home in suburban New York City was a half-timbered masterpiece. It provided hiding places in abundance, and an indoor balcony opening on to a two-story living room. Today's digitally controlled tools never came close to it during construction. The builder made measurements his way: The house had 21 separate levels, including one for every room and one or two more when the gaps between boards seemed excessive.

The Bendix clothes washer was a talented dancer, as it moved with style across the kitchen, using its power cord as a tether. My parents considered it an ill-tempered guest that leaked water, was not particularly safe, and could thump the floor close to the hearing limit of 115 db. It met the same fate as the furnace, broken up in the back of a truck on the way to the dump. Recycling was still 25 years in the future.

Don Stewart '64 Course 6, Harvard MBA 1966, started work at a Navy base in Florida for two years, then moved back to Boston working in sales and marketing. With two decades of experience, he then joined the consulting world, working with a partner to cut time-to-market for products in development. This is a self-consuming market where corporations learn how to manage development time, often with excruciating outcomes. He is grateful for the education provided by the MIT faculty.

From Pong to PCs

Jim Allen

In the Beginning

On a cold, snowy morning in 1960, I trudged across the Harvard Bridge and developed a frozen nostril on the windward side. Into the computer room I went and immediately noticed that my nose was thawing as I breathed in the almost 90° air warmed by an IBM 709. That 709 was the processor and the heat was getting higher as the upgraded vacuum tubes kicked on.

My Saturday morning lab assignment was in Building 26 on a Digital Computer Corporation's PDP1. I was to make a large dot (supposedly an airplane), drop a smaller dot (supposedly a bomb) in anticipation of getting the small dot to land on the target while the large dot was moving across the screen. I missed, but eventually got better at understanding this computer's possibilities. The intended consequences include an accurate bomb sight. An unexpected consequence would be a rocket that can find a heat source or a starwars spinoff with the ability to locate a shooter, many miles away. One can simply calculate the trajectory of the incoming bullet (adjusting for wind, the sun effect, curvature of the earth and its rotation) and then shoot back to its current source before the enemy reloads. This early version of Atari's Pong helped me to understand the "Power" of a computer in my Saturday morning Physics lab. Years later I was able to test market that new "game" in California with Atari. I was not as impressed as I should have been with either the 709, the PDP1 lab, or the Atari computer game.

Still at MIT, I entered a course taught by Jay Wright Forrester called Industrial Dynamics. I learned to plot changes in variables and created formulas where two or more variables were dependent on each other at the Sloan School of Management. I tried to work on getting a stock market model to work so that I could pay for grad school, but I was told that Dr. Forester was already working on that. My roommate was creating programs in Fortran using names of variables like hell, sex and ecstasy. I was pretending to learn COBOL.

In my summer job, a management training course at Proctor & Gamble, I was thrown a great project - how to use the accounting system for numbering jobs and equipment. We had a three-digit department code, a list of 4 digit job types like welding, or machining or replacing or packing. Then we had three digits left over from our ten digit code. I suggested a letter and number to identify the equipment like a pump, crutcher, plodder etc. My idea was accepted by all of the other managers in the plant. I came back to see its usefulness and learned more about how a computer could be used in business.

IBM Was the Place to Be

My MIT thesis required something called a library program and I was able to figure out how to use this large heavy machine that looked like a giant adding machine with a typewriter attached. Its program was "wired," not on punched cards … An IBM 403, if you recall. Before long I was at IBM, selling equipment with great lines like "more core will solve that problem" or "sounds like you need a 360 upgrade". In other words, still in the '60's I had experience with third generation machines, first and second generation equipment and grey iron all doing number crunching for useful purposes.

As the machines were getting faster and cheaper and more useful, businesses were renting or leasing. Machines were often too expensive with too short a life to buy. The equipment could do hyphenation or pagination or change fonts faster than the IBM bouncing ball. The rate of change, according to Moore's Law was roughly a doubling of capacity of computer chips every 2 years (now 18 months) and the price halved. IBM stock was about $700 per share ($12 in today's' equivalent after splits or about 10% of today's price). This stock was a great bonus as it rose ten-fold over the next twenty five years.

California and Memorex Beckon

California's Silicon Valley was also in this race. The valley was a fine agriculture region including Wineries like Morgan Hill, Paul Masson or Charles Lefranc. Many of these wine makers in Santa Clara were from European families who brought roots and started in fresh soil. When the grape phylloxera insects hit Europe, many vineyards re-imported the root stock from California and their wine industry was saved. The shift for the wine industry to Napa and other regions started since the computer companies were willing to pay more for real estate than the wine industry. Even the onion and prune industries sold out to the high flyers and took their real estate earnings into the lower cost areas of California.

While at Memorex, which began as a tape manufacturer, the company became quite profitable as they added plug compatible peripherals, thus taking some of IBM's market share at a lower price. Memorex stock went from $5 per share to over $160 per share in less than a year. The tech companies were different but also had several features in common: great grass outside their cheap one or two story buildings, lots of brilliant engineers, and lots of going away parties at their main "after work watering hole".

Robert Norton Noyce earned his PhD at MIT before he cofounded Fairchild Semiconductor in San Jose. He was nicknamed "the Mayor of Silicon Valley. " He was an American physicist who also cofounded Intel Corporation in 1968. He was almost as successful as Steve Jobs of Apple in the northern Silicon Valley. A friend of mine at Memorex was Alan Shugart. It was said that if Al Shugart walked out onto the golf course style lawn at Memorex, and asked, the whole company would follow. He was an outstanding friend who had left IBM and brought with him to Memorex a cadre of engineers. He built several different technologies for disc drives, including the first Floppy disc drive for commercial purposes. He then left and started his own manufacturing company. His best adventure was Seagate Technology, a world-wide computer hardware company where Al became close to a billionaire.

It is natural to wish to develop a technology to make more money than a typical IBM salesman. So, I founded American Conservation Company and designed a processor controller (computer) like a cheaper version of the PDP series, to measure sources of heat and A/C from either the ground or the air. Solar and geothermal were great heat resources and sinks and the cost was easily identifiable by temperature. The only problem was that one needed to have a good idea of what money costs.

Enter the PC!

The next step was to start a PC oriented company. One company, ComputerLand in San Jose, was started by a Memorex Employee who had used my same desks at Memorex twice in two jobs, one in International sales. Our revenue at Memorex grew to more than Ella Fitzgerald brought in for her signature advertising "Is it Ella or is it Memorex?"

Later, in the PC business boom of the 1980's the low-tech IBM PC took the market. Not only was it promised as a personal computer it had more computing power than the 7090 in 1962 at MIT or the 360/65 at the US Department of Defense, after seven or more of Moore's Law doublings. Really, it could calculate faster and the data ports or channels were faster AND with tiny heat issues. The defense department had about a million PC's and I was able to market the first commercially available laptop (copied from the CIA product). That product by GRID from Fremont, California. One out of every 100 Fremont citizens owned a patent in 2000. Apple was founded in Redwood City, near Fremont along with a host of other start-ups. The Grid laptop had a similar characteristic like the 709 of the early '60's, lots of heat. If you put it on a desk, it would have an auditable fan that blew the hot air across the bottom power supply and kept this very fast processor sufficiently cool. If you put it on your bed, you WOULD light your bedspread on fire.

What is clear is that the birth of computers in the USA has changed the climate for business. Without computers, every person in the USA would be a bank teller if we wished to do as many bank transactions as we now do. But, there would be no one available, since everyone would be a telephone operator if we maintained our phone call level.

Thoughts for the Future

Few understand the many applications of high technology. There are not enough people who know how to program a satellite or figure out how to keep the internet from overloading. There are not enough people who know how to make our cell phones tie into our car phones or know how to enter daylight savings time changes into their car clock. Seriously, would more memory solve that problem or do you need an upgrade?

One new prospect is Nanotechnology ... a small thing. A nanometer is one billionth of a meter … 1/50,000 the thickness of a human hair. Nanotechnology based computers use tiny molecule-sized machines that process data in a way like the complex and intricate cells of a living organism. The heat factor can be modest. The speeds will continue to grow, maybe at Moore's Law, but maybe faster. We will never be able to predict the effects from artificial intelligence in time to not have unexpected consequences. Technology challenges abound for the next MIT grads to solve.

Jim Allen, MIT'64, worked for IBM and Memorex and later founded the highly successful Entre Computing Centers. He is now retired and owner of a horse farm.

How Electronics Changed Since Graduation - A Compression of Space and Time

Bob Blumberg

Early Impressions of Computer Technology

Here I am, an ex-Chemical Engineer, writing about changes in the electronics world in the 55 years since our graduation. The only way to make sense of that paradox is to tell you that I co-founded an electronics manufacturing company which I then ran for 30 years, but more than that, I have observed what the electronics innovations have done to alter our lives.

The theme of this will be "Compression". This is not the compression we learned in Physical Chemistry, or Heat or Mass Transfer, but the compression of space and the compression of time. The most all-encompassing changes have been in the fields of computers and communications.

When we were in High School, the 1956 election was predicted on election night by a Univac computer, running vacuum tubes, and taking up a large room. When we were freshman, I remember mechanically punched cards, compiled and put in assembly language, and run on a IBM 7090, now making use of solid state electronics in the form of transistors. Computers still took up a sizable room.

Moore's Law a Major Driver in Achieving Growth in Computing Capabilities

Soon printed circuit boards took over the insides of computers, and components were connected by wire-wrap. That was first done by hand, then semi-automated. After transistors came integrated circuits, shrinking real estate further. Then came pin-through-hole and wave solder for printed circuit cards. Cost per component was driven down. Finer and finer line spacing enabled chips to contain more memory, more processing power. Engineering workstations and personal computers shrunk the real estate need for a computer enormously, and the cost of computing fell precipitously. Pin-through-hole was followed by surface mount technology, and enormous degrees of automation in manufacture.

At one point in my career I had a partner, in his 40's, who was the principal architect of the IBM 360/50 computer, its largest seller in those days. (Sad to say he was an RPI grad, not MIT!). He went into a computer store and ordered a state-of-the PC/AT. The clerk, around 19 years old said "That will be $6000" (or thereabouts). My partner responded, "I was the head of the team that designed the IBM 360/50 which was slower than this, had far less memory than this, and cost over $1 Million". The clerk looked up and said, "What else is new, Pops?"

Compression Enables Cellular Communications and Big Data

Meanwhile, in communications, the cell phone was invented, and started making inroads to the traditional wire-line telephone communications. As the number of phones increased, the density of cell towers increased, and coverage became near-universal. Continued compression of circuitry enabled some computer-like characteristics to be included with the cellphone. On the software side, the birth of computer-to-computer communications and the development of the Internet, enabled phones to become smarter and smarter.

Now, we take for granted that a computer is integrated with a phone, and both these capabilities fit into our pocket. With voice and written message communications capabilities, as well as the television built into the small screen, each of us possesses the ability to talk to anyone, anywhere and anytime, to send messages and memos similarly, to listen to our favorite music, see sporting events, the news and shows, to look up information on any subject, to translate languages, and to play interactive games. As they say, "Who woulda thunk it?"

So the space for enormous computing power has been compressed from huge rooms to something that fits in our pocket. Entire encyclopedias and every magazine and newspaper published fits in our pocket. Games, music, movies, a telephone, all things that took up space are down to a 5" x 3" x 3/8" object.

Consequences and Impacts of the Electronics Revolution

Just as astounding has been the compression of time, and how it has affected our lives. Letters, which took days or weeks to deliver, were first replaced by fax machines, and now by instantaneous e-mails. When you left work in a day, it was tough to reach you, impossible if you were anywhere other than home, and even if you could be reached, there was little you could do without driving back to work. Now, everyone is on-call 24/7, and has no excuse not to be able to put things aside and solve a problem with the tools at hand. Social media allow us to be in touch with all our friends instantaneously, regardless of location or time of day. We can reach into our pocket, take a photograph, and send it around the world, all in a matter of seconds. There is no reason to ever be bored with all the information and entertainment at our fingertips.

Although mostly for the good, this compression is not all good. Just as we learned compression of gases generates heat, this compression of time and capabilities generates its own "heat" as well. Heat to always be working or on-call. Heat to always be entertained, avoiding down time and thinking time. Heat to generate political divisiveness, which we see all too often these days. Heat that prevents quiet negotiations and diplomacy to flourish.

Yet, as we reflect on the changes in electronics and the changes their advancement has wrought, the net effect has been to raise millions of people in the world to a higher standard of living, to escape poverty. Our lives have been enriched. But like all technological advances, the benefits depend on how society uses the advances. And people are slower to learn new social habits well, than to learn use of the technology itself. Hopefully, we and our children (grandchildren now for the class of '64) will learn to use them wisely.

Bob Blumberg '64 - After a year-long MS from MIT in Chemical Engineering, Bob went up the River to HBS for his MBA. A stint at the Pentagon as a junior Army officer doing planning and budgeting, was followed by 10 years in the Venture Capital Industry. Bob then moved across the table, became an entrepreneur, and with three other MIT alumni, founded Spectragraphics, an electronics manufacturing company, which he ran as CEO for 30 years. After selling it, he has been a consultant to small and mid-size businesses, and is currently mentoring two younger MIT grads who are starting technology ventures. Bob also works for MIT's Corporate Development Council, after a term on the Corporation. Recently, he started a political blog, www.amctrst.org , dedicated to showing the need for a third, Centrist Party in our country.

From Aeronautics Student to Citizen Lobbyist

Jim Lerner

I was originally going to tell you about my work in Wind Energy and Air Pollution working for the State of California. But Climate Change turns out to be more significant, so bear with me as I tell you how I got here.

I thought I was going to be an Aero & Astro Engineer. Ever since I was a little guy, I dreamed of flying and space travel. I watched the science fiction films on the weekends and read books, both science fiction and science fact, and that really got my juices going. I will never forget what MIT Professor Jimmy Mar said to us at our 50th Reunion at MIT. He said, "We can't pay the Aero grads enough, but we know an MIT Aero student because he or she always looks up while in a parking lot when an airplane flies overhead." How true it is!

I studied Aero and Astro at MIT and loved it. After graduation in 1964 I went out west to Stanford (enough of those cold winters) and got an M.S. and Ph.D. in Aero & Astro. I loved it and would have continued a career starting at Boeing, where I worked after my M.S.

A New Direction

But the first Earth Day at Stanford in 1970 changed everything! I had no idea the Earth was so messed up. I realized I had to do something about it, but I had no clue. So, I went to Paris with the Stanford undergrads, and while I proofread my thesis in a coffee shop I also read Paul and Jane Ehrlich's "The Population Bomb" and Donella and Dennis Meadows *et al*, "The Limits to Growth." These two books changed everything for me. I still didn't know what I should do, so I stayed in Europe for two years and saw how they lived. They seemed to get by on 1/3 to 1/2 the energy and resources that we used and were very happy. Why can't we do that?

So I came home in 1974 and started looking for a job. I had several interviews but didn't know where to go until I talked to John Holdren. (John later became President Barack Obama's Climate Change advisor in the White House.) He was a year behind me in Aero and Astro at MIT, and he went to Stanford in Applied Physics, so I knew him. I contacted him, and he said to look at the California Energy Commission (CEC) in Sacramento, the State Capital, that was just starting up. I'll never forget what he said nearly 45 years ago: "Better to hand out money than to grovel for it." So, I went to the CEC and decided to work on energy and the environment.

Even though I abandoned Aero & Astro as a career, I always loved airplanes and space vehicles and followed them whenever I could. I convinced the management at CEC that I wanted to start a Wind Energy Program for the State of California. I knew that my training in Aerodynamics would help. I also had a mentor in Sweden who had started the Swedish Wind Energy Program and helped me a lot. So, in 1978, more than 40 years ago, the California Wind Energy Program was created by legislation that was signed by Governor Jerry Brown in his first term. I had the pleasure of testifying before the Legislature about this bill. My Aero background served me yet again, when I worked for the California Air Resources Board. Since I had a background in Aero my EPA counterpart sent me a book written in 1999 by the scientists of the International Panel on Climate Change called "The Global Impact of Aviation." I read it eagerly. I learned that for every pound of CO2 that comes from the exhaust of jets, the global climate change impact of jets is about 2.5 times this number, owing in large part to the "climate forcing" of CO2 at cruise altitude.

Before you start to feel guilty about flying, stop right there. Just remember that all of us fly. How did I manage to get to this Reunion in a few hours? I flew in a jet airplane across the country. So, we must find a way to produce zero emissions from jet fuel. If you're an MIT guy like me, you are already calculating the tons of CO2 from flying. Well, it's a lot, because more of us are flying farther, and that surpasses the incredible 55% improvement in fuel efficiency of a passenger jet between 1960 (Boeing 707), when commercial jets were first introduced, compared to 2009 (Boeing 787) when the Boeing long range model took its first flight.

At the time, I knew nothing about Global Warming or Climate Change as we now call it. I just knew that every barrel of imported oil we could avoid by using wind turbines to generate electricity, meant 0.4 metric tons of CO2 would not go into the atmosphere. (Aside: I didn't know at the time that the greenhouse effect was known for more than 80 years, thanks to Svante Arrhenius or that President Lyndon Johnson knew about it, thanks to a report given to him over 53 years ago.)

I loved wind energy, and after working at the CEC, I was a wind energy consultant for the City of Fairfield (midway between Sacramento and San Francisco), that had big dreams about unplugging from the local utility grid. Then I formed my own company called Wind Developers, Inc. Our goal was to develop wind farms in the mid-1980s. I felt at home doing this, because it was quite similar to the oil business in which I had grown up. You lease land from a rancher, and you provide a royalty for the privilege of installing energy - producing devices on their land. In one case, it's an oil well. In another case, it's a wind turbine.

I briefly returned to my Louisiana roots in the family oil & gas business around 1985 (No, I'm not an "oil baron" as my Stanford advisor and former MIT Aero & Astro Professor, Holt Ashley, used to call me.). I learned how hard it was to make a living from stripper oil wells that averaged less than 1/4 barrel of oil per day. I knew about the environmental impact of oil wells, but I knew nothing about Climate Change.

Climate Change is Real

In fact, I only found out about climate change in 1988, when I was with my family on a vacation in Washington, D.C. Again, Aero and Astro had a role to play. Being an aerospace junkie, I just had to go to the Air & Space Museum Annex, then located in a warehouse in the eastern end of the District. While driving there, I was listening to a radio broadcast where an expert in climate, Dr. James Hansen, who worked at NASA, was testifying before Congress. I was so shocked and interested at the same time, that I pulled the car over and listened to his entire testimony. It took a while for me to do anything about it, but the seed was planted.

When I returned home, I was wondering what to do next. A friend said I should look at the California Air Resources Board (CARB), since it had the closest thing to a "think tank," and it would allow me to continue working on energy and the environment.
I went to work there in 1990, years before they had a legislative "mandate" to start working on climate change in California. I worked on transportation and air quality planning, which means we make cars and trucks cleaner, we try to get people to take alternative modes of transportation, and we implement for California the Clean Air Act as managed by the EPA. If that sounds bureaucratic, it is!

It was late 2006 when CARB got the legislative mandate to try to reduce California's CO2 emissions in 2020 to what they were in 1990. We knew that CO2 was a global pollutant, but we wanted to see if we could do this for California without hampering the economy. I call this "taking little baby steps," since the 2020 emissions would have to be reduced by 15% from the "business as usual" scenario. The thinking was that if we could manage to do this without damaging the economy and jobs, then we could show this to the rest of the world. Of course, it's one thing to do it for a State, and quite another to do it for the entire planet.

There are six gases other than CO2 that cause global warming. One other is Methane (CH4) which is 80 times more powerful than CO2, but it is short-lived (about 12 years). CO2 has the largest effect because it is the most abundant gas produced by humans and stays in the upper atmosphere for hundreds of years, continuing to warm the planet. So, when I say "CO2", I mean all the greenhouse gases, with CO2 being the most damaging. In practice, we sometimes say CO2effective or CO2eff to stand for all the Greenhouse Gases.

It turns out that California met its requirement in 2016, four years early, so "all we need do now" is reduce this to near zero globally as soon as possible. Some say 2030, while others are more realistic in suggesting this will happen by 2045.

But go back to 2013, the year I retired from CARB. I no longer was bound by the California Legislature and could do whatever I wanted. I was looking around for something neat to do, and I discovered the Citizens Climate Lobby. In a nutshell, this group, now more than 100,000 members with chapters in nearly every Congressional District, has been working on a proposal to put a fee on CO2 emissions that is revenue neutral, i.e., the money collected is returned to households. In part, this enables the people to pay for the increased costs of fossil fuels, and on the other hand, the steadily - rising fee on CO2 sends an economic signal that enables renewable energy to become less expensive than fossil fuels. The beauty of this idea is that economic growth, jobs, and GDP increase in every region of the country, even Texas and Louisiana, as a result. I figure that if the US does this, the rest of the world will take notice and will redouble its efforts.

The Citizens Climate Lobby lobbies Members of Congress. So, I am going to DC right after our 55th Reunion, to lobby Congress for the 6th time in 4 years. The skills needed to do this are totally different from the skills I learned at MIT and practiced in my career. It turns out that listening and communicating in a way that people not only understand you, but also get the message across are much more important that solving a complex equation and explaining it to the Members of Congress. I leave the science to the climatologists and biologists who spend their lives studying this and writing papers. We have maybe 15 minutes to at most a half - hour to tell a Member or their aide what he or she needs to know, answer their questions, and leave some materials with them. The steady work has paid off. There is now a bipartisan (meaning Democratic and Republican co-sponsors) bill in the House called the Energy Innovation and Carbon Dividend Act (HR773) that does all the things we propose. And the fact that we are strictly bipartisan really helps. This is not about one political party. It's about working together to save the Earth.

Think of this as equivalent to a Moon Shot only much harder. President Kennedy said in 1961 that we were going to put a man on the moon and return him safely to earth before the end of the sixties. We did it. Similarly, we undertook to protect the world from being overrun by the Nazis during WWII. We did it. Likewise, we must be able to do this for Climate Change.

We Must Do Something

In a nutshell, we must do something about this very soon, or life as we know it will not be possible on the Earth. We might not be able to "solve" it, but we can reduce suffering. That's what keeps me going. And we might even be able to reduce the excess CO2 that is in the upper atmosphere causing global warming to continue.

A +2 degrees C. increase in average temperature by the end of this century is no longer tenable. Neither is 1.5 degrees C in my humble opinion. Why? We are at nearly +1 degrees C, and things are no longer viable. We are getting extreme weather, people are dying, and there's no end in sight. Consequently we not only need to reduce the annual emissions of CO2 from 40 billion tons per year to zero as soon as possible, but we also need to reduce most if not all of the 1 trillion tons of CO2 (25 times the annual emissions) in the upper atmosphere as well as the dissolved CO2 in the oceans.

Can we all just leave the Earth and be saved? No. This is our home, and the Blue Dot is the only place that we can call home. We must take care of the Earth.

Dr. Jim Lerner, '64, has 3 degrees in Aeronautics & Astronautics. He worked at the California Energy Commission, where he started the State Wind Energy Program and the California Air Resources Board, where he worked on a number of projects related to the air pollution impacts of aviation. He is now the Senior Policy Advisor for the Sacramento Chapter of the Citizens Climate Lobby.

Reflections on Energy

Jim Monk

In the late 60's, I started a new career direction in the field of energy. When the Class of 1964 had graduated, I started out in manufacturing, thinking this was a solid field that would last forever. But the Vietnam War and my being drafted let me back out of one field and move to another. While attending the Sloan School in the late 60's, I became interested in how our society was organized and run – all with the aid of enormous amounts of energy from hydrocarbons. This seemed like an exciting, necessary and useful area, so off I went to be an energy specialist when I graduated again from MIT in 1971.

I started work for a very large energy company and was soon working on developing a business plan for a new refinery. A refinery does nothing but take a raw material – crude oil -- and turn it into some useful products, such as gasoline, kerosene and diesel oil. But there is a hefty cost of bringing a new refinery into being. It would take decades to pay for the investment and a new issue was raising its head at that time – the environmentalists were beginning to object to this strange commodity called pollution. Our development job was to decide two things: how big a refinery was needed and where should we locate it. As we worked through the process another new concept began to emerge: rather than go out and build a brand new refinery in a brand new location – a "greenfields" project – perhaps we could go to an existing location and simply expand operations there. Additional capacity could be added without substantially enlarging the facility and it would thus be less likely to attract opposition from the environmentalists.

As my small part of that fairly large project, I and others were tasked with developing a forecast of the future cost of that raw material we were going to use in large quantities. At that time, the organization for which I worked obtained most of its raw material from Saudi Arabia. The cost was around fifty cents a barrel, or about a penny a gallon. What might that cost be in the future? I had access to lots of experts within the company who were experienced in the cost of development of oil fields so there were a variety of opinions of what was going to be the future cost of crude oil. Some of that experience came from developing oil fields here in the US, where the oil formations were smaller and the expenses higher than in the sandy deserts of the Middle East. In particular, we looked at what was happening in West Texas as an example of where costs might go.

Now let me take a sidebar for a moment to discuss that concept of "Cost" versus "Price". At that time, most of the hydrocarbon energy industries – coal, natural gas, oil – operated on the concept of the cost of the material. We went to some lengths to define exactly how much it cost to drill, mine, lay pipelines, build ships and harbors – we were focused on the supply side of things. In just a few years into the future, that whole world was turned upside down and we had to adjust to the concept of "Price". Price is what you can obtain in the market place for your products. It has almost nothing to do with cost. Price is set by peoples' perceived need for the product and thus what they are willing to pay for it. But for us in the bowels of a large energy company who worked on the supply side of things, it was only cost that drove us at that time.

In 1972, we forecast that twenty years out the cost of that barrel of crude oil we needed to run through the new refinery would cost over $5 per barrel – ten times the current cost. Oh, yes, we were good forecasters! Lots of senior folks in the oil company thought we were crazy. But the economics were solid even with the price increases, so the refinery project was given the green light.

Just so you know, a barrel of oil contains 42 gallons and is the standard measure used in the oil industry for volumes of oil. That standard was set in 1866 in Pennsylvania, then the powerful center of the emerging petroleum industry, but the volume actually came from English practices that dated back hundreds of years. A 42 gallon barrel of oil weighs about 300 pounds and was about all the oil field workers could handle.

Forecasting is Not Easy

On reflection, we missed just a whole bunch of things – OPEC, environmental regulations, fracking – in making our energy price prediction. Clearly, the emergence of the Organization of Petroleum Exporting Countries (OPEC) and its ability to set the price of oil in the marketplace has had a dramatic effect on all the citizens of the world. OPEC engendered one of the most massive reallocations of real wealth the world has ever seen. Money, and power, flowed to OPEC in obscene quantities for more than 20 years. Now, their hold on the world has been loosened somewhat by that last item, fracking, which has generated a surge of new hydrocarbon supplies for the world to consume. In the meantime, the environmental regulations have taken serious hold of the world's attention and are having the effect of lowering the demand for hydrocarbons as they encourage the use of other sources of energy, such as wind and sun power.

There was no discussion in the early 70's over the impact of hydrocarbon usage on the atmosphere, other than the beginnings of discussions of how sulfur that was bound up in the fuels was creating acid rain. And most of that talk focused on coal, rather than oil or natural gas. Beyond the sulfur issue, there was simply no concept that the hydrocarbons in the fuels were being broken down into end products that included carbon dioxide that might have an impact on the atmosphere. Rachael Carson published her ground-breaking book, ***Silent Spring***, in 1962, but it was focused primarily on the impact of chemicals on the environment. While her book started the environmental movement, it took a couple of decades before that movement had a serious impact on the oil industry.

Carbon dioxide was indeed understood by the scientific community to be an item of interest, and steps were taken to start measuring that compound in the atmosphere. High up on the slopes of the largest volcano on earth, Mauna Loa – located on the Big Island of Hawaii – a carbon dioxide measurement station was established in 1954. I have visited this facility. There is a tall tower that puts the air collection point more than a hundred feet above the surface, which itself stands over 11,000 feet above sea level. I have put my hands around the four inch plastic pipe that comes down from the top of the tower and goes into the measurement room. These carbon dioxide concentration numbers became famous when Al Gore climbed a ladder in his movie, An Inconvenient Truth, to show just how much the amount of carbon dioxide has risen over time and how it is rising exponentially at the current time. The fundamental number of parts per million of carbon dioxide has now risen to over 400 PPM in early 2017 – the first time that number has been that high in literally millions of years. The implications of that single number are probably huge, and it keeps getting higher every year so far.

Adventures in Algeria

From the energy company, I moved to a consulting company and was soon sent to work in Algeria. This was in the late 1970's. We had a team of folks there to help the government think about its assets, including oil and natural gas. They had just started exporting natural gas to the United States in the form of LNG – Liquefied Natural Gas – which is natural gas chilled to about minus 260 degrees Fahrenheit to turn it into a liquid, thereby reducing its volume by a factor of over 600 times, making it economical to ship long distances. Now the United States is using the same technology to export natural gas to the world since we have created so much supply with that fracking technology.

One of our major projects in Algeria was to help the government's representatives to OPEC begin to set the price of oil at the wellhead. We helped develop the concept of Netback as a method to set the price of oil. We scoured the newspapers of Europe and America to see what people were paying for their energy supplies. This was the price people were already willing to pay. We then took careful measurement of the costs involved in the long supply chain back to the wellhead to net back the market price to the source of the energy supply. We found the OPEC countries could charge just a whole lot more than the cost of production based on the current price in the energy market place. We suggested a new price of $7 per barrel as what OPEC could charge for Saudi Arabian Light – a key crude oil in the world market. As this price rolled through the supply chain, we witnessed gasoline shortages in the United States, rationing and the whole Energy Shock phenomena. Today, that price is long forgotten, and the world has survived nicely.

We were also involved with Algeria's negotiations over the LNG supplies. Two stories stand out. There was a team of folks from one particular US utility that had come over to negotiate for a long-term supply of gas. After a few days, the leader of that team came to the meeting with a bottle of mouth wash, laid it on the table and said that everyone was to take a swig. It seems the Algerian dental care industry is far behind that of the US! But after the negotiations were over the Algerians were gloating about how well they had done. They said how much they liked to negotiate with American engineers – and that the whole team of folks from the utility were engineers, some of whom had been promoted to high levels within the company – because the engineers thought in a straight line and were all focused on costs, whereas the Algerians were focused on value and price. They hammered the American engineers!

The second story didn't get started until I was back in the USA. After I had returned, we continued a project that had gotten started with some questions asked by the Algerians. How long will we be able to charge the prices we've recently set? How long is the world going to continue to have oil and natural gas to use? This major project had us scouring the world to assess how much oil and gas still remained underground and how much of it could be recovered over time. On one time scale, we totally blew the assignment, but on a different scale, our predictions are still true.

The result of our studies told us that by around the turn of the century – this study was done in the early 1980's, so we were looking 20 – 30 years out into the future – the world would begin to run out of oil. Well, lo and behold, the new century has arrived and no one is making any assertions that we are running out of oil. As I see it, there are three main reasons our forecasts were in error.

The main short-term error was not accounting for the economic impact of the Energy Shock of the late 1970's on the world's demand for oil. When you look at oil usage curves from that time, there was a distinct drop in demand as oil prices jumped precipitously in the late 70's and that lowered demand stayed that way for more than a decade. That had the impact of sliding the day of reckoning a good way into the future.

Our next error was not being able to really know if all the oil had already been discovered – and it hadn't! Right after our study was completed, work started on the North Sea discoveries that were to provide Europe with an oil and gas boom for decades. There were other major discoveries made in the 80's but by the late 90's almost no new major discoveries were being made. Instead, technology came to the rescue.

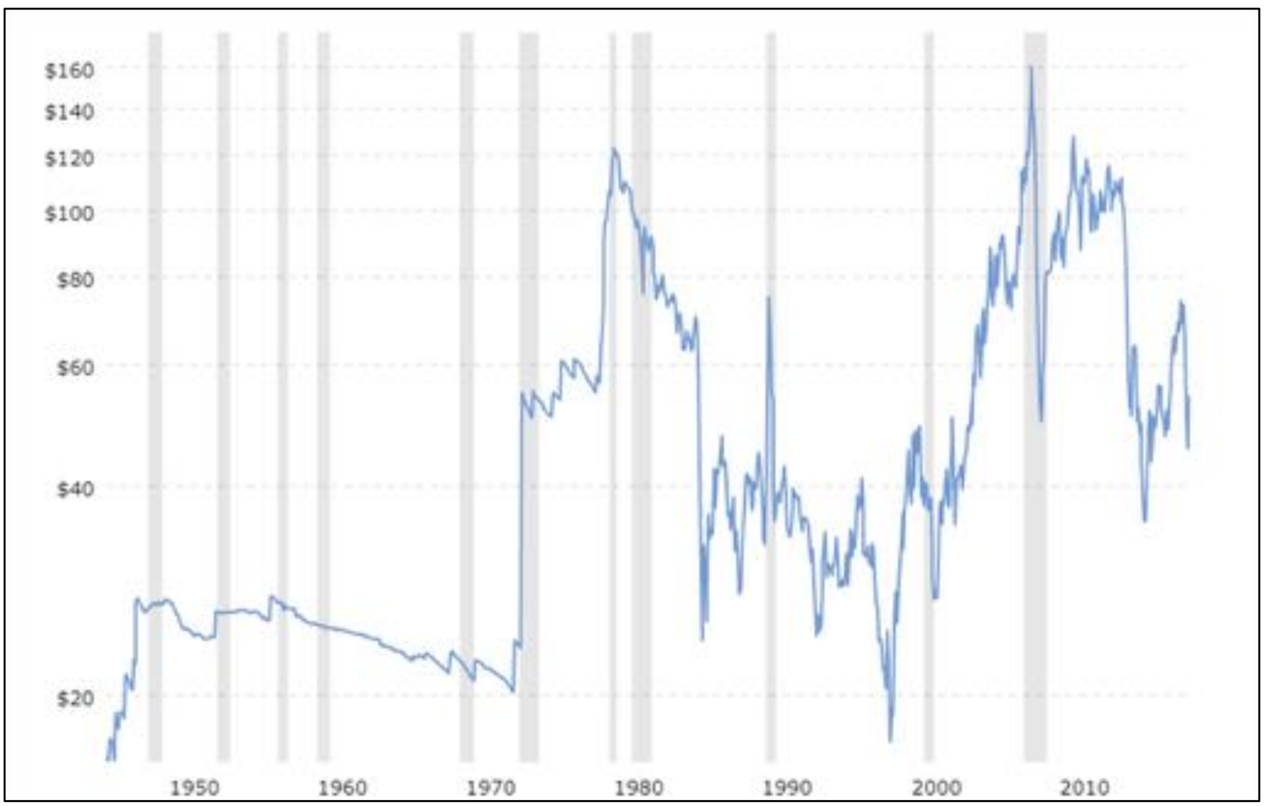
So, the final reason for the error in our forecast is technological: the oil industry has benefited from some really unique developments which have increased oil and natural gas supplies enormously. This technology is fracking. And fracking itself benefits from a variety of technological developments that allow for precise measurement and control of well drilling. Fracking is conceptually simple. Many geological formations that contain hydrocarbons are "tight", that is to say, the rock is so dense, or tight, it will not allow the hydrocarbons to seep out of the rock at all quickly. If you can fracture (frack) the rock formation and then hold it open, the amount of open surface area in the formation is increased enormously which allows even a slow rate of seeping to become a significant volume of hydrocarbons coming to the surface. This one development has increased the supply of natural gas in the United States many fold and has moved us from a position of not having nearly enough natural gas for all the demand, to actually exporting natural gas to other countries because we have more than we can use. Fracking has opened up huge new areas in the United States, and now overseas, to produce natural gas and, increasingly, crude oil. Fracking has also engendered a lot of controversy and has even been banned in some states. But one of the clear results of all this fracking is for oil and natural gas prices to be a whole lot lower than they might be otherwise. And that is a very good thing for consumers.
On a longer time scale than the few decades that have been covered so far, our prediction that the supply of oil and natural gas would begin to diminish remains absolutely true. The world is not making more oil and natural gas at anywhere the rate people are consuming it, which means that at some point, there simply will not be enough of these key energy sources to go around. But <u>when</u> that will occur is up for some serious debate. Will solar

and wind power projects become so successful that oil and natural gas simply are not needed as much? Offsetting that, will the developing countries in the world begin to use the same amounts of energy as America and Europe have consumed in the past? If so, demand is going to shoot up and the shortage issue will rear its ugly head again.

Future Energy Directions

When I was involved in doing price forecasts in the late 1980's, we predicted prices would be over $120 per barrel by the turn of the new century. They didn't make it on our schedule, but by mid-2008 the price reached over $145 per barrel – the highest yet – but then proceeded to sink for many years afterwards as the United States went through its financial crisis. That crisis eventually affected the whole world, especially China, and oil prices plummeted as demand slackened while producers continued to pump their products.

Just to help think about all these prices, here is a sample chart that shows the price of West Texas Crude Oil – which is a key product of the US and is intimately linked to world oil prices. The prices shown from 1946 to the present have all been adjusted by the Consumer Price Index and are thus in current 2018 dollars. This chart was produced by Macrotrends LLC and is used by permission.



The chart shows that energy prices have seen a lot of volatility over the last 70 years and have responded to two dramatic incidents, plus some others. The oil shock of the late 70's drove down demand and prices for the following two decades. The economic shock of 2008 also had a dramatic impact on prices which was coupled with the burgeoning supply of energy coming out of the US, and other countries, due to the technological revolution of fracking.

I'm no economist, but I know the laws of supply and demand at the heart of economics apply with full force to the supply of hydrocarbons and the demand for them. If you come up with extra supply in one part of the world, it lowers the price for the resultant products. Or if demand zips up quickly, prices are sure to follow. A practical example that occurs virtually every year in the US is the rise and subsequent fall of gasoline prices at times of peak demand, such as around the Fourth of July when the peak vacation driving time occurs. That happens if the marketplace is allowed to operate unfettered.

But the reality is the hydrocarbon market place does not always operate unfettered. If you have been driving around in Europe recently, you see that impact in your wallet – European Union gasoline prices are a whole lot higher than they are in the US. There is no inherent reason why their prices are higher than those of the US. It's simply that the EU nations like the tax revenue and are also working to reduce demand by raising prices. Now, another consideration is coming to the fore: should energy prices be increased by additional taxes to (a) further reduce demand and (b) pay for alternative ways of producing useful energy. This is the carbon tax. How it might be imposed and whether is should be imposed are political issues that are beyond this simple engineer's pay grade.

My only observation will be that energy prices have a very pervasive impact on any economy. The OPEC induced price shock of the 1970's sent world economies into a tailspin for more than a decade. Now, if parts of the world impose a carbon tax and other regions do not, it will have the effect of reallocating who uses how much energy. In the '60's and '70's the United States became the high priced manufacturer of lots of items due to a variety of forces that raised our costs of manufacturing, and what happened? A large portion of our manufacturing sector moved elsewhere to find lower prices and now we have a Rust Belt where we once had the mightiest manufacturing region in the world. Our economy sputtered for a long time. Energy supply and demand cannot be controlled by any one country – it is a world wide process – and unilateral changes to its energy prices by one country may well create unforeseen consequences throughout its economy.

Now that the world has emerged from the financial shock that started in 2008, demand for petroleum products is picking up once again, but right now the fracking revolution is keeping supplies high, so prices are staying reasonably low. While I've been wrong every time I tried to forecast energy prices, the direction that those prices are going to go in the long term is very easy to predict. They will go up and the world will have to adjust once again to substantially higher energy prices. That's my forecast and I'm sticking with it.

Jim Monk '64, SM '71 went into manufacturing after leaving MIT the first time. That was interrupted by being drafted into the Army during the Vietnam Conflict. When that rude experience was over he came back to MIT for a Master of Science in Management from the Sloan School. Thus armed, he embarked on a long range plan that found him after 27 years as the CEO of an energy company. From there he became an independent consultant in facilities management and energy and morphed into the CFO of a small health care company. To break with all traditions, he became a coffee farmer in Hawaii where he lives at present.

My Personal Odyssey in Climate Science

Warren Wiscombe

Perhaps my experience "growing up" in climate science will help personalize a subject that nowadays can seem depressingly doom-and-gloom. But the subject did not begin that way in the 1970s – far from it! So perhaps I can communicate a little of the excitement which accompanied the creation of an entirely new field, quite distinct from "climatology".

I entered the working world in 1969 with an almost-completed PhD in Applied Math from Caltech and an undergrad degree in Physics from MIT. (I left grad school early because I was burned out on school life and wanted to begin a real life.) In normal times, with degrees from high-tech schools, I would have had a wide range of job options, but such options were drying up fast after a wild splurge of hiring in the 1960s, when almost anyone could get a science position to help "beat the Russians". 1970 was a well-known low point in physics hiring, due partly to the prohibition of direct Department of Defense (DoD) funding of university research by the "Mansfield Amendment" of 1969 (a result of Vietnam War protests on many campuses).

Radiative Transfer Beginning

So I felt lucky to get a job doing research at a small private company in La Jolla with DoD contracts. There, a famous WWII Los Alamos veteran named Burt Freeman mentored me in radiative transfer, and I was encouraged to learn Fortran and numerical analysis and begin writing large computer programs. But those programs were for underground nuclear tests, and I was increasingly anxious to find another line of work, especially since I was an early convert to the environmental movement, which was just getting started in the early 1970s with Earth Day and Nixon's creation of EPA.

The company had a small contract with DoD's Advanced Research Projects Agency (ARPA, the inventor of the internet) to work on climate, and I found out that the lead person on the radiative transfer part of that work was leaving the company. So I said "I can do that". Overnight, having studied no radiative transfer in school, I became an atmospheric radiative transfer expert in the ARPA Climate Dynamics Program! I proceeded to develop the most advanced atmospheric radiative transfer program of the day, called, fittingly, ATRAD. Lucky for me, radiation is the heart and soul of climate science.

ARPA funded the US's first major climate program. It attracted first-rate talent like: Jakob Bjerknes, discoverer of the El Nino/Southern Oscillation (ENSO); and John Imbrie, who proved the Milankovitch theory of ice ages. At the center of the program was the Mintz-Arakawa climate model based at UCLA (we used one of the first internet links to run the model from La Jolla). Soon, we got another grant to work on radiative transfer in Arctic stratus clouds, as part of the Arctic Ice Dynamics Joint EXperiment (AIDJEX) Program that was putting year-long search camps out on permanent sea-ice floes (mostly melted now due to Arctic warming).

Climate Science Begins

All this work got me noticed by Steve Schneider at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, which led to an offer to join their fledgling Climate Section. (Later, Steve would become a major spokesperson and book-writer for climate science.) NCAR was exactly the right place to be in climate science in the 1970s, although I only appreciated that in retrospect. When I got to NCAR, I was immediately met with hostility from the old-time meteorologists, who regarded climate as an unimportant upstart field. They were contemptuous that I couldn't read a weather map. Their interest lay in Numerical Weather Prediction, a subject that took off in the 1950s with the invention of digital stored-program computers and which became the central (and nearly sole) focus of US meteorology. Climate was, to them, a boring field involving mere data collection and statistics – "the province of the halt and the lame" according to one wag. How things would change in only 10 years!

The visionary NCAR Director, Walt Roberts, saw the need for climate science and had long been interested in Sun-climate connections. The 1970s saw a one-time surge of outsiders into atmospheric science, and, due to Walt, NCAR was the epicenter of this surge. There, I met many of the physicists, chemists, and other outsiders who entered the nascent climate field. I spent a joyful 6 years at NCAR, playing in the giant sandbox that was climate science. No political attention was focused on us, and we had virtually unlimited budgets to bring visitors to NCAR. Luminaries like Paul Crutzen, eventual Nobel Prize winner; V. Ramanathan, discoverer of some "non-CO2 greenhouse gases"; Susan Solomon, future leader of the Intergovernmental Panel on Climate Change; and Ed Lorenz, discoverer of chaos theory, all passed through NCAR and stayed a while.

While the cloud of hostility somewhat dissipated over my 6 years at NCAR, it never really disappeared, and in 1985, in frustration, Ramanathan and I published an article in Bulletin of the American Meteorological Society titled "The Role of Radiation and Other Renascent Subfields in Atmospheric Science". This stirred up a hornet's nest among the old-time weather folk, but, a few years later, most of these people switched sides and rebranded themselves as "climate scientists". By the end of the 1980s, meteorology had pretty much evolved to become climate science, with weather taking a back seat. And in a satisfying rebuff to my old enemies, the American Meteorological Society elected me a Fellow in 1989.

Some Later Years

I had always wanted to try my hand at being a university professor, but chose poorly – a department at NYU that was subsequently disbanded. Fortunately, while at NCAR, I had met Dave Atlas, a famous radar expert, who moved to NASA Goddard Space Flight Center in 1979 as the new Director of the Atmosphere Lab, with virtually unlimited hiring authority. Dave had made me an offer while I was still at NCAR, and he reactivated it in 1983. I was hired in 1984 just before the hiring door closed, due to Dave's fight with some people at NASA HQ. I spent a happy 30 years at NASA working on various climate problems centering on the role of clouds in Earth's radiation budget. In the near-final part of my career, I was "borrowed" by the Dept. of Energy for 5 years to be Chief Scientist of their huge Atmospheric Radiation Measurements Program, which was then the largest non-satellite climate program in the US government.

Paleoclimate Thoughts

Like all my colleagues in the early days, I had a strong interest in paleoclimatology, the study of climates prevalent at a particular time in the geological past. Indeed, energy-balance climate models in 1969 predicted a Snowball Earth if ice sheets ever got within 30 degrees latitude of the Equator. Later, we studied the previous interglacial (120,000 years ago), the Pliocene (3 million years ago), and the Paleocene-Eocene Thermal Maximum (55 million years ago) as analogs for the future global warming.

Warren Wiscombe '64, spent his career …

Nuclear Deterrence and Satellite Communications

By Tom Seay

This essay describes some of my participation in the development of military and commercial satellite communications. The context for my first decades was the Cold War and nuclear deterrence. So, this essay provides a summary of nuclear deterrence in that era, and closes with some thoughts about nuclear deterrence in the future.

Nuclear Deterrence and the Cold War

The class of 1964 entered MIT during the Cold War. The highest priority of the Department of Defense (DoD) was and is deterring nuclear attack and maintaining the nuclear capabilities necessary to do so. Deterrence means that a potential adversary should believe the costs and risks of proposed actions outweigh any gains it might hope to achieve. To deter attack against the US, in the late 60's the US had 1054 land-based intercontinental missiles (ICBMs), 469 strategic bombers, and 41 Fleet Ballistic Missile Submarines (FBMs), over 30,000+ nuclear warheads, and airborne command centers. The intent was to be able to absorb a first strike and still retaliate. The Soviet Union had 1427 ICBMs,140 strategic bombers, 30 FBMs, and an estimated 10,000+ nuclear warheads. Thus, mutually assured destruction (MAD).

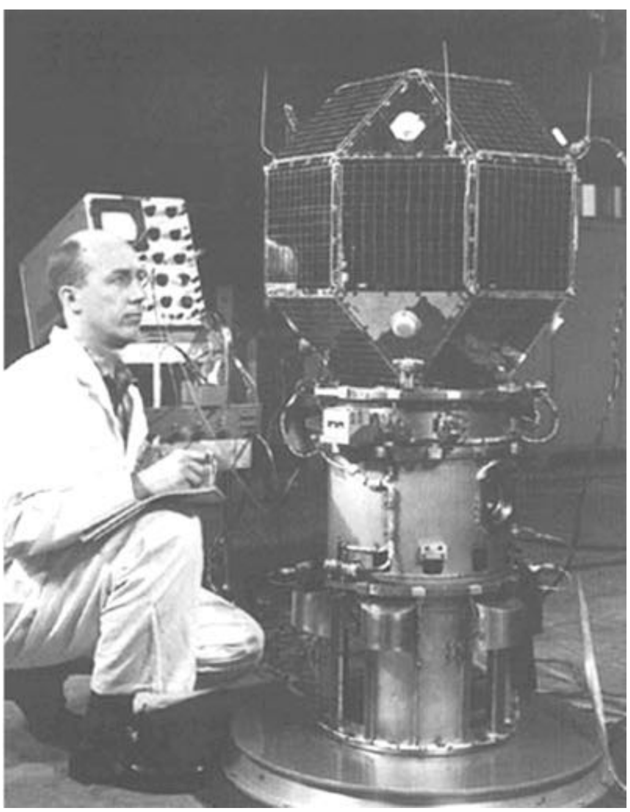
The US posture was intended to foster stability, i.e., no accidental start of a nuclear exchange. The US would not strike first. We would only launch upon positive command from the National Command Authority. The ability to absorb a first strike and still retaliate implied an appropriate level of readiness. US confidence in this capability depended upon knowledge of current threats, detection of emerging threats developed to counter existing and new systems, and an ability to adjust/counter an overwhelming threat. Implied attributes: extremely reliable equipment and procedures, excellent command security and weapon protection, and tolerable sustainment cost.

Remembering the effects of nuclear weapon use at the end of WWII, virtually all senior US personnel took very seriously the danger of nuclear weapon use, imparting some stability into the world situation. It can be argued that MAD worked, as the US and Soviet Union did not have an all-out war, but it can also be argued that crises, such as over Berlin and Cuba, brought the world dangerously close to nuclear war.

Radars, and later surveillance satellites, were expected to alert multiple concurrent launches, which could only be for an attack upon the US, and only from the Soviet Union. The nuclear command and control (NC3) system must support: detection, warning and attack characterization; adaptive response planning; decision-making via critical conferences; dissemination of Presidential orders; and management and direction of forces. The system was intended to permit launching of our ICBMs before incoming missiles could destroy our ICBMs in their silos. While only low data rates were required, the system must work reliably through pre-, trans-, and post-attack environments, provide seamless connectivity over most of the northern hemisphere, and have negligible probability of false message delivery.

MIT Lincoln Laboratory Satellite Communications Programs

In 1963, just 6 years after the launch of Sputnik, MIT Lincoln Laboratory was chartered to demonstrate active satellite communications systems that could support Nuclear Command and Control capability. The first program emphasized enhancing satellite downlinks. The downlink signal (from a satellite to a terrestrial terminal) is generally the weak link in satellite communications. The uplink can be improved by increasing the power of a transmitter; the downlink can be strengthened only by maximizing the effective radiated power per unit mass in orbit — a more complex task. To resolve the downlink problem in satellite communications, Lincoln developed high-efficiency spacecraft transmitters in the downlink frequency band. These and other spacecraft-related technologies were addressed by a series of Lincoln Experimental Satellites (LESs). High-efficiency systems of modulation and demodulation, together with encoding and decoding signal for detection and correction of errors, minimized the required signal to noise ratios, and thus the required downlink transmitter power. Also needed were interference-resistant, multiple-access signaling techniques that would permit simultaneous use of a satellite by tens or hundreds of users, some of them mobile, without invoking elaborate systems for synchronization and centralized control. These and other terminal-related problems were addressed by a series of Lincoln Experimental Terminals (LETs) that went hand in hand with the LESs.

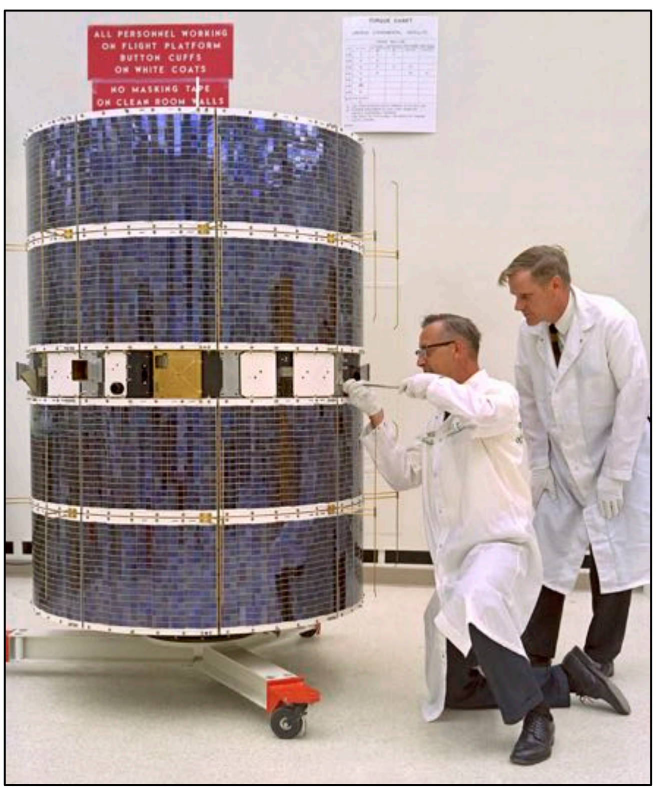


LES-1. 37 kg spin-stabilized polyhedron, SHF beam switching. 200 mw ERIP

The objective of the first four LESs and associated LETs was simply to make long-range military communications routinely available for large, transportable terminals operating in the military SHF band (7-8 GHz). All of these all-solid-state satellites were simple transponders in which the uplink passband was frequency translated and amplified with a hard limiting amplifier, and transmitted back down. LES-1 and LES-2 were essentially identical. Each satellite was a 37 kg polyhedron covered with solar cells generating about 25 w of prime power, and spin stabilized. LES-1 was launched in early 1965, but a flaw in the ordnance circuitry left the satellite tumbling in a parking orbit. LES-2 was successfully orbited later in 1965 into a 32^{o} inclined, 2700 km by 14,800 km elliptical orbit. The Effective Isotropic Radiated Power (EIRP) radiated toward the earth was 200 milliwatts. LES-4 was somewhat larger at 53 kg, 36 w prime power, 400 mw EIRP, and intended to be placed into near geosynchronous orbit. The late 1965 launch left the satellite in the transfer orbit, but considerable communications and space environment data were collected. LET-1, a tractor-trailer with a 10 kW transmitter and a 15 ft diameter antenna, was also used to communicate via a belt of passive dipoles ("needles") and via reflection by the moon.

The focus of the Lincoln program then shifted to evaluate the potential usefulness of satellite communications in the military Ultra-High Frequency (UHF) band (225-400 MHz) for small, lower cost, mobile terminals. LES-3, launched in 1965, was a 16 kg satellite with a UHF transmitter radiating 30 w EIRP for measurement of expected multipath interference from ground reflections. Multipath propagation effects were observed as expected: relative to the nominal 1 m free-space wavelength, much of earth's surface is mirrorlike, so electromagnetic waves can be propagated between the satellite and the airborne terminal by a direct path and also by paths involving reflections off the earth's surface. By knowing the likely parameters of the signal delays, the Lincoln team was able to design systems of modulation and demodulation for UHF satellite communications that mitigated multipath propagation effects.

LES-5 and LES-6 were all solid state, "bent-pipe" satellites: they received an uplink band of frequencies, translated to the downlink band, and retransmitted everything received from the uplink. LES-5 was a 104 kg satellite with 136 w maximum start of life prime power, radiating 45 w EIRP. LES-6 was a 181 kg satellite with 220 w maximum start of life prime power, radiating 890 w EIRP. The greater radiated power came from a 4X increase in transmitter output power, and a 5X improvement in the effective antenna gain. LES-6 was the first satellite to demonstrate autonomous orbit control.



LES-6. 181 kg spin-stabilized cylinder. Autonomous orbit-keeping. UHF switched array. 890 W EIRP

The associated terrestrial communications terminals used simple, non-directional terminals and moderately powered transmitters, enabling affordable airborne equipment. Advanced band-spreading, modulation and coding provided resistance to jamming and channel degradations such as multipath, inband interferers, and nuclear-induced scintillation.

In 1965, I was fortunate to get a summer job in the Lincoln Laboratory Communications Division while still in graduate school, and converted to full time in 1966, upon completion of my Engineers degree in Electrical Engineering. My first assignment was to develop an unattended receiver to automatically acquire and track beacon signals from LES-5. The 3 Watt beacon signal provided a time and frequency reference for communications terminals, as well as auxiliary telemetry data. The signal was to be received at a very low signal-to-noise ratio, in the presence of channel degradations like multipath and Doppler shift.

The beacon signal turned out to provide the critical initial communications with LES-5. Imagine the tension not only for me, but the entire Lincoln team and sponsors while waiting for the signal to appear after launch in July 1967! Fortunately, the launch to geostationary orbit was successful, the satellite properly deployed, and the beacon receiver telemetry reported all systems good. This experience showed that one could predict possible performance, and performance limitations, and then build real equipment that would perform as predicted. I also discovered that my palms would sweat under very stressful conditions!

A second generation version of the Beacon Receiver was developed for LES-6 and used in many airborne tests and demonstrations after the successful launch in September 1968.

Supported by the LES-5/6 demonstration successes, the government proceeded to procure eight FLTSATCOM geostationary UHF communications satellites with launches 1978 -1989, subsequently replaced by eleven UHF Follow On (UFO) geostationary satellites with launches 1993-2003. These were MUCH larger satellites: FLTSATCOM satellite launch masses were 1884 kg to 2310 kg and generated 2500 w of prime power. The Army, Navy and Air Force developed militarized versions of the terminals: over 20,000 were deployed. The Air Force portion of the payloads and terminals was known as AFSATCOM.

After UHF military SATCOM feasibility was established, the Lincoln program focus evolved toward making the communications systems electromagnetically and physically survivable, capable of functioning despite determined efforts by an adversary to interfere with them by jamming or by physical attack. The next generation of Lincoln communications satellites (LES-8/9) and associated terminals demonstrated greatly improved performance compared to LES-5/6 and all other communications satellites before that time. Some of the firsts were: 1.) digital onboard processing for signal extraction so that the downlinks would only contain user information, and for digital interconnection between different frequency bands, 2.) use of Extremely High Frequency (EHF) signals to maximize the directivity and gain for a limited mobile aperture, and wider bandwidth for greater capacity and interference resistance, 3.) use of UHF for lower cost terminals with non-directional antennas, 4.) crosslinks between satellites for connectivity among mobile terminals located around the world, 5.) a third generation Gyro for autonomous on-orbit operation, 6.) A Multi-Hundred Watt Radioisotope Thermoelectric Generator (MHW-RTG) for high resistance to environmental degradations and extended lifetime[1].

[1] A MHW-RTG was also used to power the Voyager spacecraft, which have both operated for over 40 years. Voyager 1 was the first spacecraft to enter the interstellar medium.

In the collegial atmosphere of Lincoln at that time, I was heavily involved in creation of the underlying rationale and identifying needed capabilities. Then I performed much of the high level design of the communications payload, and the detailed signal waveforms and onboard processing constrained by stringent limitations of flyable technology. [Our flyable integrated circuits, which had two flipflops per package, were obtained from the production line established for the Minuteman missile program.] Then we proposed and developed what was probably the first radio/modem to use microprocessors and carrying two programs: one to support the early signals, and another to support the more robust LES-8/9 signals. This innovation facilitated introduction of new capabilities into operational aircraft without losing legacy capabilities needed during a transition period.

The pair of 450 kg satellites were successfully launched by a single Titan III launcher into inclined geosynchronous orbits in March 1976 and were extensively tested with UHF and EHF mobile terminals over the next couple of years. LES-8 was retired after 28 years of operation. LES-9 is still operational after 42 years on orbit---it is believe to be the longest continuously operating communications satellite in U.S. history. These long lifetimes are attributable to a design approach where we identified every possible means of physical failures we could think of, and mitigated each within the state of the art. For selected critical subsystems, we had two independent units that were independently designed, to minimize the possibility of a design flaw crippling the spacecraft.

Portions of the LES-8/9 technologies were implemented by contractors for the Single Channel Transponder payloads flown on the fourteen SHF DSCS III satellites, launched 1992 through 2003.

Lincoln next built two EHF payloads for the Navy, for inclusion in the UFO satellites mentioned above, and launched in December 1986 and March 1989. These payloads shifted the EHF frequencies to an operational band, versus the demonstrations of LES-8/9, and added a computer-based resource controller. These EHF payloads enabled the Navy to accelerate development and deployment of full military-qualified EHF terminals, and provided risk reduction for the subsequent MILSTAR satellites. Contractors built additional EHF payloads, so that 8 or the 11 UFOs carried the EHF capability.

The full capabilities demonstrated by LES-8/9 were finally implemented in a military program with five MILSTAR geostationary satellites, the first launched in February 1994 and the last in April 2003. The three later MILSTARs had an enhanced payload for higher data rates.

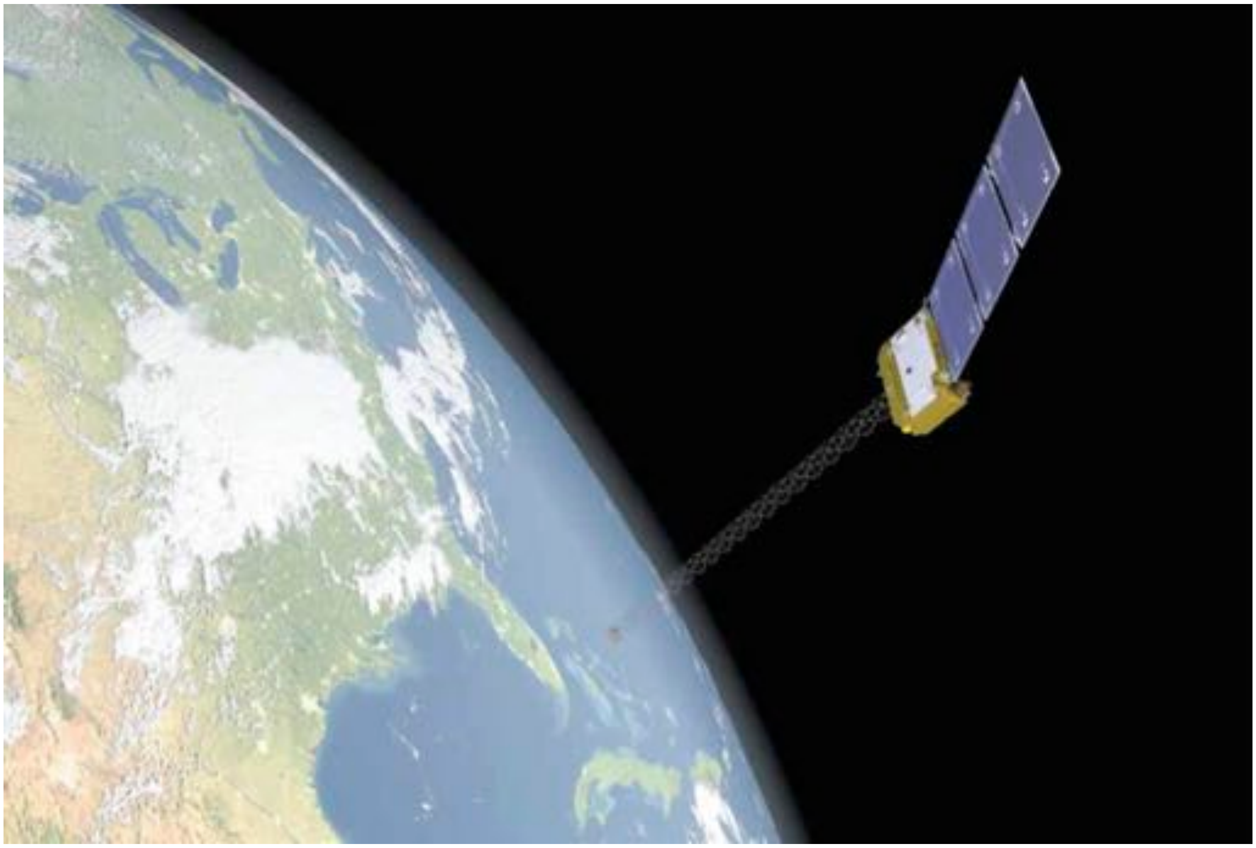
Given that the need for the capabilities of LES-8/9 for reliable nuclear command and control were understood in the mid 70's, *why did it take 18 years to get the first full realization on orbit, and another 9 years to achieve a full five-satellite constellation?* Some of the reasons were: 1. An opinion among Congressional staffers that the Air Force could only manage one major spacecraft development, and therefore tactical as well as nuclear deterrence capabilities should be included on MILSTAR, 2. Simple total cost estimates suggest it is overall most economic to amortize the host spacecraft capabilities (orbit-keeping, power generation, attitude control) over as large an number of payload capabilities as will fit within the available launcher capability (an economy of scale), 3.) For support of all the services in the budgeting process, each service had to have some capabilities included (second reason why tactical capabilities were comingled with strategic capabilities). This increased the total number of requirements, and the resulting complexity of the payload design. 4.) The desire to avoid failure resulted in much more testing and documentation than best commercial practice. The resulting MILSTAR satellites were behemoths for the time: launch mass of 4500 kg.

Experiences in the Private Sector

In 1980 I left Lincoln Laboratory to experience a public company: both in defense and commercial communications systems. The environment was quite different than at Lincoln Laboratory: as a member of senior management I had to deal with quarterly financial performance and personnel challenges, as well as engineering/technical performance and reliability of our delivered products. On the government contractor side, I experienced the impact of highly detailed requirements and a complex bureaucratic process; while on the commercial contractor side, I experienced the much faster pace permitted by simpler requirements, clear objectives, and clear lines of responsibility. Our modems for the commercial satellite industry often enabled a doubling or more of the total communications provided through a single satellite: an enormous return for assets that cost hundreds of millions of dollars.

Eventually the pressure to meet or boost quarterly earnings outweighed the intellectual and financial remuneration, so in 1989 we formed a startup corporation with a plan to bootstrap our capabilities through the government's Small Business Initiative Research program. This was the era when several commercial satellite ventures were initiated to provide worldwide connectivity to small user terminals. Serendipitously, we became a major participant in the development of the ORBCOMM system. The ORBCOMM concept was to use small low Earth Orbit (LEO)satellites with onboard signal processing to provide low data rate short message services to a large population of user terminals. Our contributions included a waveform specification, prototype payload processor, a communications protocol that increased the capacity of the system by 6X, and the gateway terminal modems. We designed a user communicator which performed much better than other terminals in the real world interference environment. We supported investor due diligence: a unique experience was a university professor telling us that we could not possibly achieve the performance we were predicting, because his simulations did not achieve our performance. When we showed him actual equipment achieving the stated performance, he decided that he needed to improve his modeling. This story hardly captures the stress of this interaction, as ORBCOMM really did need to raise financing.

ORBCOMM built and launched into LEO 35 first generation 45 kg satellites, and built out the corresponding infrastructure, for an investment of around $300 M. Build up of revenue was much slower than anticipated, such that the company went bankrupt. An investor group purchased the assets for 5 cents on the dollar---with some additional investment they were able to achieve positive cash flow. Our company was asset-stripped by the major outside investor: the resulting company refined our communicator design and produced several hundred thousand communicators.



ORBCOMM Gen 2. 172 kg, 3-axis stabilized box. Deployable helical antenna and solar array. 120 W EIRP

ORBCOMM was not a unique satellite company in going bankrupt and being resurrected for pennies on dollar of initial investment. Iridium, which was intended to provide cellphone-like service worldwide, also went bankrupt. An investor group was able to purchase the entire $3 B satellites and ground infrastructure for $35 M, and obtained a US government guarantee for $100M of annual government business. The Iridium satellites also employ onboard processing, but they also include satellite to satellite links, so the launch mass is about 698 kg, and 98 satellites were deployed in the first generation.

At the urging of several colleagues, in 2000 we formed another startup, again intending to grow a business through developments funded by the SBIR process. Much to our amazement, we were approached by ORBCOMM to help identify capabilities for a second generation constellation. They had achieved over 400,000 users, with primary positioning as the leading supplier for remote connectivity in Machine-to-Machine and Internet-of-Things sectors. We developed a Payload Specification, and then we got asked to bid to build the payloads. We devised a way to triple the effective capacity of new satellites, and were selected to build the payloads. Beginning in 2014, 18 of these second generation, 172 kg satellites have been deployed into LEO orbits.

Technology base for satellites and launching has progressed dramatically. Now, very complex, power efficient electronics are realized in custom integrated circuits where hardness is achieved in part through the circuit designs. Radiation-hard solar cells now approach 30% sunlight to DC conversion efficiency, a factor of six better than the 1960s. Flyable batteries (for power when the sun is eclipsed) now approach 100 Whr/kg, a factor 3X better than for traditional Ni-Cd batteries. 3-D printing is enabling fabrication of complex shapes with simpler and more reliable assembly. On-orbit lifetimes at geostationary orbit are routinely 15 years. Reusable large launch vehicles were developed by the private sector. In contrast to the 60's when government-funded military research and development fostered much of the technical progress, in recent times most progress has been driven by commercial satellite applications, and by deep space exploration.

Today and Looking Forward

Now, fast forward to today and the future. The two existential threats to the survival of the human race (existence of the US?) are global warming and use of nuclear weapons.

Through a series of bilateral arms control agreements between the US and Soviet Union/Russia, there are currently an estimated total of about 15,000 nuclear warheads, with more than 90% belonging to the US and Russia. However, there are now 8 nuclear nation states. The possibility exists even for a non-state actor to obtain a few nuclear weapons. Deterrence of use of nuclear weapons against the US requires that the US develop the ability to reliably determine the originator of a nuclear attack of any scale, and be able to respond against the political leadership of the originating entity. Stability requires that all potential opponents believe that the US will not initiate a nuclear attack of any sort. The accuracy of delivery systems has led to the fielding of smaller weapons, compared to the 1960's.

Nuclear power may be crucial to reduction of the environmental impact of energy generation. Unfortunately, traditional nuclear fission power reactors using uranium also are the major source of weapons grade material. Nuclear fission using thorium salts (molten-salt reactors) enables reactors that will not melt-down, and the residuals are not easy to weaponize. A worldwide ban on uranium-based energy generation would reduce the likelihood of more nuclear weapons, and could be effectively monitored. Eventually nuclear fusion is expected to produce even more energy with the same safety and arms control benefits.

A US decision to use nuclear weapons can only be made by the President. As time has passed since the last use of nuclear weapons, the senior leadership typically has limited awareness of the possible effects of the use of nuclear weapons---there tends to be a view that nuclear weapons are simply "bigger bombs," with little appreciation for the potential scale of devastation and lingering after effects.

Historically, a launch on warning posture was maintained, assuming the posture reduced the probability that the land based missiles would all be destroyed by a surprise attack. This assumption is valid only with a very short detection and decision cycle, and in the absence of any ambiguity about the attacker identity. Thus, the historic launch on warning posture no longer enhances deterrence, but in fact reduces the assurance that an attacker can be reliably determined on a short time line.

For stability, there is a need for comprehensive understanding by decision makers of the full world situation, and ongoing actions and capabilities of all players. Widespread access to real time information is necessary. An objective means is needed to determine if information is factual and trustworthy. Implied is a real need for machine aides to provide useful real time background, analysis, and inputs to decision making about nuclear weapons, and broader geopolitical situations.

Humans will remain "in the loop" for use of nuclear weapons, but delivery platforms may become unmanned for cost and endurance reasons. Such operations will require absolutely foolproof and verifiable command and control between decision makers and such platforms.

Dispersion and mobility will be needed for survivability against large surprise attacks. Satellite communications for nuclear command and control will continue to evolve to provide higher assurance of correctness, resistance to adverse actions, and robust connectivity among widespread forces. Space is no longer a sanctuary against attacks (if it ever was), but there are concepts, different from traditional communications satellites, that offer the potential for survivability sufficient to support nuclear deterrence.

Deterrence is not a substitute for defensive measures, particularly against threat sources who have relatively little to lose, or are driven by goals we would not consider rational. Concrete examples are terrorists, criminals, and rogue nation-states. For example, an effective missile defense system needs to be developed and deployed, to reduce the likelihood of an EMP attack by a single, high altitude nuclear burst.

Tom Seay '64, SB, SM and EE degrees in Electrical Engineering joined MIT Lincoln Laboratory upon graduation, and was involved in early satellite communications. He joined the private sector in 1980, and served in a series of senior management positions. He founded of several advanced communications startups and now works part time with Lincoln, primarily helping define new high technology demonstrations in support of deterrence.

Mirror-Twin Magnet Maven and Mountaineer

Bob Weggel

The Golden Years!

How off-target my journey began, how farfetched my grade-school dream of "President, or at least Senator"! Ideal candidates are tall, handsome, poised, outgoing, self-confident, and energetic - not short, plain, clumsy, shy, insecure, and weary from laboring to perform to ultrahigh expectations. My high-school graduation yearbook perceptively labeled my mirror twin Carl and me "Most Intelligent" - not "Most Likely to Succeed".

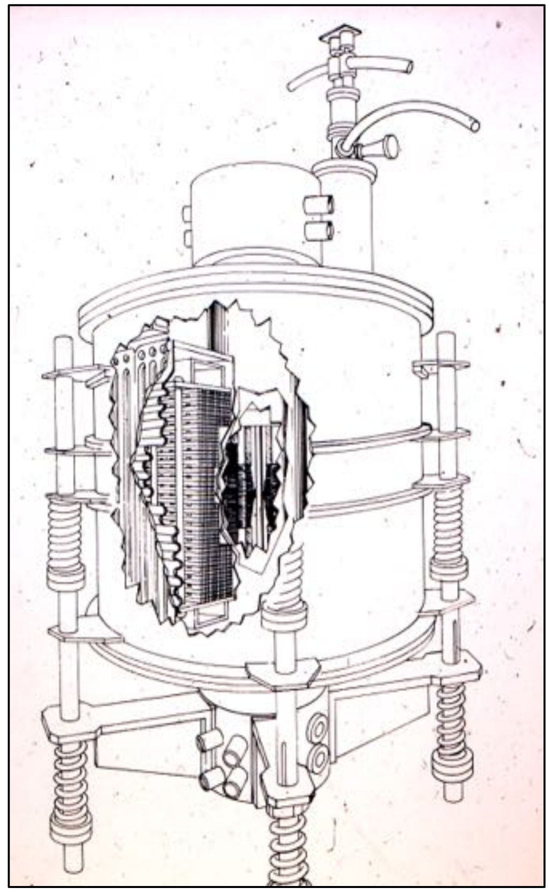
Mt. Sneffels, San Juan Range, 2012

I've come to accept my limitations. Book larnin' has brought a measure of success, the fruit of science and math talent, prioritizing scholarship, and phenomenal good fortune. Good fortune to be still alive and thriving: my parent's shortevity would have added my name to your Departed List by 2002 or 2003. Good fortune in health: not a day of hospitalization until 2014, for a prophylactic stent. Good fortune to live in America, with its natural beauty, prosperity and ideals of democracy, egalitarianism and meritocracy (albeit corrupted by plutocracy). Good fortune for four middle-school years in Europe, savoring its sophisticated culture and awesome Alps. Good fortune that my education featured such excellent teachers and classmates at Ann Arbor, Michigan; Wiesbaden, Germany; and Massachusetts (Winchester, Arlington, MIT, Harvard, and MassArt).

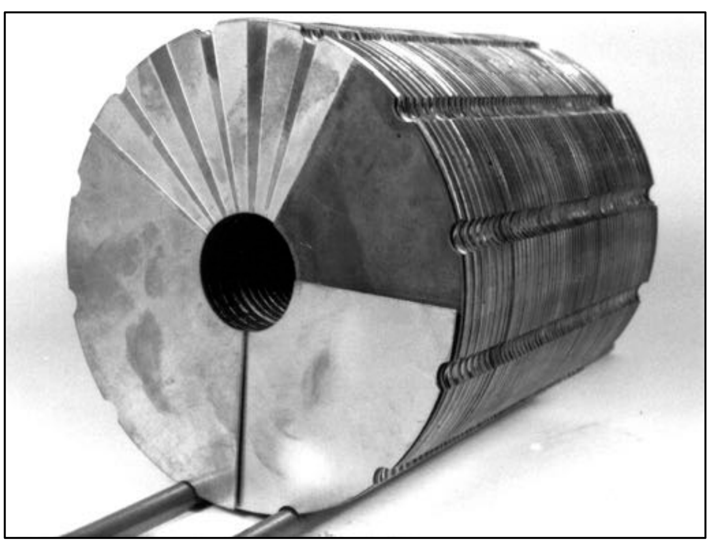
Magnet Wonk

MIT launched my career as a magnet-design engineer, from 1961 through 1966 apprenticing every summer, and part-time during the school year, at the nascent National Magnet Laboratory on Albany Street, mentored superbly by Bruce Montgomery, Mat Leupold, Hab Brechna, Henry Kolm, John Williams, Larry Rubin and Prof. Francis Bitter. Until its closure in 1995, the High-Field Division of the Francis Bitter National Magnet Laboratory (FBNML) provided me with income, purpose, identity, and citation in 1980s editions of the *Guinness Book of World Records*:

"The strongest magnetic field strength achieved has been one of 30.1 teslas at the Francis Bitter National Magnet Laboratory in Cambridge, Mass. by Mathias J. Leupold and Robert J. Weggel, announced in July, 1977."



Left, 1961- The National Magnet Laboratory gets clean cool water from the Charles River. Right, FBNML Hybrid II: The magnet that pioneered combining a water-cooled insert and a large-bore superconducting magnet to generate fields more intense than either could do alone.



The inner coil, of 40 mm inner diameter (32 mm bore) and 156 mm outer diameter.

The radially-cooled windings of the insert magnet that at 9 MW contributed 22 teslas (T) to FBNML's 30.1-tesla world record for continuous magnetic field intensity (June 16, 1977).

A similar insert, in the 356-mm bore of a superconducting magnet generating up to 13 T instead of 8 T, employing Nb_3Sn as well as NbTi, bathed in superfluid rather than normal helium, set world records of 33.6 T on 12/18/91, 34.2 T on 12/10/92, and 35.2 T on 5/25/94.

When the field volume sufficed, holmium pole tips, bathed in liquid helium were magnetized to twice the level of iron, this could raise the field intensity to as much as 37 T.

Summer vacations and travel to Magnet Technology conferences indulged my wanderlust. 10,500 miles in 1970 - with a pair of hitchhikers at the wheel from California to British Columbia to Colorado! - awed me with the spectacular natural wonders of the West, including nighttime atop Longs Peak, the crown of Rocky Mountain National Park. 1975 fulfilled a dream to view Mt. Everest, trekking two hundred miles.

Earth Day Impact

Earth Day 1979 changed my life. A rally for the Massachusetts Bottle Bill rewarded me with Love at First Sight - Diane Avery, an art quilter, pianist, and RN at MGH. Since marrying in 1980, we've resided in her home town of Reading, MA. We chose not to add to the world's overpopulation; instead, we care for the environment and enjoy a seaside cottage on Bailey Island, overlooking Casco Bay.

For a week each September from 1998 through 2010 Diane and I troweled and sifted at Fort St. George (1607-08), the sister colony to Jamestown, Virginia. Artifacts that we unearthed included a silver shilling from 1592-1595 (Queen Elizabeth I)! Jamestown has merely a sixpence.

Silver shilling unearthed by Bob & Diane Weggel in the autumn of 2010 during one of that year's two week-long sessions of archaeology at Fort St. George (1607-1608) at Popham, Maine led by Prof. Jeffry Brain of Harvard for the Maine State Museum.

Diane and I contributed to all but the first and last one or two of Prof. Brain's dozen digs on the site from 1997 through 2011.

Archaeology with Diane at Fort St. George, 1607-1608

In 2003, after half a dozen years at Brookhaven National Laboratory, my work reverted to consulting (Magnet Optimization Research Engineering, "You deserve M.O.R.E.") and part time at Particle Beam Lasers, collaborating with BNL on Small Business Innovation Research grants. The latest project is PI to design the world's best magnet for neutron scattering experiments.

MIT? Alleluia! - I'm back! And so's my twin, who from 1966 to 1980 was at the FBNML when not at Harvard and, subsequently, Tufts Graduate School. We now are senior magnet designers for the MIT spinout Commonwealth Fusion Systems, Inc., tasked to expeditiously design, fabricate, test, and mass-produce controlled thermonuclear fusion tokamaks to generate abundant, economical, environmentally-responsible electricity to a world desperate for energy.

Mountains and Nature

I ***love*** mountains. Summiting Mt. Whitney in 2004 led to climbs of all but nine of Colorado's 53 fourteeners - mountains more than fourteen thousand feet high - plus Devil's Tower and the Matterhorn! *Nota bene*, however: my Tower was in South Dakota, not Wyoming, and my Matterhorn in Colorado, not Switzerland. I ***love*** wildlife, too - both flora and fauna - and am thrilled when wild critters cooperate, allow me to approach, and pose for the camera.

In 2006 trail maintenance became a major activity, courtesy "Volunteer Vacations" of the American Hiking Society and the Rocky Mountain Field Institute, Colorado Springs. We carve tread way, build bog bridges, move boulders and set them, and blast ledge. My specialty is rockwork: walls, causeways, and steps. Adopting for the Appalachian Mountain Club a trail in the Middlesex Fells Reservation north of Boston led to my joining the Board of the Friends of the Fells, eventually establishing their first endowment fund. The Harpswell Heritage Land Trust (Casco Bay, Maine), RMFI and Maine's First Ship likewise have become beneficiaries of six-figure endowment funds.

Diane, on his steps to the beach on Bailey Island, Maine.

Who would have imagined that I, such an egghead when at high school, would find such satisfaction in climbing mountains and wrestling boulders into position? It's that I, once such a dud of an athlete, rejoice in the ability to do so.

At age 76, my climbing days may be drawing to a close. But, along with mountaineer Geoffrey Winthrop Young, I continue to hold my head high.

I have not lost the magic of long days; I live them, dream them still.
Still am I master of the starry ways, and freeman of the hill.
Shattered my glass, ere half the sands had run -
I hold the heights, I hold the heights I won.

Mine still the hope that hailed me from each height, mine the unresting flame.
With dreams I charmed each doing to delight; I charm the rest the same.
Severed the skein, ere half the strands were spun -
I keep the dreams, I keep the dreams I won.

What if I live no more these kingly days? Their night sleeps with me still.
I dream my feet upon the starry ways; my heart rests in the hill.
I may not grudge the little left undone;
I hold the heights, I keep the dreams I won

Robert J Weggel, '64, joined MIT's nascent National Magnet Laboratory the summer of his freshman year, and rose over 35 years to Assistant Director of its High Field Division. He's been cited personally in the *Guinness Book of World Records* for "*strongest magnetic field strength*". For the past dozen years, he has designed magnets under DOE SBIR awards. Recently he joined the MIT spinout Commonwealth Fusion Systems, Inc. to develop fusion electricity. His extracurricular passions include mountain hiking, rockwork for hiking trails and soil-retention walls, wilderness conservation, and wildlife photography.

The Evolution of Instant Photography

Paul Lubin

The Start of Instant Photography

Polaroid Corporation was launched in 1937 to exploit the invention of sheet polarizer invented by Edwin Land. In 1943, while on vacation in Santa Fe, Land took a picture of his daughter, Jennifer, who asked him why she could not see the picture right away. This began Land's quest for a product that would deliver a finished photographic print in 60 seconds.

The original Polaroid Land Camera was introduced in 1948. This model 95A was available from 1954-1957.

When we were freshmen in 1960, the mother of my roommate (Steve Portnoy, XVIII, '64) called and asked me to pick up an easy-to-use camera for his birthday. I had heard of Polaroid cameras (my father-in-law had one) and I knew that they were fool proof. I went to Jordan Marsh in Boston where these cameras had been introduced in 1948 and picked up a model with a built-in flash. We used it quite a lot. The pictures were in black and white; you pressed a button, out came a paper sandwich, you waited 60 seconds, peeled the sandwich apart and you had a 3" x 4" picture. In your hand. Right away. Okay, you had to coat it with a viscous acetic acid smelling fluid. It was sticky and you had to wave it around to dry it. But it was very different from "Someday my prints will come".

I knew something about photography. I took 36 pictures with my 35mm camera and sent the finished canister of negatives to Kodak where the negatives were developed and stabilized in a series of temperature controlled baths then exposed to light-sensitive paper (three times if it was a color picture) and dried. In a week or so the prints came in the mail.

The SX-70 introduced in 1972 was the first model to eject the print, and had no chemical residue.

Arrival at Polaroid

After graduation, I worked for a year as a chemist at MIT Instrument Laboratory at 45 Osborne Street in Cambridge where the guidance system for the Apollo project was being refined. I had a very interesting project which ended successfully after nine months. I asked what to work on next. I was told to go to the library and something would come up. But I was a Type A new MIT grad, 22 years old and I was impatient. I went to the Alumni Placement Office and asked what local companies were hiring chemists. I interviewed at a few and ended up at Polaroid Corporation at 2 Osborne Street. My big career move. I stayed at Polaroid for 31 years as a chemist and a manager, ending as New Media Development Manager in 1996.in 1996.

I learned how to make light sensitive silver halide "emulsions", design the developer fluid (the goo that went into the little pod), and participated in the development of the negative that started as nine layers coated at the same time and became nineteen layers by the time I left. The Company had learned how to deal with creating a push the button picture delivery that gave a finished print in 60 seconds, developed in the light at temperatures from 35 degrees to 85 degrees, and didn't have to be shaken to dry. Polaroid continued to improve the color quality and image stability but was not prepared for the digital revolution.

The SX-70 Sonar One Step introduced in 1978 was the first to offer auto focus.

The Rise of Digital Technology

Silver halide photography, the basis of roll film and Polaroid technology, had an inherent resolution of 8 megapixels. The belief in the Company was that digital photography could never reach the resolution required by photographers or by the amateur user. But as electronics became more and more refined, digital cameras reached resolution as good as film very quickly. Now the resolution of our smartphone's camera far exceeds that of film. Polaroid had the technology to succeed in the digital world, but the culture that precluded layoffs prevented the company from downsizing from 20,000 employees manufacturing film and cameras to a much smaller company making digital devices. In 1995, Polaroid hired its first outside CEO from a company that manufactured hand tools. He stated that spending 12% of sales on R&D was too much. I was an R&D Manager and decided to accept a voluntary severance package in 1996.

The Joycam introduced in 1999 was one of the last instant products offered.

Polaroid declared bankruptcy in 2001. Kodak filed for bankruptcy in 2012 and sold its photographic film business.

Today I love having my iPhone with me so that I can both smell the roses and photograph them at my leisure in retirement.

Paul Lubin ’64 grew up in Chelsea, Massachusetts, and decided he wanted to go to MIT in 1957 after Sputnik was launched. He graduated in Course 5 and went to work as a chemist at the MIT Instrumentation Lab, where he had worked for three summers. In 1964, he married his high-school sweetheart, Myrna; and they have one daughter, and three mostly grown grandsons. They live in Freetown, Massachusetts.

Recreation

Left, Dingy sailing on the Charles River in the 1960s. Many sports have changed in incremental ways over the years – new equipment, better understanding of what leads to success. The pleasure of participating or watching continues.

Below, This scene is from Red Death Redemption. Video games now offer realistic worlds that you can walk or ride through and participate in adventures. In the early 1960s no one played video games at home. At MIT there was a Digital Equipment Corporation (now gone from the computer scene) PDP-1 mini-computer (a class of computers now gone as well) on which a very basic space war game could be played. Now powerful computers and fast Internet connections bring to us experiences we used to have go to the theater for, or at least make a trip to acquire physical media.

Amateur Photography and Cinematography

Robert P. Popadic

Technique 1961 Photo Staff

Shown here is the 1961 Technique, MIT yearbook, photo staff complete with 35mm and 4x5 film cameras. Not shown is the 2 1/4 x 2 1/4 Hasselblad, and the "little" strobes we borrowed from Doc Edgerton. These were all popular camera formats in the early 1960s. While we had access to strobes, we were also using flashbulbs.

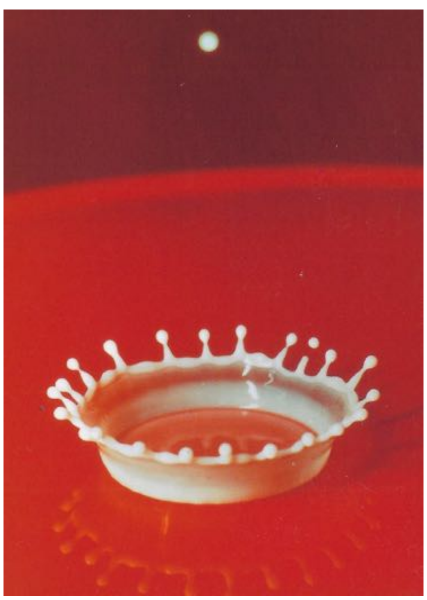
We built a new Technique darkroom in1960, for film loading, developing and printing. Our three enlargers could handle 35mm to 4x5 sheet film. Our film was kept fresh in a 1930s vintage refrigerator, where we also kept our soft drinks. The 1962 Technique acknowledged the Coca-Cola Bottling Company, which struck at deadline time, "for doing their utmost to see that TECHNIQUE did not appear."

Before MIT

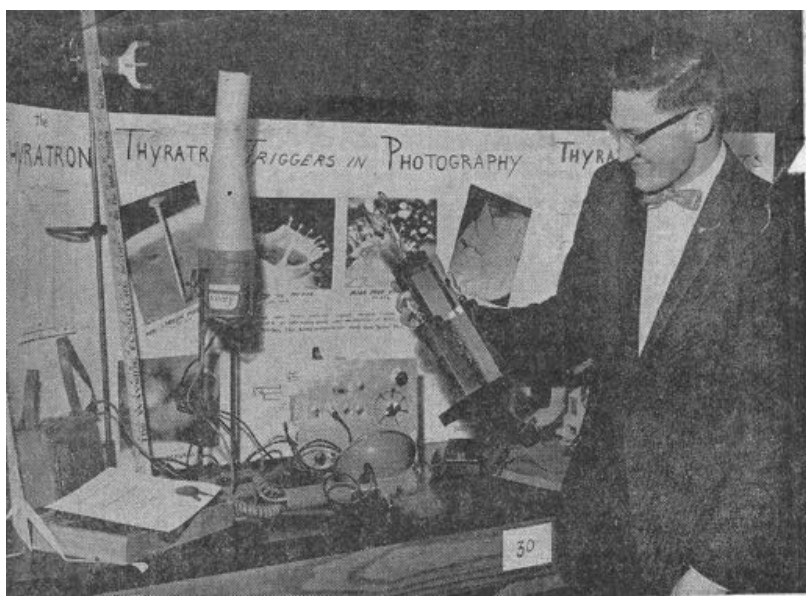
In the late '50s, I had a 35mm range finder camera (whose brand I cannot remember) and a Yashica twin lens reflex – styles that are still with us, but gone digital. The 35mm came from a drug store, one of the few stores that could be open on Sunday; and where you got your film processed. The Yashica came from mail order. Interestingly a number of drug stores over time morphed into camera stores, like Hunt Camera in Mass.

I was into available light photography, but did other types of work as well. This included: photographs for the high school newspaper, away game football pictures sold to the local newspaper ($2 a picture - $17 in 2018 dollars) who usually bought 2, a glamour spread in a Sunday newspaper supplement, weddings (for poor teachers my price was right), baby pictures and copied photos.

My lighting equipment included Photo Flood #1 and #2 bulbs, reflectors and stands – still have some in the basement - unused; and a couple of strobes. My first strobe had a 500+ volt battery and was built from a Heath Kit. Back then most people used flash bulbs, so I got asked a lot of questions. I subsequently acquired an Ultrablitz 200 watt second unit powered by a wet cell. It had a big head with two flash tubes of different flash duration, and the ability to power multiple strobe heads. It had what I thought then was a large capacitor (the size of a very large soda can). Later using Doc Edgerton's units, which he used to take pictures of cities from 20,000 feet, I got to know what large was (if memory serves me, about 1x2 feet on top and 9 inches high with the unit on rollers).



Edgerton's milk drop photo



Science fair project - Thyratron Triggers in Photography

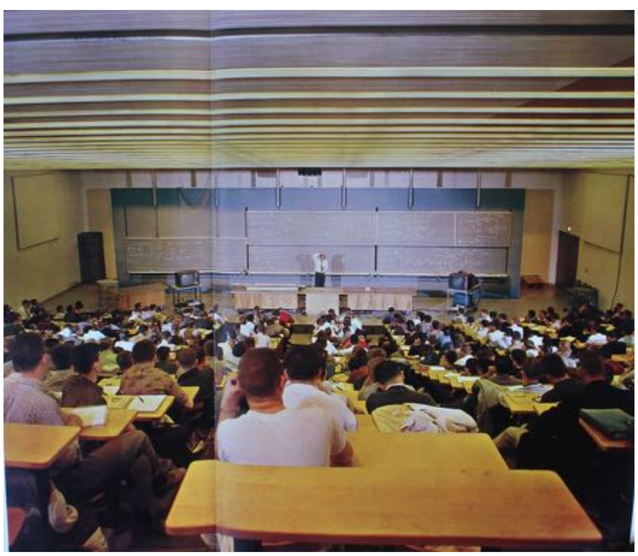
I used the Ultrablitz in replicating Doc 's milk drop photos. I designed two sensors, and a timer, which delayed triggering the flash. One was a photo sensor triggered by a milk drop leaving a pipette. The other was a metal disk cemented to a speaker cone that was triggered by the milk drop striking it. The camera was my enlarger with a 2 1/4 x 3 1/4 sheet film holder where the negative to be enlarged would normally be. Lights out, pull the slide on the film holder and wait for a milk drop to trigger the flash. The project won grand prize at the Southern CT Science Fair.

Called "Flash" in high school, I had to drop that nickname as already taken when I got to Doc's lab at MIT.

I shot mostly black and white and some Ektachrome slide film, processing both in my basement lab. Photo paper wasn't coated the way it is today so print washing took awhile. I had a rubber bathtub for washing, which sometime was full of prints of various sizes. Prints were hand crafted: by "burning in" using cardboard with a hole cut in it, by dodging with shapes taped to the end of a coat hanger, by raising corners of the paper easel to correct parallax, by selecting the correct contrast paper grade, by counting to measure exposure, and by selectively accelerating developing with finger heat. Most of these have digital equivalents in Photoshop, which first became available in 1990, only for the Mac.

MIT 1960-1964

When I got to MIT I joined the photography staff of Technique and had great fun with Doc Edgerton's strobes and two recently acquired cameras - a Graflex Super Speed Graphic 4x5 (in production from 1961 to 1970) and a Hasselblad 500C introduced in 1957 that used 120 roll film. Freshman year we built a new darkroom in Walker Memorial with a giant wet area for developing, 3 enlarger bays, and a 4x4 foot changing room for loading and unloading film. In 1965 Technique and the darkroom moved to the Student Center, which was just coming out of the ground when we graduated.



Room 26-100 - Academics Divider from Technique 1963

Doc's strobe units were impressive. You could char newsprint at 3 feet, freeze the Wellesley Water Ballet in Alumni Pool and impress professional photographers. One day with a large freshman crew to move lights and the capacitor banks, and run cables, we were shooting in the 26-100 lecture hall when a magazine photographer showed up with his on camera Honeywell strobe. He was duly impressed.

In the1960s serious amateurs were using small off-camera strobes, but most consumers were still using flash bulbs. In 1965 the flashcube was introduced, which allowed 4 shots without changing the cube. Today most consumer digital cameras have a small low power built in flash that pops up when needed. Today hardly anyone uses flashbulbs, but they are still available.

We used 4x5 cameras because the large negative made higher quality black and white prints and because our yearbook printer for full page or two-page spread color required we provide a 4x5 transparency. Shooting sheet film we were more careful than with 35mm. Per shot the film was much more expensive than 35mm; and with one sheet per side of a holder you'd need 18 holders to equal a 35mm 36 exposure cassette. Shooting color transparency also required getting the exposure right so we used a Polaroid back with black and white film to check the exposure. Today you can still buy 4x5 film, but usage is dramatically down from what it was in the early1960s.

Sophomore year I was photography editor and enjoyed major production shoots where freshman carted around the rather heavy capacitors for Doc's lights. It was also an opportunity to feature my woman classmate friends in a variety of pictures. I kept taking pictures through my senior year, when I was editor-in-chief.

Senior year working in Doc's lab we got some pre-release Polaroid color film to test and provide some pictures for the New York City announcement. I photographed a bullet piercing a yellow balloon, one of Doc's classic shoots repeated, against a blue background. Blue selected because the film was shifting blue at the short strobe exposures. That picture went to New York and I used the rest of the film for some family pictures. Polaroid instant photography was introduced in 1948 and by 1964 the value of its cameras sold in the US exceed that of both 35mm and 8mm movie camera (source Polaroid 1964 film for dealers). It offered film speeds of ASA (later ISO) 100, 200, 400, 3,000 and 10,000. The original Polaroid Corporation is no more, having gone bankrupt in 2001 and 2008. The current corporation with the name is a brand licensor, and Polaroid film is still available. Digital is the new Instant photography.

Photoshop was years in the future. When one of the members of the Technique managing board didn't look well in a group picture where everyone else did, we cut his head out from another exposure and glued it over the head in the first. On close inspection it showed, unlike the results we get today where its virtually impossible to detect alterations in photographs.

After Grad School and Navy – 1968 – 1989

After grad school and a short stint in the Navy I got a Nikon F, a great camera with a very fast f1.4 lens, bought by a Navy roommate who got it in the PX where he was stationed in Japan. The camera, introduced in 1959 and in production until 1973, was very popular with photojournalist. The body, F1.4 lens and a 55mm f3.5 macro lens including customs duty cost me less than $300 ($2,140 in 2018 dollars). The US list for the camera and lens only was $388 ($2,765 in 2018 dollars). I mention this only because later I'll describe the less professional and less expensive still cameras I use today. I used the Nikon F actively up until 2012. The f1.4 lens is still in use and faster than anything I have on my digital cameras. Today new manual prime (non-zoom) 50mm lenses cost $400 to $700, more than a lot of digital camera with kit lenses.

Nikon F

Nikon F

Our youngest son even used the Nikon F for a grade school camera class. Around 1989 we were on a trip to Battleship Cove and he was taking pictures of the inside of PT 109, which was in a shed. A dad came up to us with his son and asked how my son was able to take pictures. My son turned the camera towards him and he saw the large piece of glass and he said “I see.”

We had a darkroom in the basement and I moved up to an electronic timer and using variable contrast black and white paper, where with filters one achieved a range of contrast from a single paper stock. I never returned to processing transparency film myself, as I had done in high school.

Chemical photography was still king. Film speeds increased, film grain got smaller, more folks shifted from flash bulbs to strobes, printing became more automated, and you could get low resolution scans of your negatives put on a CD. If you wanted to share photos you printed them after dropping off or mailing in your film for processing and printing. Dial up was king as well, which meant there wasn’t enough bandwidth available to upload pictures for viewing or for remote printing. I was happy with my aging equipment that was still pretty current as technology hadn’t changed a lot; and I became increasingly interested in video.

Analog Video 1990 - 1998

Sony – Video 8 Handycam

Our first video camera, just found while cleaning our eldest son’s part of the shop. Son went to grad school in the UK and stayed, which is why his shop is frozen in time.

Home movies with 8mm cameras were popular in the 1950’s when I was in high school, but I didn’t get into home movies until 1990 when we got a 8mm Sony video camera. The 8mm video was an analog format introduced in 1984 with about the same resolution as the VHS camcorders of the same era. Our first use of the Sony was on an outdoor ice rink in NH, the kids took turns seeing who could make the best swish pan, long before these became popular in films. In 1993 I filmed the 350thanniversary of Wenham, where we live. 2018 was the 375thanniversary and I managed to read the 25-year old tape and produce a DVD. Still have a stack of old 8mm tapes that I hope to edit before they become unreadable. Back when they were made, people talked about a 10-year life before reading problems developed. These are well past that.

When I started editing, I hadn't read much about the process, so I plunged in and plugged the Sony output into our VHS deck and manually hit the playback on the Sony and the record on the VHS to edit. This was a VHS deck that maintained tracking by mechanical adjustment of the heads. The base was heavy to maintain head registration. This was in contrast to our next VHS deck that was very light and maintained tracking dynamically.
My next step up in editing was a program for the Mac 8500 that basically automated what I had been doing with my fingers, started the tapes rolling and cut the recording in at the right time. The control to the Sony camcorder was two-way (send and receive), while the control to the VHS deck was one way (send the signal and hope it got acted upon) via an infrared transmitter you put in front of the VHS's receiver window.

Our youngest son, same one described earlier and who became a film editor, was interested in theater and was in a number of community shows, so I got recruited to tape the shows and provide a master for duplication to sell to participants. For the early shows, Fiddler on the Roof, Brigadoon, Music man, I'd pick the best scenes from multiple nights of shooting and with my magic fingers edit them together creating a VHS master. No attempt was made to edit within the scene because of the limits of my fingers and this was a single camera shoot.

We later (sometime after 1994) got a Hi8 editing VCR, which in addition to editing methods previously described could do assembly editing using time code. The camera was connected to the VCR. On the VCR up to eight in and out points on the source tape could be entered in the order you wanted them recorded on the VCR. Once the edit was started, the VCR would find the selected scenes on the source tape using the time code and record them in order to the tape in the VCR. If you had more than 8 scenes the process was repeated. The Hi8 VCR had a higher resolution than the 8mm Sony camera we were using. You could add audio to a previously recorded tape by recording on the PCM track, which was a linear track separate from the video and audio tracks recorded helically. On playback you could mix the standard and PCM audio.

Serious Editing Begins 1995-96

Avid Technology introduced its editing software for the Mac in 1989 and by the early 1990s was replacing traditional film based editing tools. The very earliest versions were designed for the Apple Mackintosh II. In 1992 they were first used to edit a feature film. I visited their plant in Mass. where they were modifying either Power Macintosh 8500s or 9500s to run faster. Their software was also very popular for editing TV news.

In 1995-6 my editing capabilities took a major leap forward. I got a Power Macintosh 9500 (132 MHz processor) with a Targa coprocessor card, a RAID array with two 20 GB hard drives, an audio patch bay, audio mixer, and Premiere editing software. After digital editing the output was analog recorded to the Hi8 VCR. Show tapes now had titles and some scene editing although the show shoots were still single camera. VHS copies and later DVDs were made from the Hi8 Masters. The workflow was analog input, conversion to digital to edit, edit, analog output to the Hi8 tape deck to create the master, and copying and distribution on VHS and later digitally on DVD. Rendering (processing added titles, color correction, motion effects, etc.) on the 9500 even with the Targa card was slow, which gave me time for enforced coffee breaks. In 1997 I used this rig to edit Godspell, which our youngest son starred in.

Digital Video

Canon XL-1

My consulting business was going well, so in 1998 I got a Cannon XL-1, a prosumer video camera with lots of buttons and switches that recorded digitally on mini DV tape ($4,024, $ 6,209 in 2018 dollars). It had a 16x optical zoom and an f1.6-2.6 lens (maximum aperture changed with degree of zoom). DV has a horizontal resolution of 720 as compared to analog Hi 8 at 420, and 8mm and VHS at 250. The 1990 Sony had a lot of buttons, but as electronics got cheaper menus replaced buttons and other controls, except on high-end prosumer cameras like the XL-1. The XL-1 had in lens image stabilization. The incoming image was split into the three primary colors which went to three 1/3 inch chips with 270,000 pixels each. After compression the image was recorded digitally to mini DV tape. This resolution was somewhat better than standard broadcast TV of the era, but well short of what was to become the 2K digital Full HD broadcast standard(1920x1080) and the even more recent shift to 4K (4096 X 2160) for film production. For comparison 2K has comparable resolution to 16mm film and 4k is comparable to 35mm movie film.

In the early 2000s the XL-1 was used by professionals for commercials and some feature films. I took the camera with me in 1999 on a trip to the Holy Land and produced with the help on another tour member a one-hour video that was shown at a conference. The camera got some interesting reactions in Israel. More than once I was asked at tourist sites either not to use it, or they'd offer to “watch it for me,” while folks with small cameras went on their merry way shooting away. I suspect folks thought I was filming for profit. Interesting when leaving Israel, folks in our group with small cameras got them looked at very carefully, while my camera bag, which could hold 20 small cameras, barely got looked at.

As a member of the local library building committee (2000-2003) I used the XL-1 to document construction for broadcast on the local public access channel. Also documented our church's centennial year, and worked on a variety of other projects. Some of these involved more than one camera shooting at the same time, which made the edited product more interesting.

I used the 9500 system for editing XL-1 DV footage until upgrading to a laptop, which with Premier allowed direct control of the XL-1 using time code and digital capture. Prior to that clip capture was analog from the digital DV tape and capture done manually by starting the playback and then clicking start to capture on the computer.

This was followed in 2011 by a MacBook Pro (2.2/2.4 GHz quad core processor) with a Premier upgrade as part of Adobe's Creative Suite. It had a card reader allowing direct transfer of files from digital cameras (still and video). I added a two-terra byte external hard drive, which gave me a bit more storage than the 40 GB RAID array on the 9500 system. My once regular rendering coffee breaks didn't occur often. If one chooses not to continue working while burning Blu-Ray disks one can still get a good coffee break in. I still have the Hi8 deck and a digital to analog converter for inputting old tapes, and it will probably be around for awhile until I get the old 8mm tapes converted. Got a new MacBook Pro in 2018, because the old one died, not because I needed the performance improvement.

Digital Still Photography

I was slow to make the change to digital for stills, having spent a fair bit of money on the Canon XL-1 I was unwilling to spend a lot for a professional digital still camera even though I had been using Photoshop to work on scanned images for years. Photoshop was introduced in 1990. It took awhile for digital sensors to become available that had the resolution to compete with film for serious print sizes. Early digital cameras were fine if you were making small prints or posting images to the web.

The XL-1 took stills and had an optional flash unit. Stills were recorded for 6 seconds on tape. In 1999, digital still camera resolution was about the same as the XL-1. Still cameras of the period had 1 megapixel sensors and 4-6 MB of storage. Consequently most photo editing was hybrid – film capture, scanning and digital editing.

By 2004 basic digital cameras were offering 2-3 mega pixels. Early consumer digital cameras came with slow lenses (a cost issue), slow sensors, small sensors, and artifacts if you pushed the ISO. For the less expensive cameras there was a delay from triggering the shutter and a picture actually being taken.

My Digital Still Conversion – 2012

In 2012, my youngest son loaned me his Cannon 60D to use on a cruise. Shot thousands of pictures, which I edited on the Mac mostly using Preview and occasionally Photoshop. Later that year our children gave me a Canon Rebel T4i (pictured) for my 70thbirthday. With that camera, I've taken a lot of pictures, including for our 50threunion, copying many pictures from 1961-1965 Techniques to add to the Class of 1964's website.

Canon Rebel T4i

I found some features useful and others not so much. Having grown up in the world of manual cameras where you needed to decide what shutter speed or aperture suited your subject, I found such menu subject choices as portrait or landscape less than useful.

Autofocus on the other hand was much appreciated by aging eyes. Kit zoom lenses had a maximum aperture of F3.5, that decreases as you zoom out. The Nikon F by comparison with a F1.4 lens gave 8 times as much light through the viewfinder. Rather than use the fancy choice of multiple focus points, I usually put the focus point on where I want the focus to be taking into account what I want in focus, and lock focus before composing the shot. Similarly I'll aim at where the exposure should be taken from and hold down the exposure lock.

I often use Aperture or Speed preference. They provide the same functionality as the FTN Photomic Prism on the Nikon F, except on the F you had to turn the speed or aperture ring to center the meter reading. I really like being able to check exposure by looking at the screen after taking a test shoot. Often I'll use that exposure as the basis for going to manual settings, especially when shooting multiple exposures where backlight is involved that confuses the metering. I also don't use the built in digital filters or effects believing that it is easier apply effects and adjustments in post using Preview or Photoshop. Guess I'm an old dog that has only learned some new tricks.

Recently my son sold me his 60D kit instead of trading it in. I used to borrow this camera when I did multi-camera video shoots; and I'm still producing 2K video. He felt for his professional shooting and editing work he needed to be able to offer clients the 4K-option. Shooting in 4K is future proofing, much as folks started shooting 2K before it was being broadcast. Shooting 4K also allows cropping the video for 2K output without loss in image quality, which cropping 2K for 2k output does not. He also found the 60D to be quite heavy compared to newer options.
In the days of chemical photography when I used my Nikon F you had a camera body, lenses and film. Film improved (grain size decreased, speed went up) and options changed (color replaced black and white), but you could keep using the body and the lens. In the digital world the camera body and the film are essentially one. And image stabilization in the lens makes them more subject to obsolescence with improvements in electronics.

The sensor and the processor in the body essentially replaced film. Early sensors were small, low in resolution, low in speed, limited in latitude, and noisy when the ISO was increased above some very low values. Also relevant, especially for higher resolution video formats was how fast you can get the information off the sensor, process it and store it.

Given that a 35 MM still frame has the equivalent of 87 mega pixels (4x5 sheet film about 15 times that), it was not surprising early digital sensors were used in video cameras (standard definition - SD required .3 mega pixels) and in 1 and 2 mega pixel cameras suitable for then web posting and small prints. For reference: 8mm movie film has about the resolution of SD video, 16 mm about 2k, and 35 mm about 4k. A 35mm movie frame goes across the film and is thus smaller than a still 35mm frame, which goes along the film.

Digital camera sensor resolutions exceeded that needed for video before it was possible to get that much information off the sensor, process and store it. However when processor speed improved video became an added feature of the digital still camera. As an added feature, cameras did not offer the same ease of use of a dedicated video camera, designed to let the operator make changes while shooting, something the still photographer did not need to be able to do.

My two 2012 vintage Cannons have 18.7 mega pixel sensors (5184 x 3456). That resolution is still offered on many cameras. The move to full frame sensors, 36x24 mm (same as a 35 mm film camera) has pushed the upper end to over 45 mega pixels (Nikon 45.4 8256 x 5504). Three hundred dots per inch (DPI) makes a good quality print and 200 DPI is often acceptable. An 18.7 MP sensor even allowing for cropping will provide enough information for an 11x14 print at 300 DPI and a 16x20 at about 240 DPI.

Looking back my Nikon F was a professional camera in production for over a decade and cost about $3,000 in today's dollars. That amount of money today will get you very good professional still body. The XL-1 was in use for commercials and feature films for a relatively short period of time. It would cost about $6,200 in today's dollars, about the same as a very nice 4k professional camcorder today. Interestingly today when I use the obsolete XL-1 for backup or to capture an insert, it gets a lot of respect. It looks like what people think a professional camera should look like, even though some fine and expensive cameras today don't look like more than small black boxes. The cameras I use today cost a lot less and are not professional ones, but they are getting done what I now need to get done.

Bob Popadic '64 Course 6, Harvard MBA, spent his career in the financial services industry as a bank executive and consultant. He has been an avid photographer from grade school and a videographer from the early 1990's.

How Small Boat Coastal Navigation Has Changed

Robert P. Popadic

My decades long sailing career started at MIT in the fall of 1960 when I jumped into Alumni Pool hoping I could pass the swimming test so I could sign up for sailing. Not sure why I had that expectation, probably just a hope I would suddenly magically know how to swim. I ended up signing up for both swimming and sailing classes.

Navigating a Tech Dingy on the Charles was all visual - no compass, electronics, or charts. All you had to remember was immersion in the waters of the Charles could be unhealthy. The Charles was also reported to be bottomless – it just got thicker.

Midshipman Cruise

My first exposure to the tools of navigation was on my midshipman cruise the summer of 1963. Classmate Al Wirzburger '64 (deceased) and I traveled to Norfolk and joined the destroyer USS Leary. We made one trip to the Bridgeport CT for the Barnum Festival. I lived just north of Bridgeport so had access to a car, which made me very popular with the officers and other midshipman.

On the way we learned about charts, taking bearings using the compasses on the bridge wings, and plotting them on the chart – an art that goes back centuries. If you could get bearings on three objects ashore that were on your chart, you could plot the bearings and get hopefully a small triangle (often called a cocked hat) within which was your likely position. We learned about dead reckoning, which is basically taking a "known" position and projecting it forward based on course, speed and currents. Been done for centuries. This projected line could also be combined with shore bearing(s), if insufficient shore bearings were available to obtain a fix.

We also did some celestial navigation using a sextant – a device for measuring how far above the horizon a star, the sun or moon are. Measurements on multiple objects, accurate time, tables and some math allowed position determination. If was not until the development of accurate portable timepieces that it became possible to determine longitude from a ship. A twenty thousand pound prize was offered in the Longitude Act of 1714 that wasn't paid out until 40 years later after an accurate timepiece became available. For a long time celestial navigation was how off shore navigation was done, then electronics started displacing celestial navigation. In 2006 the Naval Academy stopped teaching how to use a sextant, only to reintroduce it in 2016 with growing concern over Global Positioning System (GPS) being jammed or unavailable.

GPS was first introduced for the military in 1973, and became available for civilian use after 1983 when Korean Air Lines Flight 007 was shot down when it strayed into forbidden airspace, BUT with an introduced error – called "selective availability." Thus you could never know your position more accurately than 150 feet horizontal and 300 feet vertically. Induced error for civilian user was removed in 2000.

The Leary's electronic navigation aid was LORAN (short for long range navigation) developed during WWII. The basic idea of LORAN was that one could compare the receipt times of two (master and a slave) transmitted signals from widely separated stations; and the difference in receipt times defined a curve on the surface of the earth somewhere upon which the ship was located. Identify three of these curves and you have a triangle in which you are located. The Leary's receiver was pretty old, even then, as you had to select the frequency and then twist a dial to line up on a CRT the trace of the two signals. The dial gave you the timing difference, which then allowed you to go to a chart and find the appropriate preprinted curve for the right station (frequency) and time difference. You were someplace on the curve. With multiple stations you could get your location by the intersection of the multiple curves.

Traditional navigation tools, consisting of parallel rulers, compass, protractor and pencils laying on a chart of Salem and Marblehead Mass.

Sailing the Chesapeake Bay

After graduation from Harvard Business School in 1966, I went on active duty at the Navy contacting office at a civilian shipyard in Newport News VA. I spent my uniform allowance as a down payment on a Ford 20 day sailer, enclosed the open cuddy cabin and set off to explore the Chesapeake Bay with my compass, charts, parallel rulers and dividers. I named the Ford 20 "Sabrina" after Audrey Hepburn's character in Breakfast at Tiffany's, not the Nordic goddess. With a center board boat that drew only a few inches, a sandy bottom and little tide it was great fun.

Being a Navy desk jockey, I thought it would be helpful to take correspondence courses in ship handling and navigation. The latter introduced me to paper charts, parallel rulers (used to transfer a bearing from the compass rose to where you were plotting) and dividers (handy for transferring distances).


Hardly a ship shape departure from the hotel dock after unexpected rain during the wedding.

I met my wife Karen shortly after arriving in Newport News in June of 1966. In June of 1968 we were married, and went on our budget (dollars and time) honeymoon with our navigation tools now supplemented by a cruising guide for the Chesapeake. Cruising guides provided in paper form what is largely available on line today – tide tables, current charts, lists of marinas and services, etc. Before the wedding we tied "Sabrina" up at the hotel dock on the James River, without putting the boom tent up. During the reception it rained. Undeterred we motored away from disappointed folks who expected us to use the car they decorated. We had water sloshing in the cockpit and headed north for the York River and the marina that advertised rooms in the cruising guide. Arrived there safely to find the rooms really weren't quite finished – bed in a loft; and received the suggestion we should stay at a hotel – the same one where our wedding party was. We didn't like that idea, so took off with the boat for dinner at a restaurant where we could dock, and then decided to anchor in mid stream in the York River to avoid the bugs and sleep in the cockpit. Worked out fine.

To Marblehead Massachusetts

Columbia 26

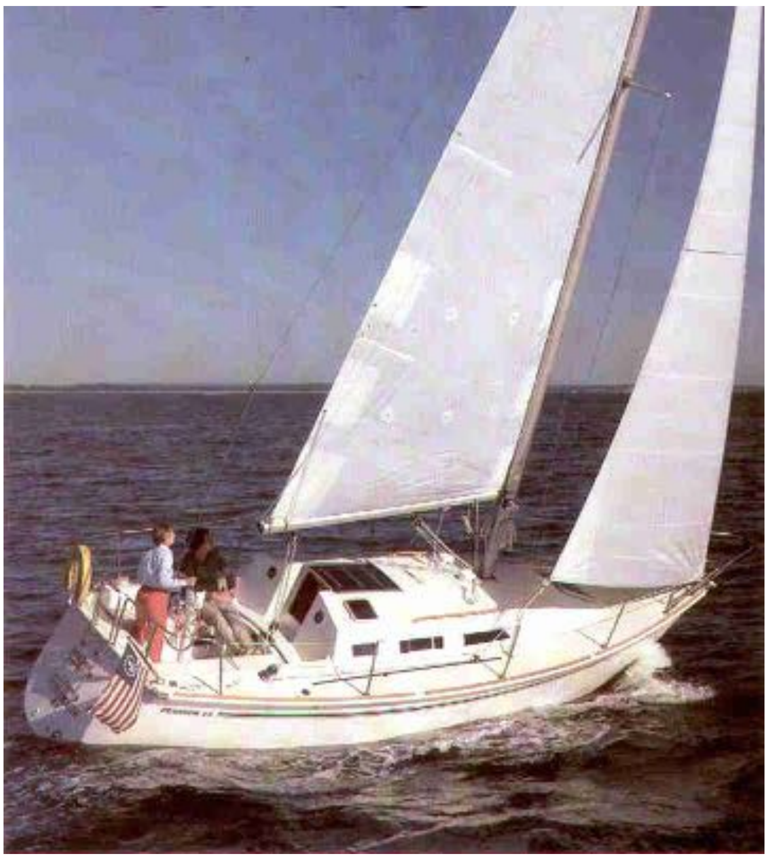
Karen finished the school year teaching and I left active duty shortly thereafter and we trailed "Sabrina", the Ford 20, to Marblehead Mass. In the summer of 1969 we sailed to Cape Cod, slept under the boom tent in the very large cockpit; and mostly went ashore to eat. That year we took delivery of a Columbia 26, which was large enough to do some comfortable cruising. We named in "Sabrina", again – no II or anything fancy like that. We added a 50-watt double sideband crystal controlled radio, a Heathkit depth sounder, which I built, a radio direction finder (for use with navigation beacons and commercial radio stations near the coast), and a fancy hand-bearing compass (nice wooden box, flashlight like handle to light the compass bowl). At that point we had more navigation tools than the lead destroyer in the 1923 squadron cruise from San Francisco to San Diego that drove itself ashore at Honda Point followed by six other ships. The lead destroyer was navigating using dead reckoning and unfortunately largely ignoring the early radio navigation aids available.

We made a number of trips to Cape Cod, Martha's Vineyard, Nantucket and places on Buzzards Bay. On trips often Karen was at the tiller a lot while I took bearings with the compass or radio direction finder, plotted course and bearings with pencil, parallel rules. One year in pea soup fog we used the depth sounder to follow a constant depth curve along the southern coast of the Cape to the bell for Falmouth Harbor. On the radio we heard a large powerboat with radar was going out to try and find a sailboat that couldn't find the harbor entrance. Most small boats didn't have traditional radar then, but there was Whistler - a poor mans radar, a square unit you hung around your neck and moved while you listening to earphones. We never got one.

We used our double side band radio for calling other boats, bridges, marinas and occasionally to make brief phone calls via the Marine Operator, where you often had to wait in line for a time to make a call; and could listen to check if they were holding land based calls for you. Double side band radios, which had considerable range could not be licensed after January 1, 1972 and were completely banned in 1976. Only allowed were single side band ones, which allowed more effective use of the radio spectrum (more channels). And you couldn't get a license for one unless you also had a VHF radio for line of sight communication. We added a VHF radio, but kept the old double side band one just in case. As I recall they were allowed and Coast Guard monitored the calling frequency for emergencies. With our VHF radio we could get weather forecasts. Once cell phones became generally available in the early 2000s, when near shore they became the primary means of communicating with folks ashore. And people could now also easily call you – so much for your sailing get away.

In 1996, a storm struck Salem Harbor while we were visiting our oldest son at Carnage Mellon. "Sabrina", the Columbia 26, ended up on the rocks in Salem Harbor – one pendant parted and the cleat for the other pendant broken.

A Bigger Boat



Pearson 28 brochure picture

In 1998 we bought a used 1985 Pearson 28 that came with full head room, hot and cold running water, an inboard engine, VHF radio, handheld VHF radio, depth sounder, speed indicator and a Loran-C unit that previously had been on a fishing boat. And yes we also named it "Sabrina". Loran-C had come a long way since the original LORAN unit I used on the USS Leary. This one actually gave you the latitude and longitude, no dial twiddling to match waveforms, but GPS still had a random error introduced for civilian users, which it was reported made Loran if not more accurate, more reproducible (help find your favorite fishing spot). By the 1970s relatively low cost Loran–C receivers were available resulting in many LORAN stations being phased out by 1980. In turn, under pressure from GPS, a number of Loran–C turn off dates were announced and then cancelled; until it finally Loran-C became history in the US and Canada in 2010.

The Pearson had a traditional "nav" station with a place for charts and navigation instruments, a table to work on, and places where we installed VHF radio, radar and laptop with navigation software linked to a GPS unit at the helm. This was also the home for handheld radio, digital hand bearing compass, various guides and navigation books. On the cockpit bulkhead were magnetic compass and traditional wind and speed instruments (not networked) and below the main sheet track was a Loran unit.

A new boat needs new toys. We got: a digital hand bearing compass, which I still use (fits in my shirt pock – hardly gets the respect the old analog one got); a hand help GPS unit (still around), a Furuno radar, and "igation software for my laptop. The units were all connected by an early network. The GPS fed the laptop to move the little boat shaped icon around on the charts, and the radar to put a circle on the screen where your next waypoint was. If you were lucky the circle wrapped around the reflection of the buoy you were heading for. Our eldest son John and I tested the new toys out on a trip to Maine early in the 1999 season. We went farther off shore then we had been before and felt very comfortable. With the radio, radar display and laptop at the "nav" station we took turns at the helm and navigating. The May trip was very early for Maine. We found fields of moorings available in popular harbors and a lot of restaurants that weren't open yet. Being a college student he may have been getting a bit too much of dad and went ashore and found some kids to play ball with. He forgot about the extent of the tide swing and where on the beach he should leave the hard dingy (non-inflatable). I saw the tide rising and called him on the hand held radio he took with him; and he came back to the dock, I powered by and he jumped on and we chased the hard dingy until we realized from the chart we were headed for shoal water. Back to the mooring, got the inflatable dingy, which was half inflated on the fore deck, pumped it up and launched. John then went off, found the dingy and had to convince folks who found the dingy it was ours and wasn't salvage.

This was the time you started to be able to get integrated displays; and electronics started to move from the "nav " station, where you could sit at a nice table, spread your charts, and commune with your electronics, to pods on the wheel pedestal or atop the cabin. Charts began to have the longitude and latitude of buoys printed on them so you could enter them as waypoints into your GPS. More expensive GPS units could also store charts and plot on them. Now for many situations the roles of navigator and helmsperson could be combined into one person. Networks continued to improve and more devices became network enabled.

Some place along the way Karen lost interest in sailing and I started sailing by myself, something I doubt I would have done without a GPS at hand. In 2000 they removed the random error introduced for civilian users. GPS was now more accurate and reproducible than LORAN. Newer GPS offerings currently available are supposed to be so accurate you get a different reading depending on which side of the cockpit you are sitting on. Not sure that will any difference to the small boat navigator.

Paper charts are still nice to have especially when the battery runs out or an electronic gremlin is about, or when a giant solar flare such as happened in 1859 occurs. Paper charts are huge, you need to be on a ship to have a "nav" table big enough to spread them out unfolded. They also have a ton of information printed on them, which you can access by getting closer especially if you are near sighted. The usable part of a digital chart is limited by the size of your screen and they come in two flavors – raster or vector. Raster charts are basically scanned paper charts – if you see something and cannot determine what it is you zoom in until you can read it. Vector charts are generated at the level you are viewing, which means at a larger scale you may not be shown say a rock unless you zoom in. Paper charts for me at least are great for getting the big picture and putting where you are in context.

A Smaller Boat

One afternoon while sailing alone in 2012, "Sabrina" the Pearson and I had a low tide encounter with a rock off a beach in home waters (it was just over the fold on a chart). In getting her off with the diesel the stuck fin keel flexed the hull enough to make the repair of an old boat a total loss. The following year we bought a trailer able keelboat, a1974 Typhoon Weekender named "My Garrison." We kept the name this time. It's 18.5 feet long and a total change from the Pearson 28. Its actually harder to single hand for a number of reason, mostly related to going from a diesel controlled from a wheel pedestal to an off center outboard hanging off the stern. However, the cockpit seats are just the right height for our now 6 and 7 year old grandchildren. Downsized a bit: no radar, no depth sounder, and only a handle held radio. Still have the same digital hand bearing compass, paper charts, and GPS. I find I use the GPS as a compass a lot, even though there is a lag vs. the magnetic compass. I use the GPS to get speed over the bottom, rather than the nice Raytheon speedometer the pervious owner installed that gives speed thru the water. With a smaller, slower boat (displacement hull speed is largely limited by water line length); and slower and probably heavier captain, I don't go as far afield and thus have simpler navigation needs.
Navigation aids are to help you get where you are going and stay out of trouble, so you can enjoy the sun, wind, sea and your sailing companions.

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The Impact of Technology on Ice Climbing

Leon Kaatz

Ice climbing and technology? Sounds like a weird marriage; not so. Technology's impact on mainstream sports is well known to most of us. Witness the design and choice of materials for football helmets to improve safety; golf club shafts and tennis racket frames to control weight, swing and accuracy. Most of these improvements center on the choice of materials and so it is with ice climbing. But materials are not the exclusive domain where technology has impacted this sport. Before jumping headfirst into this discussion a basic tutorial is in order on what is ice climbing and how it is done.

At the outset it is necessary to distinguish between ice climbing and mountaineering. Ice climbing is the climbing of steeply inclined or vertical ice walls. It has developed strictly as a sport. Ice climbs are graded in difficulty from Water Ice Wi1 (easiest) to Wi7 (hardest). The grading encompasses several factors, the most significant being the pitch. A Wi2 climb might have a 45 degree pitch. A Wi6 climb is usually dead vertical. Mountaineering is the ascent of mountains, generally across and up glacier fields. The genesis of mountaineering is more in travel and exploration than in sport. The ascent of most tall mountains requires considerable mountaineering with little or no ice climbing.[2] This essay is devoted to the impact of technology on ice climbing, not mountaineering. That being said, some of the basic equipment used in ice climbing was originally developed for mountaineering.

Crampon – top view

Crampon – bottom view

Basic Tools

The basic tools of the ice climber are a pair of crampons, a pair of ice tools (more commonly known as ice axes to the general populace), and ice screws. Crampons are an accessory that get strapped on to one's ice climbing boots. They contain sharp pointed protrusions called points along the front, back and sides. In basic ice wall climbing moves primarily the

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[2] From the base camp of Mount Everest to the summit entails about 11,000 feet of vertical gain. The only true ice climbing on that journey is on a 40 foot section just below the summit called the Hillary Step. That section of the mountain was impacted by the 2015 earthquake and, by most accounts, is no longer viewed as true ice climbing. When it did exist it was generally graded at about Wi3.

front points are used. They are kicked into the ice wall and provide the climber with a measure of contact with the ice wall.

Crampon in contact with ice wall.

The typical front point only protrudes about 1.5 inches forward from the toe of the boot. Despite this seemingly small amount of contact with the ice wall they provide a significant amount of purchase. The secret is in the accuracy of the kick and the maintenance of the points.[3] The side and rear points on crampons are used primarily for stability on glacier traverse. In this context the motion is not vertical (typically less than a 45 degree incline). The side and back points provide stability and traction on such glacier surfaces. Those readers who live in northern climes may be familiar with a product sold under the brand name of "*Yaktrax*." *Yaktrax* are strapped onto winter boots to provide traction while walking on an icy surface. The side and rear points of the crampons (along with the front points) serve this same function.

Ice tool

The second fundamental tool is the ice tool. Just as crampons are the appendages that secure the climber's feet to the ice wall, ice tools are the appendages that secure the climber's hands to the ice wall. As the climber moves up the ice wall the ice tools are thrown into the ice surface to provide upper body connection to the wall. The fundamental components of the ice tool are the shaft and the pick.

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[3] The more skilled the ice climber the better he or she is at "reading" the ice and knowing the best spots to kick into. The front points must be kept sharp. Most ice climbers will file and sharpen the front points of their crampons after each day of climbing.

Ice tool leash

Ice tool penetration

Some ice tools also have detachable leashes with one end affixed to the shaft of the tool and the other end slipped over the climber's wrist.[4] As with the front points on crampons, the tips of the ice tools, when properly thrown will provide about 1.5 inches of penetration into the ice surface. As with the front point of the crampons, placement and keeping the point sharp are critical to performance. Placement is an acquired skill that comes from knowing how to read the ice. As with the front points on crampons, most climbers will sharpen the ends of their ice tool picks after each day's usage.

Ice screw

Carabineer

Ice screw, lead, rope configuration

The third piece of equipment to be discussed is the ice screw. The ice screw is an anchor point screwed into the ice surface. Its purpose is safety. The climber's rope will be passed through a carabineer that is secured to the ice screw by a short lead. The ice screw/lead configuration is to catch a climber if he or she falls. As with crampon front points and ice tool picks, placement of ice screws is critical. Good placement requires an accurate read of the ice, how it is formed, and location of its weak points. The ice screw is secured to the ice

[4] Leashes serve the obvious function of preventing the dropping of the tool but they are shunned by most advanced climbers. More difficult climbs are sometimes facilitated by swapping the ice tools from hand to hand. Leashes make this impossible.

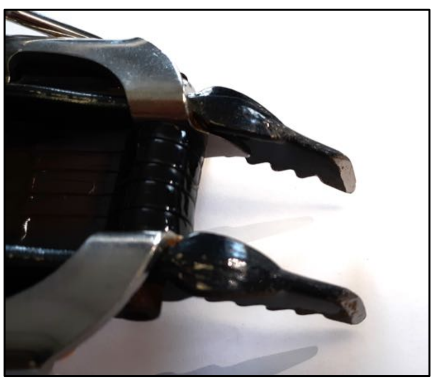
wall by gently tapping in the point and then screwing it into the surface to about a half inch from the top of the shaft. The cylindrical portion of the ice screw is hollow, thus allowing for a more secure grip in the ice.

The most significant impact of technology on ice climbing has been the advancement in the design and construction of crampons, ice tools, and ice screws.

Crampons

Crampons are not a recent development. Evidence has been found that paleo hunter gatherers used similar devices to gain traction while crossing mountains to search for food. Leather sandals with spiked plates, believed to be over 1000 years old, have been found in the Caucasus Mountains in Russia. There are even depictions of crampon-like devices on the Arch of Constantine built by the Romans in 315 A.D. The crampon in its current basic design was first manufactured for sale in 1910 by Henry Grivel, an Italian climber.[5]

Early crampons were designed with two flat front points. The front points and the body of the crampon were all one molded piece of metal. The flat front point flared back from the point tip to the base of the crampon frame with the flare being horizontal relative to the ice surface. In the mid-1990s crampon design moved into a new generation.



Vertical front points

In the more modern crampons the front points are vertical relative to the ice surface. This provides for better penetration into the ice with less power needed in the kick to produce the penetration. This more modern design produces less cracking of the ice surface as the crampon penetrates, resulting in a more secure connection to the ice wall.

Detached crampon front point

At the same time that the crampon design provided for vertical front points it also provided for interchangeable front points. Modern front points are completely detachable allowing for replacement when they ultimately wear out. This feature, in addition to allowing for replacement, allows for adjustment of position (depth of penetration) and allows for climbing with dual front points versus mono front points. This last advancement allows the crampon to be more closely tailored to the climbing conditions – mono points for a very featured ice surface, dual points for a smoother ice surface.

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[5] History of Climbing Crampon, Doug Williams, 2017.

The final advancement in crampon technology is construction with a fixed antibot plate. An issue when traversing across a snow glacier is the buildup of snow on the bottom of the crampon. This buildup impacts the climber's balance and stability and the connection to the surface. To address this impediment crampons have a fixture called an antibot affixed to the undercarriage. Early crampons did not provide for any antibots. In the next generation of crampons (1970s and 1980s) the antibots were a rubber plate that clipped to the undercarriage of the crampon. Although functionally adequate, they were difficult to use. Major issues were tears in the rubber and the insecurity of the clips affixing the plate to the crampon. Rarely did they last more than one season. Replacing them under typical cold weather climbing conditions was a dreaded task. Replacing antibot plates in the comfort of one's living room would take about 20 minutes and required a degree of manipulation with one's hands. None of this could be accomplished while wearing climbing gloves. Removing one's gloves with temperatures in the single digits (or less) was not a pleasant option. More modern crampons have a fixed built-in antibot plate (See second photo above, orange under plate). They don't break or tear and they are maintenance free.

Ice Tools

The original ice tools were designed and built for mountaineering, not ice climbing. They were meant to be used primarily for balance traversing across or up a glacier surface. When they were first developed they had straight vertical shafts up to 3 feet long and a metal pick primitively attached at the top. These tools were heavy, cumbersome, and had significant vibration when struck into an ice surface. In reality, in their first incarnation ice tools were used primarily like a walking stick. The general design of the ice tool, as used today, was developed in the early 1970s. The most significant design advancements are the use of a shorter curved shaft and detachable picks.

The curved shafts on today's ice tools allow for more flexibility in the grip and reduced strain on the wrists, elbows, and forearms. The curved shaft and shorter length provide for a much more powerful swing. For most ice climbers (particularly your author) the limiting endurance factor in ice climbing is in the arms, not the legs. The more modern shaft design provides greater "sticking power" for the pick with no added effort or strength in the swing. As noted earlier, placement of the throw is a critical factor in ice climbing. The shorter curved shaft makes it much easier to connect the throw to the ice at the precise point aimed at. The current design allows for more of the throw to come from the wrist instead of the forearm. This provides greater precision without sapping upper arm strength.

The evolution of design in ice tool shafts in the past decade has focused more on the grip and handle. The newer grips have an upward protruding lip that comes over the back of the hand. This minimizes the possibility of letting go of the tool. This advancement was spearheaded by Grivel.[6]

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[6] Grivel is always on the cutting edge of new technologies in ice climbing equipment design. This is so because, unlike other manufacturers, Grivel relies on climbers for their feedback, not engineers.

Ice tool grip

The early ice tool shafts were made of wood, typically hickory or ash. They lacked durability and were prone to snapping. The first ice tools with metal shafts were developed in the early 1960s by Scottish climbers Hamish MacInnes and Benjamin and Steven Massey.[7] The first metal ice tools had steel shafts. These shafts gave way to aluminum in an effort to cut down on vibration. Today's most modern ice tools have shafts made of carbon fiber. They are lighter and much better at absorbing shock.[8]

The advancement in ice tools is not limited to improvements in the shafts. The ice tool picks have also been the subject of considerable change both in materials and design. The picks in use in the 1960s were made of a very hard thick metal. These picks were long-lasting but very stiff. Today's picks are made of a softer metal and have a thinner design. This makes for better penetration into the ice. This is of significant importance when climbing in ultra cold weather when the ice is very brittle. The older heavy thick picks would tend to cause shattering of the ice surface on contact. This impacted penetration and the scattering of ice shards caused a safety hazard. There is hardly a veteran ice climber anywhere who hasn't, at one time or another, come home from a day of climbing with a bloodied face from flying ice.

In 1966 the design of ice picks underwent a dramatic change from a straight pick to a dramatically curved pick. This change, inspired by French climber Yvon Chouinard, was based on the principle that a curve on the pick compatible with the arc of the swing would allow the pick to stay better put in the ice. The idea worked and ushered in a new period of innovation in ice tool design.

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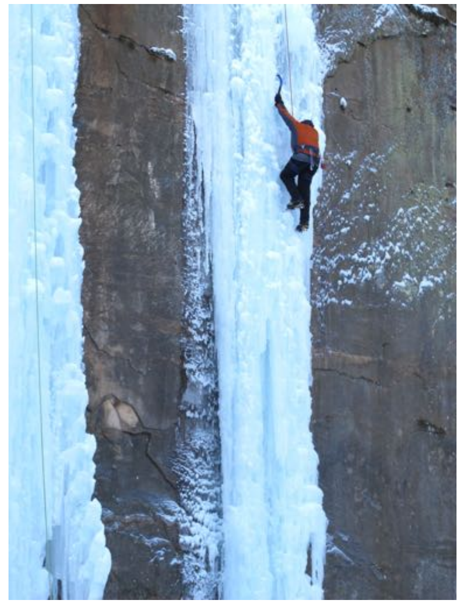
[7] According to the Scottish Mountain Heritage Collection, MacInnes created the all-metal tool after being involved in the recovery of bodies of a climbing group who fell to their deaths when the wooden shafts of their ice tools snapped.
[8] This technology was imported from bike manufacturers.

Wi5 climb



Wi6 climb

Before the advancements described herein only the most elite ice climbers could climb grade Wi5; climbing grade Wi6 was unheard of. Now grade Wi5 is, at least on a good day, within the ability of a climber with advanced intermediate skills.

Ice Screws

Ice screws as we know them today have been around since the mid 1960s. The predecessor to the ice screw, a device called a snarg, looks outwardly about the same as an ice screw. This device had narrower threads than an ice screw and needed to be pounded into the ice surface. It could be removed by turning counter-clockwise just as a normal screw would be removed. To the casual observer the obvious limitation to a snarg was the energy required to insert it and the need to carry additional equipment (ice hammer). The not so obvious limitation is lack of flexibility on where it can be placed. This point is subtle. The problem isn't a limitation on what part of the ice will accept the snarg; the problem is that in order to be able to pound in the snarg without falling it has to be at the climber's shoulder height and about 12-24 inches to the side of the arm wielding the hammer. The climber needs to be in a secure stance when the snarg is hammered in. Climbing ice is not like climbing stairs. The opportunities to gain a secure stance are limited.

Ice screw tip

Insertion of the modern ice screw is commenced by a relatively easy shove of the tip of the screw into the ice surface and then screwing it in by the handle affixed at the top.

Usually a good push is all that is required to get it started. At most the climber will have to use the tip of his/her ice tool to chip away a little bit of the surface ice to get the screw started. The point to be made is that once the climber has a secure stance the ice screw can be inserted into any adequate surface within the climber's reach. The limitation of insertion only at shoulder height does not exist when using ice screws.

Most ice screws were originally made in the Soviet Union using titanium and Cold War era missile technology. These proved to be unsatisfactory because they were too brittle and would break in extreme cold weather. Today's best ice screws are generally made from chromoly steel, they come in lengths from 10-24 cm, and have a rating of 7-8 kN. The prominent feature of today's modern ice screw is a sharp tip and sharp threads about 1/8 inch deep. These sharp edges are, however, a double edge sword (no pun intended). The sharp edges facilitate strength and ease of placement for the ice screw. However, if you do a lot of placement of these screws you are unlikely to get more than one season from your climbing gloves.

From a "techie" point of view the most interesting thing about ice screws derives from recent studies on the best way to place the screw. Not surprisingly the intuitive notion is that the ice screw is most secure when the tip is angled slightly downward into the ice surface. In 1997 Black Diamond, a major manufacturer of ice climbing equipment, conducted an exhaustive study to test the accuracy of this anecdotal belief. The findings were surprising. Black Diamond's study concluded that the screw is twice as strong when angled upward into the ice surface (into the direction of the fall).[9]

Summary

This essay has focused only on ice climbing and only on 3 basic pieces of equipment used for that endeavor. Time and space have precluded me from addressing other equipment used in ice climbing (e.g., ropes, harnesses, clothing, helmets, boots) as well as addressing the sister sport of rock climbing. Perhaps these will come out at the 60th reunion. I have been ice climbing for 27 years but until I researched this essay I had never given any serious thought to the impact of technology on the sport. Now that I have done so I am drawn to the conclusion that technology, as we commonly view it, has not had a significant impact on the sport. To be certain, changes that have been made to the equipment used in the sport have made the sport safer and accessible to more people; they are certainly responsible for raising the bar as to the level of accomplishment in this sport. That being said, my take on this is that these changes are better described as an evolution. All of the advances described herein came about slowly, one step at a time. There has been no "big bang" that dramatically impacted the sport overnight. Perhaps that is for the best. Ice climbing is, in reality, a very cerebral sport. It is actually as much about mental agility and problem solv-

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[9] I was not aware of this study or its findings until I did the research for this essay. Despite the age of this study my lack of this awareness is apparently commonplace in the climbing community. I have no recollection from any past climbing seasons of seeing any climbers placing ice screws in any direction other than the downward slope. I am curious to see the reception I will receive when I start spreading this "gospel" next winter.

ing as it is about athletic prowess. My climbing partner regularly attributes my ability at ice climbing to the mental disciplines and problem solving skills that come with an MIT education.

Epilogue

Don't be surprised if the next big advances in ice climbing come from MIT. Two venues where I regularly ice climb each winter are the annual ice climbing festival in Sandstone, Minnesota and the North Conway area in New Hampshire. Invariably when climbing at these places I run into climbers from the MIT Climbing Club. Invariably they will be testing out some new piece of equipment that they have designed and fabricated in the labs at MIT.

Leon M. Kaatz, '64, has been an active rock and ice climber since the early 1990s. He is considered one of the top 100 ice climbers in the world in his age group. In 1998 he and his climbing partner set the record for the fastest ever 2-man ascent of the Index Pinnacle in the French Alps. He is one of under 100 climbers in the world to have summited Devil's Tower in Wyoming on two or more of its faces. He has done three first ascents including a climb in the Eastern Sierras in 2001 that was named ***MIT*** in recognition of his receiving an MIT Bronze Beaver Award.