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"NEW MACHINES, OLD PROBLEMS"

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In 1981, Samuel Florman wrote a book which should be required reading entitled, "Blaming Technology: The Irrational Search for Scapegoats". In the last chapter, Florman notes that Ben Franklin was much concerned with problems associated with technology and busy finding technological ways of alleviating these problems. If he had pursued the history of technological problems, he might have concluded as I have that there are generic problems associated with technology which have changed little over time. For example, Franklin was concerned about the increase in dwelling fires as a result of the change from log cabins to frame construction. This clearly falls into the category of side effects. This paper explores the concept of generic problems using examples from aeronautics. As a preliminary, however, it seems appropriate to define technology and briefly to enumerate the classes of problems.

Technology

Technology is a combination of knowledge and know-how that enables us to accomplish material tasks. For example electronic technology enables us to build radios, radar, TV, computers, etc. Technology is not itself a product but rather a skill or set of skills which enable us to produce goods which satisfy needs. If all of this has been done with great insight -- or luck -- there will be a market for the product and we have a technological business.

Technology has a long history. Perhaps the first technology was agriculture in the Nile valley about 4000 B.C. Certainly the first stone building, also in Egypt, dates from 2500 B.C. From these, beginning technology has evolved in fits and starts and with some regressions. Civilization has gone through the bronze age, the iron age, the industrial revolution, and other landmarks of technology. Since the beginning of the nineteenth century, however, technology has had two recognizable major ingredients, science and know-how. In this context science is codified knowledge about how the universe works, while know-how represents experience, the trial and error efforts that teach what works and what doesn't. In the last two hundred years, the mix of science and know-how in technology has shifted in the direction of science. The Erie Canal was built almost entirely on the basis of know-how. The Boeing 767 was built mostly on the basis of science. This is an exceptionally clear contrast and exemplified the change. However, there are areas where know-how still dominates and we must be careful to preserve the crafts.

"High technology" is a buzzword heard everywhere. Some think it's a panacea, others think it's a curse. But if you ask what it is you get a variety of mutterings which seldom help. Fortunately the evolution of technology itself provides the answer. High technology is technology in which science dominates to the extent that it would be difficult if not impossible to develop the technology without science. There has been a continuous evolution toward truly high technology with the first examples probably being electronics and aeronautics. In both cases development started around the turn of the century and what characterizes them as high technology is the difficulty in making progress

without science. The Wright brothers for example are often characterized as inventors, but they were also practicing scientists. Among other things, they operated a small wind tunnel and made meticulous measurements of lift and drag both in the tunnel and in full scale machines. Without this scientific effort the first powered flight would certainly have occurred later and probably somewhere else. In electronics the marriage occurred in a similar way but more people were involved. An early advance was the description of vacuum tubes by a small set of numerical parameters and in more detail by a set of graphs. Resonance and feedback were two critical concepts which are really comprehensible only in mathematical terms. Both aeronautics and electronics have progressed to the point where the technologies could not exist and certainly could not progress without science. My list of high technologies is short. There are only two others, nuclear technology and biotechnology. This short list has the implication that there is a much longer list of low and intermediate technologies. This is indeed true and these other technologies should not be deprecated. The net contribution of the high technologies to our way of life is almost certainly far outweighed by the contributions of the other technologies.

Technology has associated with it problems of various kind. The most visible class of problems comprise side effects, that is, effects outside the mainstream of the technological effort. The dwelling fires which concerned Franklin fall into this category. Two major side effects are pollution and occupational health and safety problems. So much has been said about both of these that it's probably unnecessary to say more here. Both must be addressed and both must be avoided, but

even with our best efforts, I'm sure that future generations will find problems we have not anticipated. I only hope that they will be few and that they won't be calamitous. There is another side effect that has received less attention and that is the erosion of information security by the ubiquitous computer. With enormous amounts of valuable information stored in computer memories, "hackers" and outright thieves have opportunities to access that information electronically for fun or profit. This is clearly a worrisome side effect. It has in turn led to new technology for computer access, new legal concerns and even new thinking about ethics. Certainly other side effects occur and anticipating all of them is difficult. We must try, but we must not let concern for unknown side effects lead to paralysis.

A second group of problems stem from the fact that technology is difficult to understand. This difficulty provides great scope for charlatans, swindlers, profiteers, and all kindred spirits. Technology has had at least its share with making gasoline out of water and perpetual motion machines leading the pack. The difficulty in understanding technology also leads to irrational criticism, irrational expectations, and irrational fears. The criticisms are often based on failure to anticipate changes or the expectation of error-free performance. All three kinds of irrationality can be reduced by improving the technological literacy of the public. In a technological world, it is no longer enough to be able to read and write. It is also necessary to understand enough of technology, how it is developed and how it is used to be able to form independent, rational judgments about technological issues.

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The final group of problems stem from the difficulty of balancing vision against realism. On the one hand, many projects have failed or at least been placed in jeopardy because they were overoptimistic. Howard Hughes' Spruce Goose and the nuclear powered airplane are two quite different examples. On the other hand, failure to exploit technology has been equally troublesome. The U.S. Army resisted the airplane. The Navy resisted steam. A famous locomotive manufacturer failed to exploit diesel engines. He went out of business. The examples are legion and lead me to the final extreme, the reactionaries. TRW ran a wonderful advertisement in many national magazines which, by simply quoting some well-known people, makes the point much more eloquently than I could. These quotes don't all bear on technology but they're too good to miss.

Lord Kelvin, 1895 - "Heavier than air flying machines are impossible."

Charles H. Duell, 1899 - "Everything that can be invented has been invented."

Robert Millikan, 1923 - "There is no likelihood man can ever tap the power of the atom."

Harry M. Warner, 1927 - "Who the hell wants to hear actors talk."

Grover Cleveland, 1905 - "Sensible and responsible women do not want to vote."

Tris Speaker, 1921 - "Ruth made a big mistake when he gave up pitching."

These are some illustrations of the problems of technology. We must try to avoid problems, especially the deadly ones, but we must also continue to move forward with reasoned progress.

Technology also has benefits. Very few of us want to go back to gas lights, iceboxes, horse-powered transportation, doing arithmetic with a pencil and paper, or simply pushing a lawnmower. Giving up just these things would be a rude cultural shock, and the list only scratches the surface. I believe that the vast majority of the world population wants to preserve the technological benefits they have. In fact, I believe they want to extend and expand those benefits. Responsible leadership must, however, temper these aspirations with a concern for harmful side effects and risks associated with technology.

The problems which come with new technology sometimes seem to be brand new, but close examination often reveals they are only new versions of the rather small number of generic problems just noted. The development of aeronautics in the U.S. provides a fertile field for illustrating this point.

Problems and Progress in Aeronautical Technology

The monumental achievement of the Wright brothers in 1903 was not the beginning of aeronautics in the United States but their efforts clearly mark aeronautics as high technology. Their success was greeted with some enthusiasm in the United States but the Europeans went wild. The U.S. military was relatively slow to acquire their first aircraft. But finally in 1907 specifications were issued (one page) and to cut a fascinating story short, the Wright brothers delivered an airplane (flying machine) to the Army in 1908. It crashed, but was rebuilt and delivered to the Army in 1909. The Army finally had an Air Service as part of the Signal Corps. In December 1909, Lt. Benjamin Foulois [illegible] also has benefits [illegible] resources [illegible] lowered than [illegible] with a general [illegible] these things would be a race cultural [illegible] that the vast majority of the world [illegible] able to preserve the technological [illegible] wants to extend endeavors, these benefits. Resources [illegible] leadership must, however, temper these aspirations with a consideration [illegible] side effects and [illegible] associated with technology.

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By the end of 1916, 142 aircraft had been delivered to the Army. In the first three months of 1917, 82 more were delivered. None of these qualified as a combat aircraft, they were all trainer or observation types. This in spite of the fact that WWI had been underway for over two years. For comparison during WWI the British put into service 27 different types of single seat combat aircraft, and the French 31. The U.S. aversion to a standing army had something to do with this, as did isolationism, but it seems like less than adequate preparation even on a pure contingency basis. In April of 1917, the U.S. became

a combatant in WWI. What did the allies want from us? Troops, of course, but in the air warfare arena they wanted planes and engines. The fact that we had no indiginous designs for either and no significant aviation industry to produce them did not affect the request.

The response to this request was mixed. The Congress provided appropriations totalling over a billion dollars. Hall and Vincent designed the Liberty engine and put it into production in a very short time. Thirteen thousand of these engines were produced before the end of 1918. With airframes there was less success. The JN-4, Jenney, was produced very satisfactorily and many Army aviators learned their trade in it. The closest we came to producing a combat aircraft was the British designed DH-4 adapted for the Liberty engine. Most people describe the DH-4 as an observation aircraft. In passing DH-4 contracting produced one of the first high technology conflict of interest cases. Colonel Edward Deeds awarded a contract to Dayton-Wright for DH-4's before they had either plant or capital. The conflict of interest came about because of Deeds' former financial interest in predecessor organizations of Dayton-Wright. This later led to the Hughes investigation which was among the first of a long series that have continued to this day. What then did the U.S. do for combat aircraft? They simply bought them from the French, the British, and a few from the Italians. Rickenbacher did most of his flying in French Nieuport 28's and SPAD XIII aircraft. From these comments the outline of some problems can be perceived. The reactionary establishment at least trying to catch up; difficulty starting up new high technology production; more generally, the slowness

of industrial mobilization; conflict of interest in a small community. Spare parts were not a big problem and the reliability and durability of American aircraft had improved enormously since Foulois' problems in Mexico.

It would be interesting to continue in this generally historical style, but the presentation would be much too lengthy. It is more convenient to switch to an examination of classes of problems, illustrated with examples from aeronautical technology. Before starting this, however, it is worth noting some of the great successes of the interwar years. The years from 1919 to 1927 enhances our knowledge, but aeronautics was still something of a backwater. Lindberg's dramatic flight in 1927 produced a mini-boom in the aviation industry and correlates, perhaps only incidentally, with the beginning of U.S. ascendancy. Subsequent to 1927, high power radial engines developed rapidly and with them heavy aircraft, the Boeing 247, the Douglas DC-1, DC-2, and DC-3, and the Boeing B-17. The last two flew in 1935 and epitomized the state of the art in heavy aircraft when WWII began. The U.S. was preeminent in radial engines and heavy aircraft, but Britain, Germany and unknown to us Japan all had better fighters. From this time on, however, the U.S. has been preeminent in some aspects of aeronautics.

All through the development of aeronautics problems have arisen. In my opinion these problems arise, as they do in other technologies, for a limited number of reasons. The first is that technology, especially high technology, is difficult to understand. Any business arena whose basis is hard to comprehend attracts some individuals with questionable

scruples and opens the door for fraud, waste and abuse. Profiteering between the wars led to profits for Pratt and Whitney (Col. Deeds was again involved) as high as 36% of sales on Navy business and for Boeing over 20%. I have found no record of redress or punishment for either firm, but Consolidated Aircraft whose rate of profit was much smaller was compelled to sell 50 trainers to the Army for one dollar each to compensate for excess profits. Reuben Fleet said that doing business with the Army was the only thing that he had done wrong. The early years of WWII saw some profiteering with perhaps the most notorious case being Jack and Heintz in Cleveland. They were making a profit in excess of 60% on aircraft starters and strongly resisting efforts to negotiate lower prices. Congress solved this problem with the Renegotiation Act which served to limit profits and remained in effect in one form or another until 1978.

Limitation of profit, however, removes an important incentive for economic efficiency. The standard American solution is competition. Competition is often beneficial, but occasionally it backfires. Just after WWI procurement officers discovered a new way of getting competition in aircraft procurement. They inserted in such contracts a clause giving the government a non-exclusive license to the design. The Army could then compete procurement to a specific design. This was not done very often, but I have been able to find three cases which probably have never all appeared in close proximity before. In 1921 Boeing won a contract to produce 200 planes to the Thomas-Morse MB-3 design. The results were good planes; Boeing got out of the furniture business;

and Thomas-Morse faded into obscurity. Curtiss won a contract to produce "the best pursuit then available", the Orenco D. The results: a heavy plane, three dead pilots, all 50 planes wrecked or scrapped as not fit for service, and the demise of Orenco. The Martin NBS-1 bomber was also produced under competitive procurement by Curtiss, LWF and Aeromarine. The result: three subtypes of NBS-1s with parts that were not interchangeable; Curtiss lost $200,000 on their contract; the other two were so weakened that they quit business. Sourcing aircraft from two or more manufacturers was not tried again until WWII and then it was manufacturer-to-manufacturer licensing. For example, Consolidated licensed Ford to make B-24s and, incidentally, received a royalty. More recently second sourcing with a leader-follower concept has been used with considerable success. The conclusion is not that competition is bad, but rather that in procuring complicated systems it must be used wisely.

The difficulty in completely understanding technology also affects the practitioners. The most spectacular cases are unanticipated failure modes. For example, the fatigue failure of the skin on the Comet led to explosive decompression and loss of several aircraft. Another example was the in-flight structural failure of the Martin 202 wing. This and the mediocre showing of the Martin 404 compared to similar Convair types caused Martin to abandon the commercial aircraft business.

Perhaps the most interesting and pervasive problems stem from the difficult balance between vision and realism. This is a judgmental issue of considerable sophistication, and unfortunately the Monday quarterbacks all too often overlook the difficulties and content themselves with criticizing the errors.

Overoptimism is one kind of problem of this class. This can be technical as was the case in basing the entire U.S. liquid-cooled aircraft engine program on the success of the turbocharger. Another case was the building hard tooling for the F-102 before wind tunnel testing had been completed. Overoptimism can also invade production planning for high technology systems. This occurred in the manufacture of DH-4s during WWI and T-46s very recently. It is worth noting that in recent years many computer products have been delayed in production. This kind of overoptimism is not only a problem of aeronautics. Finally, overoptimism seems also to have played a role in assessing the market for the Concorde.

The converse to overoptimism is failure to exploit technological opportunities. This failure is seldom total, but it leads to delays which can cause major market problems or military inadequacy. Some examples are the very early U.S. failure to exploit aviation for military purposes, the failure to develop and exploit jet engines in the mid-forties, and slowness to develop ballistic missiles.

Other problems stem from failure to appreciate technical risk. In high technology development much depends on correctly estimating what will be available at some future time to satisfy specific requirements. There is always the risk that these estimates will be wrong and if the required advance is large then so is the risk. The first round of development of cruise missiles (in preference to ballistic missiles) was almost certainly based on an erroneous estimate of how rapidly navigational systems would develop. There was no alternative and the first cruise missile program was quickly abandoned.

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Related to both technical overoptimism and failure to appreciate technical risk are problems which stem simply from an insufficient knowledge base. This is the realm of the "unk-unk", the unknown unknown. Many of the early aeronautical failures stemmed simply from an inadequate knowledge of aerodynamics. As speeds increased to the low transsonic range, aircraft encountered new and then un-understood phenomena. A number of P-38s were lost because of loss of control in high speed dives. The problem was solved empirically but not really understood until later. The F-102 was designed in ignorance of the constant area rule. A major redesign was required to take this into account. As a result, 20,000 items of hard tooling were scrapped.

Thanks to the environmentalists at least some of our final class of problems are well known. These are the side-effects. Prominent among them are environmental and health effects. Aeronautics has, however, been remarkably free of such problems. Noise is sometimes serious, and the usual run of industrial health issues are important, but this is largely the extent of the problems. Systematic impact studies and OSHA surveys seem to keep both under control.

An interesting side effect which seems to be preferentially associated with aviation is terrorism. Why airplanes and airports are especially attractive to terrorists is something I can only speculate about. The vulnerability of passengers in planes and the crowds in airterminals may make especially attractive targets. In any case, I doubt that any amount of analysis would have led to the anticipation of this side effect.

These classes of problems: those arising from the difficulty in understanding technology; those stemming from the difficulty in balancing vision and realism; and side effects pervade the history of aeronautics and other technologies as well. We have slowly found methodical ways of dealing with some of them - fault trees, impact assessments, and others. If one could find a way of quantifying the problems and quantifying the technological advanaces I believe that the ratio would show a decline over the past hundred years; that is, less difficulty per unit benefit. Perhaps it doesn't seem that way, but the issue must be viewed from a perspective where major advances of twenty years ago are elementary today.

On the other hand, this long littany of problems is somewhat depressing. But there is a good side to it. To see the good side just ask yourself what you would give up to avoid the problems. Furthermore, most of the problems are the almost inevitable result of doing something new. All-in-all, I feel that the benefits of technology far outweigh the problems, but nonetheless responsible leaders must do their best to anticipate and alleviate the problems. I'm reminded of two comments. Michael Collins (the former astronaut) said, "But the only way to be 100% sure of avoiding air accidents is to stay on the ground.". Also, in response to a complaint about the noise and smell of automobiles and streetcars in New York City it was pointed out that if transportation still depended on horses, then the entire population of the city would be occupied in removing manure.