I have often asked myself what is the purpose, real or imagined, of an after dinner talk. In my own experience, I cannot recall ever having paid the least attention to an after dinner speaker and neither can the few friends I have whose veracity is not altogether dominated by their imagination. In trying to select a subject for tonight's speech, I inquired of a few collaborators, who had been present at previous Hydraulics Conferences, as to what were the subjects of the flow of oratory following the banquet. The answers resembled each other like drops from a leaky faucet (as you may notice, my simile is taken from the field of hydraulics). The highbrows went like this: "Now let me see . . . Sixth Hydraulics Conference . . . Ah, yes . . . Consommé à la Madrilène . . . I asked for some Chablis, Chateau Aragnac 1948, and was shocked when told: 'No wines' . . . then let me see . . . Poularde à la Parisienne . . . I could have enjoyed some Chateau Cos d'Estournel 1950 but for the rules . . . Crème glacée . . . Café . . . no, no liqueurs . . . a very witty speech by . . . yes, very witty, indeed . . . now, let me see . . . yes, I had a cigar too . . . a hand-rolled El Delicioso . . . but who was the speaker and what did he talk about? . . . no, sorry, ole chap, can't seem to recollect . . . been under a bit of pressure lately, you know."

The lowbrows expressed themselves somewhat less elegantly, but more picturesquely, like this: "Sixth Hydraulics Conference . . . Boy, did I get plastered that night (afterwards, of course) . . . I don't know nothing about no speech . . . You sure you got it straight? . . . Boy, what a head the next morning . . . I gave up drinking for three whole days."

Now such talk would ordinarily be enough to damp one's enthusiasm for such an enterprise as that of delivering a carefully prepared oratory to an unattentive audience. And if at this point one recalls the ageless words of Lao-Tse: "He who knows does not speak; he who speaks does not know," one's damped enthusiasm may well turn to fearful trepidation. However, there are two strong reasons motivating me to go through with my talk. The first is that I have a captive audience. There is nothing more heart-warming to a man who can never seem to get in a word, even edgewise, either with his wife at home (and who does?) or with his superiors at work. Of course, you will think, the audience can always slip away under cover of the soft shadows bathing the hall. That may be so, but the gentle-
men sitting at the head table are nailed to their chairs by their good breeding. The second reason is that I owe my charming host an obligation for the delightful dinner and I aim to repay it come ebb or high-water. (You will notice, of course, that this is a hydraulic metaphor.)

But I am in difficulty at the very start. In asking me to appear before you, Doctor Rouse made the condition that the talk should be both informative and entertaining. As to the latter, I was prudently warned that ladies would be present. Now this is a formidable set of boundary conditions to satisfy. In fact, I found myself in such difficulty only once before. It was during my high school days and I had been given the assignment to write a short story. To be complete, I had been told, a short story should have five qualities: it should be short, it should be slightly risqué, it should have suspense, it should have a noble quality about it, and it should be permeated by a religious feeling. After much fruitless labor I handed in my masterpiece: "My God!" (religion), said the Duchess (nobility) "Take your hands off . . . (3 points of suspension) my leg!" (that's as risqué as I dared be in those days). And it was short. My instructor, however, remained unimpressed.

But to return to my subject, if any. I shall appear to prove myself somewhat conversant with the science of hydraulics and, to this end, I will take my lead from our host.

A few years ago Doctor Rouse became the guest of Senator Fulbright and spent a happy year on the banks of the lazy Isère completing a manuscript on the history of hydraulics. It is a scholarly work, but unfortunately somewhat deceptive. Let me explain and, to this end, let me take up the story of Archimedes. As Dr. Rouse recounts it, it goes this way: "Hiero I, king of Syracuse, is said to have believed himself defrauded in the amount of gold actually utilized in the fabrication of his crown and to have placed the problem of proving the fraud in Archimedes' hands. The method of solution is supposed to have occurred to Archimedes as he entered the pool of a public bath, whereupon he elatedly left for home without pausing to dress, shouting as he ran, 'Eureka' (I have found it) !" The whole thing is so simple as to be obviously unreal. You are given a problem, you take a bath and, presto and ipso facto, you have the solution. With Americans taking a bath every day, it would seem that the country would run out of problems in practically no time at all.

Now, Dr. Rouse recounted the story as he had heard it and, by so doing, gave spur to an apocryphal legend which can bring grave danger to the research fraternity, if research administrators take it seriously. The picture is painted that between the posing of a problem and its ultimate solution there need pass only the time required for one's daily grooming. This is a subversive idea to be exorcised with bell, book, candle, incense, cabalistic phrases, and holy water. (The last, obviously, a hydraulic medium.)
Many years ago . . . I beg your pardon, a few years ago, when I was an undergraduate student, I was told about Galileo, who had discovered the law of the pendulum. This youth, namely Galileo, I was told, on attending mass one morning in the cathedral of Pisa noticed that when the verger lit the lamps from the chandeliers, they were set oscillating in isochronous motion, whereupon he conceived the law of the pendulum. This immediately gave as a corollary the law of falling bodies. He therefore set out to prove the latter by dashing across the square to climb the leaning tower, drop unequal weights from its top, disprove Aristotle, who had remained undisputed almost 2000 years, and demonstrate that Copernicus was right. All in all, a good morning’s effort.

But was it really so? I discovered in my later years that between the event of the swinging chandelier and the enunciation of the law of the pendulum almost half a century had passed and that, in the meanwhile, Galileo had fathered 3 children, discovered the moons of Jupiter and the Milky Way, had set up a telescope factory, the income from which had rendered him financially affluent, and had run into trouble with the Church. I suspected that the same might prove true with Archimedes. Having found out the real story about Galileo, I decided to inquire about the sage from Syracuse. The search was not easy, for legends have a way of becoming sacred with time, and the truth becomes buried in the dust of the ages. Finally, after assiduous ferreting and pursuing of ancient manuscripts bound in mildew, I came across the true story. It is very simple, hardly dramatic at all, and in essence no different from the story of many a living research scientist. I must tell it to you, for I am sure you haven’t heard it as yet.

It seems that Archimedes was professor of natural philosophy at the University of Syracuse. One of his students, the dullest in his class, turned in an examination paper in which he had given wrong answers to practically everything but especially to a problem in buoyancy, namely, “why do bodies float?” Archimedes promptly flunked him, for that was the ill-considered way students were treated in those days. But he remained somewhat puzzled and perturbed by the abnormal reply the student had made, for it had confused him no end. Finally he decided that there was one way to find out, so he submitted a research proposal to the local Office of Naval Research . . . I beg your pardon, of Science and Invention.

The objective of the proposal was to prove that Aristotle was right. This was a safe and uncontroversial inquiry. Archimedes stated that although Aristotle had enunciated a certain principle, namely, that the buoyancy of a body depended on its form, he had not sought to perform the experimentum crucis or obtain the functional relation connecting buoyancy and form.

To this end he proposed to weigh two bodies of the same material and
of different shape, both in air and in water, to establish the sought-for relation of buoyancy to form. Being a dutiful citizen professing homage and respect to his king, he chose the king's crown as the standard of reference, believing it (as it turned out, mistakenly) to be of pure gold. The first experiment proved to be completely and utterly inconclusive.

But he was of curious bent and, although baffled by the strange results he had obtained, he decided to inquire further into things by testing systematically all sorts of shapes and compositions.

At first he kept the composition constant, namely gold, and proceeded to test, to begin with, linear bodies such as tetrahedrons, pentahexahedrons, etc., all the way to pentacosiahedrons. He then went on with nonlinear bodies such as spheroids (both oblate and prolate), ellipsoids, hyperboloids, hypoboloids, ovoids, thyroids, paranoids, etc. From this he found out that the only metal form that would float was a concoid (referred to in some circles as a dish).

He then altered the composition systematically, starting with gold (for on account of its nobility it had precedence) proceeding to silver, iron, tin, zinc, aluminum, neptunium, uranium, plutonium, etc., and ending up with lead, because it was the basest of all. From this he found that the only material that would float was wood. But no matter how hard he tried, the law of correlation escaped him, for his standard of reference was the king's crown which he thought to be of pure gold.

At one point he became quite excited, when the idea occurred to him to mate the two superlatives and turn out a wooden dish. This, he argued, was the best of all possible floating bodies. Of course, this had been known since the dawn of history, for that was the form given to the vessels which he saw from his balcony daily; but, until then, the knowledge had been purely intuitive and not reliable. Now we had science.

In the effort to reach understanding, he developed a number of theories, some of them quite sophisticated, like the one on the anti-matter which has twice become popular since: the first time in connection with the theory of the phlogiston and the second time, these days, in nuclear physics.

But it was not until the day he heard someone remark, "All that glitters is not gold," that the real significance of the discrepancies in his results occurred to him. After that the solution was simple and the principle on which it is based is to be found in every text on hydraulics. He became positively elated about it and, with the confidence born of discovery, he went to Hiero I and stated dramatically that his crown was made of equal parts of tin and gold and proposed to prove it by melting down the crown. Of course, this was not carried out, for a king does not lightly give up a crown for melting or any other reason (well, there is one exception I know of). But Hiero I, to his greater glory, accepted Archimedes' statement at
face value and had his minter beheaded. Now how long did all this take, from flunking the student to beheading the minter? 17 years!

During this time it had been necessary to set up a laboratory (the Syracuse Institute of Hydraulic Research) and equip it with instrumentation, that had to be designed to new specifications, and with shop apparatus to make all sorts of shapes from all sorts of materials.

Among the instrumentation was a waterproof balance for use in air and water, of an accuracy greater than could be obtained with the scales from the fish market.

Archimedes had to construct a set of calibrated weights. He found out that the weights used by the local vendors, which he had hoped to use, could not be trusted: they were far too short.

He also had to build a crane for hoisting and lowering the scales in and out of water.

There being no basin available, he had one constructed which later became a public bath.

To fill the basin, a 9-mile aqueduct had to be erected to bring water from the nearby hills of Epipolae.

The whole affair came to cost a king’s fortune. It succeeded only because Hiero I had faith in Archimedes and money to spend foolishly.

I told you these stories about Galileo and Archimedes to bring out the point that the interval of time between the conception of a scientific idea and its fruition is long, often spanning decades and occasionally centuries, as is the case, for instance, with Leonardo’s flying machine. It is only simple ideas, like Archimedes’ principle of buoyancy or Albert Einstein’s unified field theory, that require only a 17-year period of incubation.

During all this time the scientist requires encouragement of two kinds: moral and financial.

Something might be said about this sort of encouragement, particularly of the latter kind.

In olden times, when a man was struck by an idea, scientific or otherwise, he sought to obtain patronage from the local prince and to this end applied to as high up the ladder of protocol as he could. The court official might or might not lend ear to him depending on his mood and on whether there were more important things on his mind, like how many buttons should be required on the cuff of his knee breeches or plumes on his hat to be duly impressive at the masked ball to be given by the new Duchess of Malfi.

Of course, the court official would not rely on his own knowledge of science to decide in the matter but would refer the idea to his favorite golf companion, to the court clown or, in extremely important cases, to his liaison amoureuse of the moment.
Given the right combination of ascending stars on the one hand, and of chance on the other—for in those days, as even now, the lives of people were governed by the laws of astrology and of stochastic processes—the philosopher received a grant which permitted him a degree of temporary leisure to pursue his work.

For this grant nothing much was expected of him except to be present at court on certain occasions to be exhibited, along with the court poet, the astrologer, the clown, and the Asian unicorns, to visiting dignitaries. On these occasions he sat at the lower end of the dining table, between the lesser nobles and the higher ignobles. The support he received depended on the fortunes of war and in those days governments tended to suffer from instability.

But in spite of the haphazard way in which ideas were financed, the prince often pulled open the purse-strings with a glimmer of understanding. Had it not been for a sympathetic Hiero I, there would be no Archimedes’ principle, and ships could not be designed to float. Had there been no Prince Cosimo, Galileo would not have discovered the principle of the pendulum, and we would have no grandfather clocks. The interest of Ludovico Sforza and of Francis I permitted Leonardo to write his Treatise on Hydraulics, and it is in part thanks to this that we are having a Seventh Hydraulics Conference these days.

The situation has changed but slightly: the king has now become the government and the prince the philanthropic foundation.

In going from the personal to the impersonal form of patronage that this involves, some minor differences of operation have manifested themselves.

Today the stars and the laws of chance still exert their influence, but the procedure has been systematized to a high degree. The proposed research is evaluated and acted upon by a complicated pattern of government or private offices each having jurisdiction over some single phase of the work: technical, contractual, fiscal, administrative, policy, liaison, security, planning, approval, etc. Whether an idea has any merit or not, it brings into operation multitudinous bodies of officials of all levels whose interest lies merely in the formalities or externals of research—not in its essence; who are able to question methodology and procedure—not value.

That this should be so results perhaps from the complexity of our civilization. But seeing all this activity for one small idea, one is tempted to misquote slightly Maréchal Bosquet witnessing at Balaklava the charge of the light brigade: “C’est magnifique, mais ce n’est pas de la science.”

Now this retinue of overseers who feed on research proposals has a curious effect on the whole development.

To be supported, an idea must be both accessible to them and in harmony
with their thinking. A safe idea to propose is one that has already proved successful. Human nature being what it is, this results in the same idea being continually reintroduced in a variety of forms, and the field of knowledge already tilled is cross-furrowed over and over again in all sorts of fantastic patterns.

The same experiments are repeated with minor variations and no change in conclusions. There is a pile-up of data that smothers all thinking and appears to lend support to the statement of Lord Melbourne that “nobody learns anything from experience; everybody does the same things over and over again.”

Now, I will not bore you with proof or details. I assure you they are there. In the spirit of the evening, take my word as Hiero I did Archimedes’. “But,” you will say, and I quote you, “this leads to the situation that vast sums are spent for half-vast ideas.” Quite so, and if you bear with me a little longer I will make the point to you with logical brilliance or brilliant logic, whichever you wish.

Every child is endowed with a creative mind and, as the world reveals itself to him in all its wonders, he becomes enthusiastic and contemplates the achievement of great and glorious things. So was it with me. So was it, I am confident, with all of you here tonight.

The child with a passion for things mechanical turns to his mother and says: “Mother, when I grow up I want to be a scientist, for I yearn to split atoms, or launch satellites and space ships, or discover new laws of nature never thought of before, or do some of the many, many things never attempted before.”

The loving mother encourages him and sees to it, at a sacrifice to herself usually, that the child gets the schooling necessary to realize his ambition. And the mother is proud, for, in the popular mind, research is a glamorous thing to pursue, brilliant with new-found glory. And the child struggles through his adolescence and young manhood to grasp the understanding that will permit him to realize his dreams. He is graduated on a bright, promising June day like today along with 75.000 others, and then he promptly goes to work in the laboratory of an industrial firm, of an academic institution, or of the government and is launched in the orbit of his career. He gets his first assignment, calibrates an instrument or two and writes his first report. The supervisor hasn’t time to read it, but since the new man is enthusiastic and has not made a nuisance of himself he gets a promotion and a second assignment.

The second report piles up on top of the first, but the young researcher’s ebbing enthusiasm is stimulated with another raise and a third assignment. This goes on, year after year, the work getting more difficult, the pile higher, the enthusiasm lower. Now you may well wonder what kind of research he is turning out under these conditions.
Well, let me argue by analogy. Suppose that instead of research being the glamorous objective to pursue, it is art. This may strike some of you as strange, but it isn’t really so. If you want to be argumentative about it, I beg you to allow me the point for the sake of the argument. I might, in justification, simply recall to you that, but a few centuries ago, this was indeed the situation that prevailed, notwithstanding the feverish scientific activity of Leonardo and Galileo and the rest. Artists were then in high demand (though, I gather, still ill-paid). Every affluent man aspiring to court a woman or impress his social circle would seek the services of an artist to write sonnets, paint portraits, cast statues, or compose mood melodies. At least twice in the history of western civilization the world has raised art on a pedestal: in Greece during the Golden Age of Pericles and during the Italian Renaissance as well, and to this day we live and feel the spell of those times. All this by way of justification, of course.

Well, suppose that art is the thing and that we are going to beat the Russians with better music rather than a better friction line. In this environment the child would say, “Mother, when I grow up I will compose opera.” And so he is sent to the conservatory and plods away at the keyboard at all hours of the day and night. He is graduated along with 75,000 others and goes to a laboratory where music is produced. He is assigned his first task, a one-act opera in one flat. After a year he turns it in. Of course, it isn’t performed (one would really be asking too much), but he gets a raise and is assigned to write a two-act opera in two flats. This one too piles up. But another year, another raise, another opera and another flat, and so the pile grows.

Now just imagine 75,000 enthusiastic composers graduating every year, each writing an opera every year to be piled up on the operas of yesteryear. What kind of music do you think you would be getting? Not very good! don’t you think? What kind of research do you think you are getting?

Now it’s easy enough to look at the world in a humorous vein and draw a caricature. And although one may be criticized for doing so, it might be well to remember that a caricature is, in the end, rough truth. As Shaw says, when a thing is funny, search it for a hidden truth.

And why do you think the music that is produced isn’t any good? It goes without saying that a first opera should not be expected to be a hit. But the real reason is that those who assign to the young musician his opera to compose cannot always read music. (They only play by ear.)

When they can read music, the fervid activity leads to inspiring results. When they cannot, you will have all the external manifestations: folios, orchestrations, recitals, concerts, and the like. But the results will be pseudo-artistic or, in the parallel field, pseudo-scientific.
Samuel Johnson is quoted as having said: "The rights of nations and of kings sink into questions of grammar, if grammarians discuss them." The statement can be applied to the present discussion by changing but a few words: "The value of research becomes a question of formalism and procedure, if bureaucrats discuss it."

And to continue in this vein, I will introduce another quotation which I heard from an anonymous scientist, "The research that is carried out today reminds me of a wedding where everybody is present but the couple to be wed."

The spirit of quotation (or rather mis-quotation) is on me and I'll give you one more. You all recall Robert Burns' poem "For A' That and A' That." You might, if you wish, add this extra stanza to it. (I will not attempt to reproduce the Scotch brogue for fear it will sound like Armenian.)

"A prince can mak' a councilman,
A bureaucrat and a' that.
But a scientist's aboon his ken.
Gude work, he mauna fa' that
For a' that and a' that.
Though pushed and scorned and a' that,
The scientist has greater worth
And higher rank than a' that."

I believe it was Hilaire Belloc who once said that any subject can be made interesting and, therefore, any subject can be made boring. I am afraid that I have only succeeded in doing the latter. But should I (and there is a random probability lurking somewhere in the room)—should I have succeeded in making it interesting, well, perhaps you will invite me again to a future Hydraulics Conference.

When the evening is convivial and one is among friends one may well laugh at oneself. I do not wish to philosophize on this point, for one cannot discourse philosophically on a full belly. But one might, in closing, look at a Scientist as he really is or aspires to be, for the significance of a man is not in what he attains but in what he longs to attain.

He is humble, for the scale he uses to measure himself is gaged to fit the great of the past whose fame lasts undiminished through the centuries.

And he is frustrated. Those who have never given birth to an original scientific idea can never know how much labor is involved in generating one. The vast majority of attempts always prove to be wrong, and sometimes all of them come to no successful conclusion.

But he is a man of value. As against the man of success, the man of value is one who gives more to the world than he takes therefrom. Because of this, he is in the minority and, consequently, often at the mercy of those organization men whose ambition leads them to positions of control.
Yet, if a young man were to ask my advice on what career to follow, I would speak to him so: "Choose science, my boy. The path will be humble, tortuous, and difficult to trod. You will often feel lost and might even despair, like Dante in the forest before he met his guide. But it is the path that has been trodden by great men who have worked to make this world an excitingly beautiful place to live in."

"Your material rewards will be small, for it has always been the Scientist's lot to be poor. But in a sense your reward will be greater than anything the world can offer you, for the light illuminating your steps will be cast by the halo of the Immortals."