As originally written by Shea. Compare with transcript of tape.

Voltaire credited with "The better is the enemy of the good." 17

THE GODDARD LECTURE

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In preparing for this lecture which bears Dr. Robert Goddard's name, I [illegible] particularly impressed by two passages found [illegible] his autobiography.[1] The first is a quotation from his high school valedictory address: "It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow."

The second is the last paragraph of the book. In 1919, [illegible]lished for the Smithsonian a paper in which he described the early rocket work he had done for the Institution and included supplementary notes on a number of topics, some of which were picked up and used in the press to make "of the paper the first real suggestion for contact between the planets."

Dr. Goddard was apparently either annoyed [illegible]ed by the fuss thus created, and goes on to say:

"From that day the whole thing was summed up in the public mind in the word 'moon-rocket', and thus it happened that, in trying to minimize the sensational side, I had really made more of a stir than I would if I had discussed transportation to Mars, which would probably have been considered ridiculous by the press representative, and doubtless never would have been mentioned."

This talk occurs at a time when his dreams have long since become the reality of today, but when the "sensational" side of our "moon rocketry"

causes a stir in the press which is, to my mind, rather out of proportion to the significance of any single event--no matter how tragic.

I shall try to lend some perspective to recent events by discussing, not the Apollo program itself, but, rather the interrelated themes which form the backdrop for technological development in today's society. Various aspects of these themes will be traced through some of the paths along which the history of technology has evolved. The concluding remarks will attempt to interpret what the lessons of history imply about the space program in particular--and, if it not sound too presumptuous, about the class of problems which this nation faces, both within and outside its borders, in its classic struggle to maintain the position of a free society in a free world. A world in which technology is playing an ever increasing--but far from dominant--role.

Montaigne observed[2], "That arts and sciences are not cast in a mold, but are formed and perfected by degrees; by often handling and polishing as bears leisurely lick their cubs into form." That thought threads through the seven main points about technology, both its relationship with the society it serves as well as the problems inherent in its development and application, which form the backdrop for this talk.

The seven main points are:

Firstly, the technology has always progressed for one of two reasons;

a. in response to specific recognized human needs,

b. as a result of intellectual curiosity which prompted, perhaps an individual, perhaps an organization, to recognize inadequacy in the body of knowledge which had been accumulated up to any particular point in history--and to expand the

the frontiers of knowledge just for the sake of understanding better the physical--the intellectual--universe.

The increased depth of understanding provided by this kind of exploration has, in general, been in advance of any specific need, but usually found its applicability in setting the basis for fulfilling the--at the time--unanticipated needs of mankind.

The increased understanding has also surprisingly quickly found its way into the pattern of human thought--expressed in one of but many ways in the classical literature of each age.

This, perhaps, is the true meaning of the phrase interdisciplinary, which really represents an appreciation of the fundamental intersection of the areas of significant human endeavor which must be correlated to truly understand the advance which organized society has made up to any particular phase of history.

The second idea is that periods of technological advance, for whichever of the above reasons they happened, have usually been followed by eras in which, for one reason or another, society has concluded one of two things--

a. Either the body of knowledge at each level of society (and of course knowledge is a function of where you are in the social structure) is considered essentially complete, or if not complete, at least sufficient to the designs or the intent of the society at this particular point in time.

b. Society in general fears change for one reason or another, and this reflects itself in a conviction that all conceivable

needs are actually fulfilled.

These periods, characteristically termed the "Dark Ages", have recurred throughout recorded, and I suspect even the yet unrecorded evolutionary history of the human race. Fortunately, they have been superseded by periods of enlightenment in which some of the most significant advances, both in application and in future knowledge, have taken place.

The third point is that, at least in technology, the projects--and in general, even the fundamental research--has progressed from something which one individual did completely by himself, to experiments carried out in small laboratories by closely knit teams. Then, as the industrial revolution and the demands of an increasingly organized and interdependent society began to really require technological advance, we put into today's dramatic expansion beginning sometime in the 19th Century, and the size of laboratories increased. Companies, industries, then nations, and perhaps ultimately the world--sponsor increasingly complex projects which will have, as their purpose, the attainment of a specific goal.

The increased scope of activity and the compression of time in a technologically exploding world have transformed such large projects from the efforts of a single individual to the organized contribution of hundreds, thousands and perhaps ultimately even millions of individuals who are often geographically, as well as intellectually, separated. The challenge this represents for responsible management is perhaps obvious--but will be touched upon again in the summary.

The fourth idea is that progress is never made without problems. There

is a price for progress. The history of technology is studded with ultimately successful projects which have experienced setbacks for one of perhaps several reasons:

a. The body of knowledge--call it scientific principle, design know-how, materials, organization--available at the time of the initiation was not sufficient to permit attainment of the particular goal intended. In a phrase, invention or a scientific breakthrough was required.

b. The body of knowledge was sufficient--in other words, the fundamentals were there--but the understanding of that available information was imperfectly applied. In other words, either the system concept or the detailed design was not as good as it might, in retrospect, have been.

c. The implementation of the design--in other words, the translation into hardware--did not faithfully reproduce the design intent. In our terms, the "as built" hardware had defects.

d. The checks and balances which should be applied in a reasonable management structure to guard against any of the above three were either inadequate or imperfectly applied.

The fifth theme of the topic is that the element of society for which the development was being done--which the development was attempting to serve--did not sense either the immediate or future implications. The sponsoring organization failed, perhaps, to integrate such implications with other problems with which it was also struggling.

A sixth point, which you will see in the anecdotal illustrations, is that the expansion of technology--particularly in areas of transportation and communication--has played a significant role in the gradual evolution of organized society--from caves; to tribes; to cities; to states; to nations; to continental entities, and perhaps, ultimately, to a single world.

The seventh and last point, which we will come back to many times in the remainder of the talk, is that simplicity is a virtue; not a vice. That which has worked well before should indeed be the starting point for any new venture.

With the preceding montage of thoughts as a backdrop, I would now like to illustrate the points with a potpourri of examples gleaned from a random sampling of "The History of Technology", and other sources, duly referenced in the bibliography.

To start with, let me make the point that one thing which distinguished man from all other products of evolution--at least on this earth--is the use of tools and a search for knowledge. Probably the first tool was either a stick or some rock which happened to have a useful shape. Research done recently by the National Geographic Society has shown that even primates--chimpanzees in particular--were smart enough to use tools available to them.

Dr. Leakey, at the Olduvai Gorge, under the sponsorship of the National Geographic Society, has discovered the earliest manlike civilization yet found, that of the Zinjanthropus, a tribe which developed a hand ax culture. Again, these first humans just used whatever stones came to hand. Relatively soon, however, the Zinjanthropus recognized that when he did something like striking two rocks together, he would occasionally produce a stone of useful shape.

To provide some perspective to the pace of development in those days, you might note that some 200,000 years elapsed during which the hand ax evolved from what one might call an individual development effort to a tribally supported effort. During that time people learned how to manufacture several varieties of hand axe. Through the knowledge of materials and manufacturing techniques, man could produce intentionally, not on a random basis, a family of artifacts which could be used in a variety of ways, all still controlled by the human hand.

The other natural weapon or natural tool for man to use was an elongated piece of material--wooden sticks, animal bones--devices which extended man's reach and provided some mechanical advantage above that of the human arm. Eons and eons elapsed before stone and stick were conjointly used to produce the first hafted utensils.

Such developments are extremely dependent on the materials available and the techniques of fabrication developed in prior cultures and evolved as the new materials and physical understanding emerged. The ax, and most other common tools, can be traced through stone age culture, to the iron age, the bronze age, and on up to the present day.

But even with that long history of development and use experience, ax handles still break, heads fly off, or people injure themselves by unskilled operation.

One might observe that this first development project started somewhat as a hit or miss proposition--and many programs today still appear to be a chip off that old block.

Another fundamental development which can be traced through recorded history is the bridge--a device responsive to the fundamental need to cross gaps in the earth--rivers, gorges--as man began to expand his geographic frontiers beyond the environs of his particular cave.

Here again, the first bridges were undoubtedly structures accidentally provided by nature--perhaps a tree felled across a stream during a storm or some eager beavers. But what nature could provide by chance, man could reproduce by intent.

From felled trees to more complex wooden devices, to stone structures, again required eons--but many examples of well constructed Roman bridges still exist today--archaic as they seem in light of today's knowledge of structural design principles and materials.

One of the major advances in the concept of bridge design was the use of

a single arch to span the entire gap--obviating the need for supports in the center which could obstruct river traffic or be subjected to heavy loads in times of flood.

At least as early as 1500, Leonardo da Vinci understood the principle of the arch quite well. His notebooks contain sketches of experiments which show essentially the way in which the loads are reacted at the foundation and transmitted along the structure. He apparently carried out several small scale experiments which convinced him that his theories were correct.

Indeed, he was so confident of his ability that he proposed in 1509 to the Sultan of Turkey to construct a single span bridge across the [illegible] span would have been some 900 feet, with an arch height of 180 feet. [illegible] depth at the crown was some 30 feet. Altogether, the structure would have utilized about three quarters of a million tons of stone.

Such a project would be impressive, even today. Apparently it was too arch for the Sultan, and he and Leonardo never really got around to talking Turkey--the straits remaining unspanned until

One bridge with an interesting history in line with our central themes is the Pont-y-Ty-Prydd in Wales. In the mid-18th Century, who was both a farmer and a minister, proposed to his local community to build a bridge across a stream which was difficult to ford--particularly during times of flood. A contract was negotiated in which he agreed, for the sum of [illegible]00 pounds, to construct the bridge and maintain it for a period of seven years.

His initial design consisted of several short spans, with attendant supports in the river bed. The bridge stood for about a year and a half before a heavy flood washed out the center supports and destroyed the structure.

Recognizing that his problem was the load which the flood waters put on the pilings--and probably still wanting to earn his 5000 pounds--he redesigned the structure into a single span. With the help of a friend, construction of the new bridge began with foundations at the river banks. Scaffolding was required in the center of the stream until the arch was closed and could support itself. Unfortunately, just before the structure was completed, a flood washed out the scaffolding and again the structure was destroyed.

must have been a particularly tenacious man. Not daunted by the event, they rebuilt the bridge to the new plan, completing it at a time when the water level was fairly low. About three or four months later, however, in November 1752, the flood level rose once more. This time the foundations for the arch washed out and again the bridge was no more.

must have considered persistence a virtue, and was also perceptive enough to realize the deficiencies in the design of the foundations. The project was started for the fourth time, completed, and the bridge still stands today. It is used as a foot path and is paralleled by a more modern structure which handles modern vehicular traffic.

Persistence, perception, and finally a solid foundation ultimately produced the desired results. As an interesting aftermath, although he must

have lost money on that first contract, the ultimate success earned him a reputation as a builder of good bridges. He was invited to design and construct bridges all over England. Thus, the understanding so hard won on that first project resulted in many opportunities to recoup his losses and earn from his experience.

Perhaps the next major conceptual advance was the suspension bridge, which could utilize modern materials--metal cables, steel and concrete. As materials improved and the theory of design became better understood, spans became longer and longer and the mass of the structure lighter and lighter.

A classic example of the evolution of such design refinement into an entirely new (to bridge builders) physical problem is the Tacoma Narrows Bridge, which collapsed in spectacular fashion in

Original stops also at this point

This is the original

In the sixteenth century a major revolution was taking place in scientific thought. Copernicus, a Pole, who was a pole apart from conventional thinking, theorized that the sun, not the earth, was the center of the solar system. The world was slow to accept so radical a thought. The theory was complex, and few understood it. But the main reason for rejection was, perhaps, that it placed the world, and consequently man, on a less central place in the order of things. In the long run, this humbler status has undoubtedly helped us to put our existence on a sounder philosophical basis.

Acceptance was slow, and accompanied by some persecution of those who espoused the new theory. One of the most prominent of these men was Galileo who, in 1609, made accessible two instruments that had the profoundest influence on the subsequent development of science, the telescope and microscope. His earliest discoveries with the telescope were issued in a little pamphlet of 24 pages, his Starry Messenger ("Sidereus nuntius") in 1610. There are no 24 pages in all scientific literature that contain more important revelations.

The first half of that famous booklet is occupied by observations on the moon. The surface of the moon, far from being smooth and polished, as it appeared to the naked eye, was now seen to be rough, with high mountains and deep depressions. The latter Galileo interpreted as rivers, lakes, and seas. From the shadows of the illuminated mountain tops he could estimate the height of some of them. He found them to rise four or five miles above the general level.

Galileo's lunar observations have an interesting relationship with English literature. In 1638 he was old and blind and nominally a prisoner of the Inquisition at Fiesole. He was visited there by Milton. The incident

inspired several artists and writers. In 1658, sixteen years after Galileo's death, Milton began his Paradise Lost, completing it in 1665. Its cosmology is deliberately Ptolemaic, not Copernican. Nevertheless, Paradise Lost does recall the poet's induction into the new astronomy twenty-seven years previously. It describes Satan's shield of which the

> broad circumference
> Hung on his shoulders
> like the moon, whose orb
> Through optic glass the
> Tuscan artist views
> At evening, from the top of Fesole,
> Or in Valdarno, to descry new lands
> Rivers, or mountains, in her
> spotty globe.

(Paradise Lost, i. 286-91)

The freedom of scientific thought brought about by the theories of Copernicus and the observations of Galileo was one of the major lights which led the world out of the dark ages. This scientific revolution has continued unabated ever since, and has been a most significant factor in shaping the twentieth-century world.

As Lord Hailsham, British Minister of Science, stated recently in a speech on "Society and the Sciences," it does not take a scientist to see, or to say, that the human race is in a state of crisis--and that, unlike

all previous human crises, the nature of the crisis is such as to affect not simply human groups or institutions but the entire life and condition --perhaps the survival--of the human species on the planet.

"For this, of course, the responsibility lies upon the progress of technology, the application of organized human knowledge to the processes of manufacture, distribution, transport, and the dissemination of ideas. It is this which has revolutionized human life in a matter of generations; it is this which has confronted at last the widely separated branches of the human family in almost infinite contiguity after long eons of separation. It is this which has organized the possibility of mass annihilation by the evolution of the sophisticated guidance systems of modern rocketry and the immensely destructive powers of modern fission and fusion.

"It is therefore this--and the intriguing possibility that science may afford even more challenging prospects of agreement and cooperation--a way out, as it were, of the ideological impasse through understanding and cooperation on technological essentials which can lend significance and hope."

One of the most significant possibilities for controlling cost and maintaining schedules within a research and development program is the reasonable--I'm tempted to say rational--interpretation of requirements, particularly specifications and quality control documentation and procedures.

The detailed specifications with which we control most of the systems in a spacecraft are an interesting admixture of essential requirements--those without which the lunar landing could not be safely accomplished--and convenient requirements--things which need to be specified for completeness, but whose absolute values are intended to represent reasonable practice rather than essential performance.

In circumstances where convenient requirements are not met--either in qualification test or in acceptance test on individual flight units--but where there is no failure to perform functionally, it is usually in the best interest of the program to accept the as designed or as built condition of the hardware, rather than force either redesign or rework, with attendant cost and schedule problems. The key to implementing this general philosophy is an awareness at appropriate levels in the program of the "real requirements" inherent in placing a man on the moon in this decade, and an open technical communication channel from subcontractor to the prime, and from the prime to NASA. This information flow, prompt awareness of problems, and a recognition that waivers or specification relief can really be in the best interest of the program are essential to the kind of quick reaction capability we will need to help the Apollo spacecraft through the next several months of critical testing and manufacturing.

Of equal importance with the specifications is the world of quality control, particularly as it interacts with the manufacturing process. The NASA has issued a set of documents--the so-called 200 series--which delineates the general requirements of a quality program. The documents permit a relatively wide spectrum of interpretation, and we have noted a tendency for contractors to overreact, creating cumbersome inspection systems, awkward decision-making processes and much unnecessary paper.

Here again, interpretation must hark back to the real requirements--which in this are ca be stated as:

1. Assure that the hardware is made in conformance with the drawings.
2. Assure that good practices are used in processes.
3. Assure that deviations in configuration or performance are noted and either corrected or deemed acceptable by responsible personnel.
4. Provide a record of the deviations for future review.

Key to efficient operation in this area is the proper balance of things like mandatory inspection points, the working relationship between company and government inspection personnel, and, particularly, an effective material review procedure in which decisions are made, whenever possible, when the problem is first discovered; the paper cycle becoming a documentation of action taken rather than an in-line element between problem identification and ultimate correction. To this end, we encourage the use of engineering dispositions, "on-the-spot" engineering orders, waivers of unimportant non-compliances, standard repair techniques, and reasonable interpretation

of detailed process requirements (i.e., the soldering specifications).

I would emphasize that we are not asking for lower quality hardware--rather we are seeking a focus on those elements of the quality control process which do in fact contribute to the ability of the hardware to perform its intended mission reliably, rather than the trivia which all too often creeps into a program and focuses on cosmetic details, redundant paper work, and ultimately creates a system with much form but little content.

The above statements are unfortunately very general, but they arise from examination of many real problems which need not have plagued the program had they been handled rationally. I would emphasize that what we want is content, not form, and that the NASA has an open mind on the interpretation of requirements or procedures which the contractors feel are restricting their performance without contributing to the improvement of the program.

Only by review at each level can this type of problem be flushed to the surface. We have the common goal of assuring that all effort spent on Apollo is truly efficiently directed toward our one ultimate goal.

The above philosophy can be summed up in a phrase which appears, at least in Voltaire, and can probably be traced back much further in the evolution of human thought: "The better is the enemy of the good."

This statement, without sufficient amplification by example, can perhaps too easily be misinterpreted as not asking for the very best.

Some examples are so obvious that no questions arise--perhaps the wrong shade of paint or some minor scratch.

But there are many subtler things--instrumentation off by a few percent; engines which don't quite meet the original performance specifications but which will still do the mission if the overall system design

is rebalanced by modifying trajectories or weight allocations or carrying more fuel.

Such utilization of the products of the development process by rebalancing the system design is an essential element if a program is to meet its objectives economically and when required.

The rebalancing I term dynamic systems engineering.

But because living with the original specifications or someone else's requirements is intellectually easier (and safer, because you never have to remake a decision), the decision maker is vulnerable to a perhaps inevitable second guessing.

The definition of and focus on the "real requirements", frequently results in significant modification to the original systems approach as specific hardware problems arise in the course of development. The resultant decisions can, occasionally, even be resented by those inside--or outside--the program whose favorite ideas are tried in this type of intellectual balance and found wanting.

Obviously, I have overexpanded the intent of this [illegible] but would like to finish by coming back to the future of Apollo.

The heritage of our program is too deeply rooted in the successful Mercury and Gemini programs and in the long development process which has brought Apollo to the threshold of flight for the event of January 27 to represent more than one of the many contingencies which we have tried to allow for in the overall planning of the program.

This slide, showing the earth and moon, taken from Gemini [illegible], is perhaps symbolic of its contributions to Apollo's thrust toward the moon. This next slide taken from the first unmanned Apollo atop the first Saturn I-B during the final count down before its launch in February _____ is perhaps symbolic of the fact that we will [illegible] be ready to fly on the Saturn I-B once the changes, which are now being under discussion and have been reviewed openly with the Congress, have been implemented.

In recent weeks, the Prometheus legend has been much in my mind and it seems to me that perhaps these lines which [illegible] Shelley's epic poem, Prometheus Unbound, represent the present spirit of our program as we press forward.

"To suffer woes which Hope thinks infinite;
To forgive wrongs darker than death or night;
To defy Power, which seems omnipotent;
To love, and bear; to hope till Hope creates
From its own wreck the thing it contemplates;
Neither to change, nor falter, nor repent;
This, like thy glory, "Apollo", is to be
Good, great and joyous, beautiful and free;
This is alone Life, Joy, "Nation", and Victory."