Session 23A2

The Need for Engineering Ethics Education

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Abstract

As society becomes increasingly dependent on technology, it is more and more incumbent on the masters of technology to assume the responsibility for protecting the public from technology gone awry. The engineering marvel of antiquity, the Great Pyramids at Giza, prove that technology built on the will of the people endures. In recent history, the Manhattan project members, after Hiroshima and Nagasaki became painfully aware of their social responsibility. A comparison of the actual events of the Space Shuttle Challenger disaster with the IEEE Code of Ethics reveals that this Code is not widely implemented in the engineering workplace. Although the TQM movement helps by creating a corporate atmosphere of openness, it is up to the engineering schools to empower their graduates with the skills and the determination to live up to the IEEE Code of Ethics.

Need for Ethical Responsibility

As our society becomes increasingly dependent on technology, it is also more and more vulnerable to and impacted by technology. The individual members of the consuming public are increasingly at the mercy of technology they cannot control and in which they have no voice.

But at the same time the engineer whose work affects the public works anonymously. If your doctor mistreats you, you know who he is and you can sue him for malpractice. Where however do you turn to redress the grievance of being unable to place a 911 call because the telephone network is downed by a software error; of a failed thermostat in your automatic coffee maker starting a fire that kills your family; of your son's life lost because a software glitch shut down the Patriot missile's radar system, allowing a Scud missile to hit his barracks? In all these cases the engineers never see the public whose lives they affect, and the public never sees them. Engineers therefore need an even more acute sense of social responsibility than do doctors.

In response to past engineering disasters such as the Apollo fire, engineering organizations such as NASA turned to the disciplines of product assurance, hoping that better configuration management, quality assurance, validation and verification, and testing would avert future disasters. However, the presence of such disciplines alone is not enough if the ethical culture in which they exist frustrates their full employment. In the next few paragraphs we will use examples from ancient and recent history to consider aspects of this ethical culture.

Engineering Success in Ancient History

The three Great Pyramids at Giza have been standing for some 4,600 years. The length of the base of the largest one, the pyramid of Khufu, is roughly 230 meters, while the pyramid's overall height is some 147 meters. An estimated 2.75 million blocks of stone, each weighing an average of 2.5 tons, were used in its construction.

Actually, between 80 and 200 other pyramids - varying widely in size and structure - were built in Egypt in addition to the Great Pyramids. However, the majority of these were unable to stand the test of time and were reduced to rubble.

Daisaku Ikeda, in his address "A Pyramid Created by the People will Last Eternally" [1] raises the question, "Why were the Great Pyramids at Giza able to endure? The secret of the pyramid's timelessness lies in the people. The people worked on this great endeavor with passion and of their own free will. This enabled the ancient pyramids to be built with an unparalleled perfection, with not even the slightest crevice or omission...I spoke with one of France's most authoritative Egyptologists, Professor Jean Leclant...He said 'They were filled with a sense of mission to immortalize their king's glory. They were also convinced that through the pyramids, they would be able to convey humanity's eternal nature to future generations. This is why they were able to achieve this miracle. That is my belief.'"

The construction was designed with the people in mind. King Khufu scheduled the construction during the annual flooding of the Nile - in order to allow farmers, who were idle during this time, to use their leisure time to work on the pyramids. Moreover, for the peasant farmworkers, being able to participate in the construction saved them from unemployment during the annual flooding.

Hieroglyphics representing the names of the work songs and spirituals of the stonemasons, as well as the names of their individual work units, have been discovered at ancient quarry sites. Names such as "Vitality Unit", "Endurance Unit", and "Health Unit" illustrate the sense of pride and competitive spirit that existed between the individual groups.

This sense of pride must have impelled them to point out and correct defects as they occurred. The flawlessness of the construction testifies to this, as it is inconceivable that all 2.75 million stones were measured, cut, and placed correctly the first time.

Engineering Ethical Dilemma in Recent History

Consider Einstein's dilemma in 1939. He knew atomic energy could probably make a bomb of awesome power, and he also suspected that Hitler's people were working on the development of such a bomb. Should he remain silent, and risk allowing Hitler to rule the world with it, or should he step forward and offer his services to help the United States develop it first and win the war with it? Although a pacifist at heart, he chose the latter.

Then, alarmed at how his invention devastated Hiroshima and Nagasaki, and united with other American physicists, he strove in vain to take control of atomic energy out of the hands of the military.

Michael Amrine, who served as publications editor for Einstein, Oppenheimer and others during this campaign, described their feelings in his novel Secret, a fictionalized account of the Manhattan project. As the novel concludes, one of the project members, Halverson, is arriving at "N" lab, Building X-1088 at the University of Chicago, and thinking to himself.

"We are children playing with matches on an island of gunpowder. We are a party of explorers bickering and battling as we go along the edge of the abyss -- and no man knows the depth of the abyss until we pull each other over....

"'They have been waiting for you,' said the MP. 'It is all in order, if you wish to go in.'

"With loathing Halverson looked at the face of the MP on the porch of Laboratory N, with a cold chill in his stomach. Halverson looked at the blue gleam of the moonlight on the gun in the holster. He thought to himself: You simply do not know it is loaded..." [2]

Recent Engineering Failure: The Challenger

To learn how engineering failures happen, we will examine the Challenger disaster in detail. The facts and quotations included in the following chronology are derived from the special report on the subject in IEEE Spectrum, February, 1987. [3]

In studying this event, I do not wish to pillory the mentioned individuals, who have all suffered enough from this tragedy. Rather I would like to take the viewpoint that all these individuals were at some point engineering students, and to ask the question, "What was lacking in their engineering education that they behave this way, once subjected to the pressures of the engineering workplace?"

November 19, 1973. NASA's source evaluation board reports on four proposals for the design of a solid-fuel rocket motor for the space shuttle. Only one does not bid a segmented design, noting "A one-piece case is always superior in inherent reliability and economy to a segmented solid rocket motor," and pointing out that the only advantage to a segmented rocket lay in the convenience in transporting it from manufacturer to launch site -- a convenience gained "at the ultimate compromise of crew safety." The source evaluation board rejects this proposal. They also reject two proposals that the motor performance should be tested at 40° to 90° F. Separate "temperature conditioning...to verify the motor performance" over those extremes, the board said, "is not required, as this data can be obtained from the normal variation in ambient conditions." The board chooses the low bidder, Thiokol, which ranks lowest in motor design, development, and verification, but whose bid came in $100 million lower than its competitors. The main reason for the choice is that NASA is furiously cutting costs to stay within its shrinking post-Apollo budget.

1981. On the second shuttle flight, the right booster rocket field joint suffers an erosion - a significant decomposition or vaporization of the O-ring's cross-section by combustion gases. Two O-rings, made of synthetic Viton rubber, seal each joint between the booster rocket's segments. The booster's 11 sections contain propellant and igniters that, together with the main fuel tank, enable the shuttle to launch itself into orbit.

July 31, 1985. By this time, erosion and blow-by -- passage of gas or debris around the O-ring before it has sealed the joint -- is accepted as normal. Four of the nine shuttle missions launched in 1983-1984 experienced this problem. Thiokol has unofficially assigned a group to work on solving this problem. On this day Roger Boisjoly, a Thiokol staff engineer, writes a memorandum asking that Thiokol's unofficial O-ring task force be officially endorsed.

August 19 and 26, 1985. Thiokol presents its assessment of O-ring seal problems, along with 63 new joint designs, to Michael Weeks, who is standing in for Jesse Moore, the Level I man in the launch decision chain (see Figure 1).

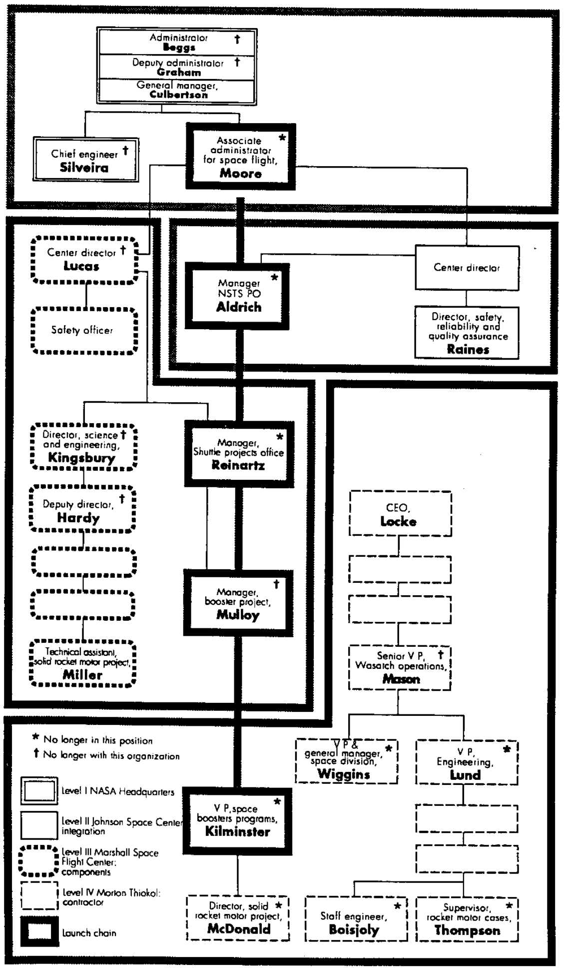

Figure 1. The Launch Chain (adapted from [3])

August 27, 1985. Thiokol formally institutes its Nozzle O-ring Investigation Task Force.

October, 1985. Boisjoly pleads with Joe Kilminster, Vice-President of Thiokol's space boosters program, for help. As Boisjoly and others leave the room after this meeting, Kilminster remarks, "Well, it was a good bullshit session anyway." Boisjoly later testified that at the time he was "really ticked because we were pleading for help and we couldn't get it. We were fighting all the major inertia in the plant, just like everybody else, and yet we were supposed to be this tiger team to get a very severe problem solved. [Kilminster] just didn't basically understand the problem. We were trying to explain it to him and he just wouldn't hear it. He felt, I guess, that we were crying wolf."

This is a fatal failure in communication, on both sides. How can Boisjoly present his case so that Kilminster understands? How can Kilminster be better able to listen to individual contributors like Boisjoly? What does this mean for us as engineering educators?

Attorney Robert Levin, who worked on the Challenger disaster investigation, commented "One of the things that's clear to me is that engineers do not speak the same language as managers. And engineers as a group are not politically savvy. What I would very much like to come out of all this -- legislative or otherwise -- is that the next time this kind of dispute comes up, one of these engineers can say 'Damn it! Look what it cost Thiokol'. Now you're talking the language those folks understand."

Monday, January 27, 2 PM EST. The Challenger launch suffers its fourth postponement. Eagerly waiting the launch is Christa McCauliffe, a science teacher from Massachusetts, who was selected to be the first teacher to go into space. Her 3 year old daughter had not wanted her to go, but Christa felt a sense of mission that overrode her personal concerns. All across the land science classrooms are tuned in to watch the launch, and many schools have sent their students to Cape Canaveral to view it in person. President Reagan is due to give his State of the Union address, which mentions the "teacher in space" the next day. At the Kennedy Space Center in Florida are the four key people representing NASA in the launch-decision chain: Lawrence Mulloy, manager of the booster project, from Marshall Space Flight Center (MSFC) in Gainesville, Georgia; his boss Stanley Reinartz, Manager, Shuttle Projects Office at MSFC, which has responsibility for the Shuttle's rockets; Arnold Aldrich from Johnson Space Flight Center in Houston, Texas, who as Manager of the National Space Transportation System Program Office has overall responsibility for the Shuttle; and Jesse Moore, Associate Administrator for Space Flight from NASA headquarters in Washington DC. The weather forecast is for clear and cold, with an overnight low of 18° F.

2:30 PM. NASA asks Morton-Thiokol to review the cold snap's possible effects. Five of their engineers - including Roger Boisjoly and Arnold Thompson, the rocket motor cases supervisor - firmly believe that the cold could render the O-rings so stiff that they could not properly seal the booster rocket joints against hot gases.

8:45 PM. A teleconference begins among 34 engineers and managers from NASA and Thiokol, including everyone so far mentioned. Boisjoly and Thompson show charts of a history of O-ring erosion for the booster rocket joints primary seals. Boisjoly says his calculations indicate that cold makes the rubber rings stiffer and harder so that they can not properly seal the joint. He and Thompson show photographs of O-rings from previous flights showing that the gases had eroded deeply into the primary O-rings, and that the colder the weather, the more the hot gases were able to escape around the O-ring. They point out that during one launch, January 1985, when the O-rings' temperature had been 53° F, the joint had not sealed at all. The NASA/GSFC booster project manager Mulloy asks Thiokol management for a recommendation. Joe Kilminster, the company's vice president for the shuttle boosters, says that he can not recommend a launch at any temperature below the limit of their experience - in other words, below 53° F.

At that, George B. Hardy, NASA's deputy director of science and engineering at Marshall, exclaims that he is "appalled." Reinartz says that he thought the booster was qualified for a launch at any temperature from 40 to 90° F. Mulloy points out that no launch-commit criterion has ever been set for the booster joint's temperature. "The eve of a launch," he exclaims, "is a hell of a time to be inventing new criteria." Mulloy is later quoted by some of those present to have remarked: "My God, Thiokol, when do you want me to launch, next April?"

Kilminster quickly responds by asking for a five-minute caucus for the Thiokol personnel, off the teleconference net.

10:30 PM. The Thiokol caucus among the 14 engineers and managers at the Utah plant lasts closer to 30 minutes. As soon as the telephone connection is cut, Thiokol's general manager says: "We have to make a management decision."

Thompson draws a sketch on graph paper, illustrating again for the managers why he believes cold threatened the sealing of the joints. Boisjoly has photographs of joints from other shuttle launches, showing black soot where hot gases had blown through. He implores them not to ignore the implications of these pictures: that the joints seem less likely to seal in cold weather. But eventually both men realize they have done everything they could. No one is listening; they go back to their seats.

Boisjoly later testified that he did as much as he felt he could to air his concerns about the joint, short of risking being fired. He saw himself as a loyal employee, believing in the chain of command. "I must emphasize, I had my say, and I never take any management right to take the input of an engineer and then make a decision based upon that input, and I truly believe that...So there was no point in me doing anything any further."

Is this how we will train future generations of engineers and engineering managers? What are the costs to the whistle blower?

After that, Thiokol's top management holds a final review. Kilminster and Robert K. Lund, vice president of engineering, are still reluctant to go against the engineers' objections. But Jerald E. Mason, vice president of Wasatch operations, urges Lund: "Take off your engineering hat and put on your management hat." At last they all agree that it was safe to launch, even though no engineer or technician thinks so.

How can we so empower the individual contributor who knows the problem intimately to protect the public and the corporation from such misguided decisions?

11:00 PM. Resuming the teleconference, Kilminster says Thiokol recommends launching.

11:30 PM. Mulloy and Reinartz tell Aldrich that Thiokol recommended a launch. Aldrich later said he was not told about the concern over the O-rings that had been voiced by Thiokol's Boisjoly and Thompson. He must have known about the O-ring problem in general, because his boss had been briefed on it five months before, but Mulloy and Reinartz did not convey to him the seriousness of the engineers' continuing concerns.

"The fact that people are in a hierarchy tends to amplify misperceptions," says William H. Starbuck, ITT professor of creative management at New York University's Graduate School of Business Administration. "A low-level person has a fear that something might happen and reports it to a higher level. As it goes up the hierarchy, information gets distorted, usually to reflect the interests of the bosses."

11:39 PM. In Houston, the mission evaluation room manager at Johnson Space Centers shuttle mission control center requests permission from Houston's flight control team to waive the 31° F lower limit on the shuttle's overall launch-commit criterion if the morning turned out to be colder than that. Half an hour later the flight director agrees; no limitations are identified on any system.

January 28, 1986, 6:54 AM. A team of technicians charged with checking ice conditions measures the right booster segment at 8° F near the aft joint. As no launch-commit criterion has been set for the booster's surface temperature, the team does not report its finding.

8:30 AM. Challenger's crew are strapped into their seats.

9:00 AM. The mission management team - including Mulloy, Reinartz, Aldrich, Moore and Lucas -- decide to go ahead with the launch.

11:23 AM. The flight director in Houston gives the final "Go ahead" for launch at Kennedy.

11:38 AM. Flight 51-L, carrying Challenger, lifts off Launch Pad 39B. The ambient temperature is 36° F.

11:39 AM. Challenger is destroyed; all seven on board die. Students at Christa McCauliffe's class see their teacher perish in a fireball.

February 3, 1986. President Reagan appoints the Rogers commission to investigate the disaster.

June 6, 1986. The commission announces its conclusion: The immediate physical cause of Challenger's destruction was "a failure in the joint between the two lower segments of the right solid Rocket Motor. The specific failure was the destruction of the seals that are intended to prevent hot gases from leaking through the joint during the propellant burn..."

But contributing to the accident was, in the commission's now famous words, the fact that "the decision to launch the Challenger was flawed." The report continues, "those who made the decisions were unaware of the recent history of problems concerning the O-rings and the joint and were unaware of the initial written recommendation of the contractor advising against the launch at temperatures below 53 degrees Fahrenheit and the continued opposition of the engineers at Thiokol after the management reversed its position." It faults the management structure of both Thiokol and NASA for not allowing such information to flow to the people who needed to know it.

The Rogers commission also notes the absence of safety personnel in making the decision to launch Challenger. Arnold Aldrich told the commission of five distinct failures that contributed to the decision, four of them relating to safety, reliability, and quality assurance. There was, he said, a lack of problem reporting requirements, an inaccurate analysis of trends, a misrepresentation of criticality, and a failure to involve NASA safety office in critical discussions.

The US House of Representatives Committee on Science and Technology conducted its own hearings and concluded in November, 1986 "meeting flight schedules and cutting costs were given a higher priority than flight safety."

There was a disaster on the ground as well. Within a year, all 5 government and contractor managers in the launch chain of command, as well as 12 other senior NASA and contractor officials, were no longer in those positions or had left their respective organizations. And those people will take to their graves their regrets about these events.

Is this how we will educate the future generations of engineers? To have to live with their own regrets?

The Challenger disaster is not an isolated incident. About the "Hubble Trouble", the New York Times quoted the Allen report on the subject: "During the testimony, it was indicated that some technical personnel in the Optical Operations Division were deeply concerned at the time that the discrepant optical data might indicate a flaw...There are no indications that these concerns were formally expressed outside this division." [4]

Clearly, something more needs to be done, and it is my conviction that we as engineering educators can choose to be part of the solution.

What IEEE Is Doing

The IEEE has a Code of Ethics, which was recently updated, and the IEEE Society for the Social Implications of Technology (SSIT) focuses its program on these issues.

The newly revised IEEE Code of Ethics became effective on January 1, 1991, and states:

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

"o Accept responsibility in making engineering decisions consistent with the safety, health, and welfare of the public, and disclose promptly factors that might endanger the public or the environment;

"o Avoid real or perceived conflicts of interest whenever possible, and disclose them to affected parties when they do exist;

"o Be honest and realistic in stating claims or estimates based on available data;

"o Reject bribery in all its forms;

"o Improve the understanding of technology, its appropriate application, and potential consequences;

"o Maintain and improve our technical competence and undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;

"o Seek, accept, and offer honest criticism of technical work; acknowledge and correct errors, and credit properly the contributions of others;

"o Treat fairly all persons regardless of such factors as race, religion, gender, disability, age, or national origin;

"o Avoid injuring others, their property, reputation, or employment by false or malicious action;

"o Assist colleagues and co-workers in their professional development and support them in following this Code of Ethics." [5]

We can see from comparing these ideals to the reality of the Challenger disaster that as the saying goes "Between the cup and the lip there's many a slip."

It is obviously not enough to simply have a Code of Ethics. Putting it into practice is what is important.

The IEEE Society for the Social Implications of Technology (SSIT) sponsors a Member Conduct Committee to hear cases of unethical behavior, and has a fund to protect members from the financial repercussions of ethical behavior.

However, in the March 1990 issue of the SSIT periodical Technology and Society, the SSIT President raises the editorial question "Why this paucity of cases [before the Member Conduct Committee]?" [6] One reason is that education and reeducation are needed. Merely publishing a Code of Ethics does not make it ipso facto a part of the workday of every engineer.

What's Needed

Following are some proposals for engineering ethics education.

1. Establish an Engineering Oath Modelled on the Hippocratic Oath. In the context of his dialogue with Daisaku Ikeda, Arnold Toynbee writes "In the age of technological civilization, education in the right way to live needs to be supplemented by vocational training in special branches of knowledge and kinds of skill. But before entering his profession, everyone who has received professional training ought to take the Hippocratic Oath that is prescribed for entrants into the medical profession. Every entrant into any profession ought to pledge himself to use his special knowledge and skill for serving his fellow human beings and not for exploiting them. He should give his obligation of service priority over his incidental needs to make a living for himself and his family. Maximum service, not maximum profit, is the objective to which he should dedicate himself." [7]

This oath should be developed through wide-scale professional dialogue throughout IEEE, related professional associations, engineering schools, and technical institutes, so that as many people as possible have the opportunity to participate.

2. Increase Requirements for Courses in Ethical Engineering and Effective Communications. We will need to modify the curricula of engineering schools, and the on-going training of the engineering work force, to include training in ethics. We need to put engineering ethics on the map, make it part of the engineering culture, what it means to be an engineer. These ethics courses -- one per year, including graduate school -- can be based on actual case studies, such as the study of the Challenger disaster included in this paper, and can use role playing to explore the dynamics of cases that have come before the Member Conduct Committee sponsored by SSIT.

Also included in the ethics curriculum should be training in the communications skills and political skills necessary to press a point and be heard in a complex organization.

3. Provide On-the-Job Training for Practicing Engineers. In addition, the Education Society can sponsor the development of on-the-job training programs and continuing education programs on the subject, and can advocate a special column be devoted to the subject in such widely read periodicals as IEEE Spectrum.

4. Support the Total Quality Management (TQM) Movement. As the TQM movement has the effect of creating more open communications in the workplace, and empowering the individual worker, it is related to the ethics movement and should be encouraged.

Conclusion

Let's educate engineers rich in humanity, full of vital life force, who will wholeheartedly develop value creative engineering and technology to serve the needs of the people; and who will rise up to challenge any abuse of technology that endangers the people.

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