AOPE Dept. Seminar Transcript with Bob Frosch on April2, 2008

(http://acoustics.whoi.edu/acoustician_series/lectures.html)

AOPE Chairman Jim Lynch

Would everybody grab a seat. Sorry, the conditions are a little bit crowded here. As everybody knows the conference room is finally, after a decade of asking, being redone. So, hopefully we'll have a conference room in a few weeks a little better than this. But for the time being, this is our small, cozy, adequate conference room.

I would like to welcome again Bob Frosch. I am not going to give a complete introduction. I think everybody here knows Bob pretty well. He is a visiting scientist in our department and trustee and has a resume everybody can envy for hours. At any rate, Bob also likes to speak about things so Bob has agreed to give us another talk here.

Bob Frosch

I actually came to this village for the first time to talk to people at this institution for the first time in February 1952 in a driving Nor'easter. And I started to work with Bracket Hersey for 25 to 30 years.

So let's start with what application oriented R&D is. The distinction I make is only that if you are not doing application R&D, you are probably thinking up the questions yourself. If you are doing application oriented R&D, somebody else probably thinks up the questions. Or you sit there saying suppose I was somebody else, what would I like to be able to do. And, nonetheless, application or not, this is the great statement about getting anything done. If you don't know how the universe works, then you are unlikely be able to trick it into doing what you wanted.

And just say what this is all accumulated out, is a lot of stuff starting by being a physicist, doing acoustics in the ocean, and a whole bunch of other stuff. Mostly [I was] trying to arrange things so other people could do research.

Now this is the first thing. They all look alike. Everybody says, 'Gee wasn't GM entirely different than NASA' and the answer is, 'Not particularly'. The labs were about the same and so on. I would say this institution is probably kind of out at the tail of the distribution from the point of view of the way it is organized. But this is an important thing, they all look alike because, especially if they are big, they are all fractal and the bigs ones are made up of alot of littler ones, organized in some heirarchical fashion. I don't know what the fractal dimension is. But I think we can find out.

And of course the organization diagram isn't the real organization. If you look at the GM organization diagram, one of the scientists in the research lab, in order to talk to an engineer in a division where they made engines, would have to walk through the CEO's office. And, of course, no one would pay any attention to that.

And real organization can be complicated. We had a department at GM research called operating research, which was mostly social science, it was economics and the epidemiology of automobile accidents, quantitative sociology, and marketing. I got them to hire an ethinologist. And she wandered around for abit and wondered what to do and found some problems.

One of the problems she found was called parts chasing. You have an assembly plant which has 3000 people assembling cars and was nearly a quarter of a mile long. And parts come in. Stuff. At the front end component, pieces of metal, and all along the line and when you get down to the end of the line there's a gallon of gas in the car and someone drives it away. So that's an assembly plant, fairly complicated.

Different times cars are going down, different colors, different radios, different engines, maybe even 2 brands and very complicated. And sometimes the part that supposed to go in this car isn't there. And there is actually a trade, a union trade, called parts chasing. Help. We haven't got the part and someone goes chasing it down.

There were reports with difficulty with parts chasing. So, Liz went off and insinuated herself into the plant as a skilled anthropologist and wandered around. Everybody agreed this is the way parts chasing is done, this is the official way. Everybody agreed nobody does parts chasing the official way. Here's how they really do it. So she wandered around and discovered that here's how they really do it isn't how they actually did it, but there was a third layer of sort of political and social arrangements where they really did it. And the problem was coming because it was sort of submerged that way and she figured out some things to do about it without disrupting everything.

And it was our practice to write a report. So she wrote a kind of an anthropologist's report, with a summary of what it all said. And it was also our practice, we had a standard distribution list which sends such a copy of the report to anybody in the company who we thought might be interested. So it went to lots of plants.

For a year and a half thereafter, Liz would get a phone call and there would be some guy on the other end saying, I am the operations manager in plant number such and such, and I have seen your report, and I want to know how you got into my plant and found all that out without my knowing. To which she said, 'It wasn't your plant'.
Every single one of them had this 3 layer, 4 layer thing. It's a general phenomena.

Next comment on that. (Slide title: Bureaucracy, rules, policies and standards are all necessary BUT no one who is obeying ALL the rules can possibly be doing any work!) In fact, you know about 'back to rules' strikes. The Paris guys who run the Metro, can't go on strike, don't want to go on strike, so the word goes out, we're going to obey all the rules tomorrow. Fun stuff...

R&D organizations don't pay any attention to this. And as I said this one is kind of out on the edge of the distribution of the relaxed and choatic as opposed to the organized and systematic.

This is interesting because I saw this [cartoon on slide] in the globe about a month ago. [laughs] OK, so that's about a month ago. And the next slide I got from my opposite number, when I was the Navy secretary, who was the UK's science advisor to the admiralty, or whatever, and he had sent me that one [next slide]. [laughs]

You'll notice the guys with the orange... [laughs]

Then there's a question with applied R&D, particularly, that its starts with one kind of person, the scientist or the engineer, who is designing and building the first one and working out stuff. But eventually in an automobile plant, for example, its gotta go to a different kind of people entirely, who are going the detailed engineering for production and then to the guys left to figure out how to put it together. And they're not the same kinds of people as the guys who designed it.

And you know, this might be a little scientist/engineer chauvinist but you don't have to worry about the informal part at the front end because the people involved in it are generally grown up in a training where they are self-disciplined with regards to error and how good it has to be.

But the guys you hire on the production line or even for supervision and so on don't necessarily have the same discipline. So you have to put in a more formal operating discipline, as you do on a ship for example. And I am sure the operating discipline on Oceanus and Knorr is a lot more stringent than on a little boat, where there are 3 guys and they yell at each other and it gets done. So you have to worry about this.

And now this is thinking about it in terms of procurement and in terms of satisfying the guys who wants you to do something. And in my experience the customer for R&D is always wrong. Now that does not mean that the provider is always right. And we'll get to that. The customers in my experience don't say what the problem is, they come and tell you 'what I need is'. And usually it's their solution in the head, not their question in the head. So if you go ahead and do exactly what they say, you may be in for a big disappointment on both ends. Because customers here, internal customers, are much more sophisticated and you talk all the time. But if you go between the research labs and the car division, they don't know what the technical possibilities are. They have some idea how to do it, but that might not be the right way to do it. And they might not be asking the right questions. The technologist doesn't know what that question is. It may be very difficult to invent weapons if you have never actually been in the field trying to use one on a real enemy.

And this is an example of an admiral in charge of airplanes, asks the secretary, 'we gotta get a faster fighter aircraft'. Ok, so why do we need a faster fighter aircraft? Well, so that we can out fly the other guy in the dogfight. But the first thing happens in a dogfight is you make a tight turn. And you are not going anywhere at all. So maybe its manuverability you need. 'Well, yeah, yeah, you're right.' And he goes way then comes back, 'Well we need a faster fighter aircraft so we can get to the dogfight while the other guy isn't ready.' Oh, but why do you want to do that? Oh, we want to shoot them down before he knows what is going on. Well, do you really need to be at the dogfight to do that?

So anyway, you go through this and in the end the question was 'Gee we need a somewhat longer range, faster air-to-air weapon. And not go back to the airplanes. So you get that kind of a dialogue, And it happens at all levels.

This is not so much for here but this is for procurement people who write specifications as if they were going to buy shoes. That is they are assuming they are buying something that exists, that if you say is going to have these properties and in the back of their minds, it is like a shoe store. You look at them at the proposal and you buy the one that fits. But they don't understand that it is about a future possibility, the result doesn't exist, you can't see it, you can't try it on. You have a problem with discussing what it means. And when you say I require a missile that'll go so far, it's a guess about a possible future. And, by the way, the specifications for something don't actually specify. The only thing that specifies the object is the object, and how it was actually made. Which you write down in the specifications is an incomplete set of things about it. And in fact you usually don't specify the specifications how it's to be manufactured. And I've seen cases in which manufacturer A was perfectly happily making an object that somebody decided there should be two sources so they competed for a second source and told manufacturer B to make the object and gave them all the specs and manufacturer B could not make the object. It was a little technology and a particular way of doing things that A had and that B had never heard of. It wasn't in the specs you just had to know about that. If you gave a contract to somebody who is going to have to do aluminum welding or high quality steal welding, and they don't normally do aluminum welding or high quality steal welding, then you're going to get a mess on your hands. Which the Navy did once in a submarine procure, they let pressure hull stuff to people who didn't have the welding technology. Fortunately, early caught disaster.

And then, of course, requirements come, into play. Which is my favorite crazy, requirement. This helicopter should take off from 14,000 feet on a 90 degree day, that was an actual spec. (And by the way, it got all through the system and the cost of this helicopter and the problems kept going up and going up until somebody finally said, in desperation, they come to the research people and say we're through). And that was an actual spec, but when you went back into it, it was a kind of an innocent mistake by an ignorant procurement guy who had gotten all the helicopter specs and he had gotten a helicopter spec that said this helicopter should take off from 14000 feet and there was another spec that said it should operate on a 90 degree day and he said well that just looks as if it's two…we will just make one…we will simplify it.

Then there is tacit knowledge. Well you guys know about tacit knowledge, but lots of people don't know about tacit knowledge. This is one of my favorite tacit knowledge cases. Traveling wave tubes are the big radar tubes, big microwave tubes, that run on the front end of military radar, and they normally have quite a long life – a thousand, several thousand hours, when Hughes was making it – which meant you could put it in the airplane and airplanes don't fly all that many hours at that time so that was almost the life of the airplane and occasionally we would go out and the carrier would have a couple in the back bin and would be able to fix it. Except one day, the traveling wave tubes started having lifetimes like 100 hours, 20 hours. That's an inventory disaster and all sorts of things. And Hughes couldn't figure out what was wrong. You know they walked their own production line and everything was fine and they got so desperate they started looking at the personnel records and they discovered somebody had retired, more or less, about that time they were doing that. And they went and dug that guy up and he started to walk the production line and he got to where they weld the filaments in and he said "no no no, you have to turn the tube upside down when you weld the filaments in so they have the right sag when they are welded in so when you turn it back up they don't short out …". You know, somebody had learned that on the production line early in the process and nobody ever wrote it in – why would you write it in? it's a spec, you don't tell the machine exactly how to do the machining.

Okay, this is just a comment, so figuring out the problem and what it is you're trying to do in application for is usually harder than doing it. (And thing I just threw into my thing). It's about inventing problems. One of the biggest difficulties in inventing and solving problems is there is always somebody there who says you can't do that.

Now sometimes it's right. I remember standing in the hallway of the Pentagon with Charlie Hirchfeld when he was the director of Operan, and I was the deputy director of Operan, and a guy we knew came running up and told us of this marvelous new technological thing that was going to solve a whole set of problems and Charlie listened to this and looked at him and said, "Give me a number. How big? Within a factor of two? Within the order of magnitude? In the exponent?" Okay, so all that comes out to saying that in many places application oriented R and D is thought to be something you do by you write the specifications, go through the requirements and the specifications, and you have a competition and you look at the prices and so on and you pick somebody to do it. You say, "Here's the money, go away and you'll deliver it in two years, and we will test it."

And that is a recipe for disaster, for all the reasons aforesaid, so it's a contact sport, you have to keep talking to the customer, and talking to the supplier, and find out whether the supplier thinks they're supplying the same thing you thought you were buying. It's not the shoe you saw, it's the shoe they haven't designed yet. This is R and D, it's not production yet. So you got to have a *very* early dialogue, as I have pointed out. You know, what is it we are really trying to do here? And so the current mode of there is so much conflict of interest that if you actually talk to somebody – or God for bid, have dinner with them – that you have to do it at arm's length. But since you can't do it at arm's length, you have to pay attention to what everybody is doing. You can't just say, "Oh, well you know, it's all just fine". And you've got to keep doing this because in the middle of the design/development process you are going to find some stuff that didn't work. It just plain didn't work, so you've got to go back and do something else. And if you're not talking about what you really need, there is something else the guy's going to do, maybe the wrong something else, something you didn't want.

So what do you do about conflict of bias? You play poker with everybody's hands above the table is what you do. You know. And you trust, but you verify, so you keep watching and you've got to kind of be around all the time. All newspaper reporters and editors have a continuing severe conflict of interest. They are in the business of selling news so they want news that people will buy. No reporter who has spent six weeks on a feature story will conclude, "Well it's pretty dull but nothing terrible has happened". That's wasted time and money. You guys do that with proposals too. After you've worked on a proposal for a while you aren't likely going to conclude it isn't worth doing something with it. You're likely to figure out what you can put in so it is a proposal, you all do that, that's perfectly reasonable.

Nowadays it's an aphorism in the manufacturing business that you cannot inspect quality in. That means if you made it badly to begin with and the blocks don't quite fit, that just inspecting them and throwing away the really bad ones and trying to patch up the not so bad ones, produces a cruddy project no matter what you do, so you can't build it and inspect it afterwards, you've got to build it right. But you can't order honesty in, either, on a conflict of interest. But you've got to audit and you should audit, as we've just find out in the prime mortgage thing, that people were doing some very strange things for several years and no body paid attention, the auditor's going to compound the mess probably. So somehow or another you have to get past this business of the thing.

This is well summed up: the best fertilizer is the footprint of the owner. That's the point about the customer and the provider have got to be working together all the time. Now, this was told to me as a Sicilian proverb but it actually goes back to Pliny the Elder. I just looked it up, he didn't die at Pompeii, he died at Starvia. He was the commander of the roman fleet. And when Vesuvius went off and they had runners beginning to tell them that there was real serious trouble in Pompeii and Herculaneum, he tried to take some ships over there and rescue people and was overcome by the sulfur gases. Interesting tale. By the way, in addition, there was this account of him: The best fertilizer story that he tells is of a farmer, not far from Rome, who was accused by his neighbors of dishonest practice because he always had more harvest and better quality than any of his neighbors. His neighbors were all absentee landlords, by the way. So there was a trial, a formal trial, and Pliny I think was one of the lawyers, and the guy came in and dragged into the courtroom all of his farm tools and all of the people. He says, "We own this farm, this is my family and the people who worked for me. These are our tools, we are out there every morning at sunup with the animals and the fields" and the so on and so on and so forth. And he was acquitted, so Pliny had it right.

Now, this is one I don't know what to do about. And it has to do with some slides coming up in a moment. That is, if you're running an industrial lab, or even this lab, what kinds of skills do you need? What do you actually have to know in order to do this kind of stuff? And it's not very easy to figure out what it is you can dispense with. And I'll show you why that is. Well, here is a comment on it, to tell you what this means.

This is the first time a person wants to build a car door on the outer part, the skin of a car door, with monolithic fiberglass reinforced punnel?. And they knew how to do it, and everything was fine, up until they put the whole process together two weeks, or three weeks, before production was supposed to start. Because they never had everything together again. Here is an example of it comes along and then bites you later. Everything was fine until they painted the door and looked at it. In order to keep the thing stiff enough so that it didn't buckle, or crack, they had molded in rib, down the right part of the door, and after they painted the door every time you looked at it you could see the rib. Somehow or another the shape was just enough off so that, well, you can't sell cars like that. Why, I don't know? It was functioning perfectly fine. But it is a fact that when all of us go and shop for a car we want it to look like wet vinyl. If it doesn't look like perfect wet vinyl there is something wrong with the car. So what the hell were they to do? They got so desperate that they came to the research people. And so the polymers guys went over and looked at it and looked at the manufacturing set up and said, "Can we have a door?" and so they gave them a door and went back to our own pilot thing and figured it out, they knew a lot, and in about two weeks they came back and said okay here is your molding press, I want you to move this cooling line here and run this cooling line 10 degrees higher and I think we need another little cooling line, try it. Of course they do it, perfect, no read out. I happen to run into the head of the division in a meeting and the head of the division said, "Oh my guys told me what you're guys did, that must have been a really easy problem, they solved it in two weeks." I said, "No no no, they solved it in twenty years, it's just that they never got to use the earlier twenty years for that problem." So, you know, if we had gone to the division and said should we be doing this kind of work on polymer doors they would have just said, "We make doors out of steal, what are you fooling around with polymers for?"

Here's another one. I mentioned what an assembly plant is. So you've got two or three kinds of cars; L6s, L4 engines; and you don't want to put them together because it takes longer to put in a 6 engine than a 4 engine; and you got white ones, and blue ones, and red ones; and you'd like to paint all the white ones together because you have to purchase the paint system between white and blue; and you have all kinds of radios and so it's very complicated. And by the way, you would like all the cars that are going to Toledo to come off about the same time so they can go to the truck and so forth. So you've got a lot of constraints and big problems. And there was a scheduling solution which had really been arrived at by what we call Cherry Picking. That's what the guys called it. What they meant was you schedule for a week. (And by the way, this is scheduling for 65 cars an hour, *at least* 65 cars and hour, 8 hours a day, for six days a week. And sometimes two shifts, so it's twelve days a week. That's a lot of cars.) So what they would do is figure out Monday by picking it off a list. Monday was fine, Tuesday was harder, and by the time you got to Friday of Saturday it was really awful. So the guys decided to set up the question of how do you optimize this? And they began to play with it and they discovered they could write an algorithm but they could not figure out how to optimize in that algorithm. In principle you could put it on a cray and keep trying cases but there wasn't enough cray time in the known universe to do that. And there happened to be a lunch room where all the sort of reasonably seniors sat and the rule in the lunch room was that you came in and you sat down at the next empty seat, (unless you had a guest) So to some degree there was a sort of randomization as to who was talking to whom. Now these guys were bitching about the problem they couldn't solve, and there was this mathematician – well he wasn't a mathematician. Actually he was a theoretical solid state physicist. So he listens to this and says, "That has a very familiar ring to it, now tell me what the question is. I think there must be a theorem." So he goes, "I'll go away and think."

So he comes back and he says, "Now there is a technique we use in solid state physics called simulated annealing. Which amounts to starting with randomization and then letting it settle in and so on." And he let the guys look at it, and they tried it, and ran it on the cray. It was a big problem and it really did the job. Of course once you know you have an algorithm for doing it, you can start simplifying it. (If you leave this out, is it alright, And so on.) First of all, they got it down so they can do it on a sun work station and then the problem was, how do you get it into practice? You don't go to a plant manager who is running a three billion plant, 65 cars an hour and say "hey can we borrow your plant for a week? We've got this experiment of scheduling." So one of the guys found a plant manager he knew well enough so he could sweet talk him into a more complicated deal. And the deal was that the plant had its own scheduling computers so they were keeping track of what they were doing and they allowed us to put our computer, our sun work station, next to theirs. As they ran their week, we would run the week the way we thought it would go if they did this thing. And he said, "Well when things start to get quiet along about July, just before the model change, I'm willing to try it." But every day he would come by and kind of sneak a peak at things and finally about the end of May he said, "Awe hell. Let's try it next week." And of course it actually worked. I don't know what it cost us to do the R and D. It can't have been much because it was all theoretical stuff, so maybe a million bucks to do the R and D. It was worth two hundred million a year to the company. The financial guy said so.

And this is another interesting thing. One of the first things my boss at GM… This is a little industrial oriented because I set it up first to give a talk to the American Physical Society in a session on industrial research and that might be the stuff that is least familiar to you guys. My boss said, what we need is a way to make one day dies. Now the die is a big, steal object. Which goes into a giant press and a chunk of sheet steal comes in and is pressed down and when it comes out it's the outer of a door, or a hood, or whatever. So this is several tons of die, which is generally made by pouring one sort of about to the right shape and then it goes to a specialized machining process and gets machined. The right shape by the way, is not the shape of the hood because after you take the steal out of the dye it springs back a little. So you fake the shape so it springs back. So we need a one day die, it takes too long to make all these dies. Now that wasn't the problem, it was really a procurement problem. The procurement problem being all the manufacturers have the same seasonality, so they are all suddenly yelling to have their dies machined at the same time and there is a lot of jockeying for a limited capacity. So if we could pour a die in one day, that would be great, with the shape and size and so on. Now, it was well known there were try out dies. Where you only punch five of them to see if you got the shapes about right. They were made out of a zinc alloy but the zinc alloy wore out so you couldn't do that but the guys thought they had some ideas about it. And so they, a very good metalergy department, they did real examination of the aluminum copper zinc turnery alloy phase diagram. They did more or less the whole diagram and they found something that they thought would work and actually made a die about that big and they persuaded the guys who punch the air cleaner covers, the air filter covers, to try it out and they punched a million out but we could never sell it to any of the big die guys. They wouldn't take the risk, try that, there were some of the union guys who told me there was a back door footsie with the machining company.

So we just forgot about it. And one day somebody came in and said, "We have this little interlock that has to be put in for safety purposes and it has to have the creap and strength properties of steal. But it can't be cast and we are machining it and it costs like 20 bucks for each one and it's absurd. Can you guys do something." And I said, "Eh, I'm not sure." So they went back to the aluminum copper zinc and they went back to the phase diagram and they found a way to get into the right place in the phase diagram and they had an aluminum copper zinc alloy that had 1/1000th the creap of other aluminum copper zinc stuff and the strength of steal roughly. Wow. Furthermore, it was die capable so it cost about three cents each or something. So all that stuff with the aluminum copper zinc, that was irrelevant, except for when it became relevent The motto I have…someone would say, "Why do you have a big metalergy Department?" The answer would be, "Well we make a lot of stuff out of metal." Which was not generally, in the industry, considered a good answer. I've been told that. In fact the physical society, one of my colleagues who talked about his industry, had a good answer: "You would be spending a lot of money on stuff that didn't matter." This is just a way of thinking about these things.

Suppose I want to make a more efficient or lower emissions anyway. What do I have to know about it? Even if I'm going to do it by improving the shape of the combustion chamber, I have to know about the combustion chemistry, I have to know about and how to set the flame off so I have to know about something that will work with this situation. I have to get the stuff into the engine and the exhaust out of it, I have to wonder whether it's the same heat or different heat and where does it go? And the piston has to go up and down and the materials have to be right and so on. After you've done that you have to go to the next level of details. So you get something that looks like this. Down the left side are all those factors and down along the top are all those disciplines so, as you guys know, it's complicated stuff. You make stuff out of electronics and electrical materials and pressure and fluid. Again, this is well understood here and it is not necessarily well understood in politico. My conclusion was that if you're going to do this, you are going to have to have some kind of an organization that's got to be fairly central. Or at least it's a matrix manage thing because you're managing a matrix of knowledge.

Now, for example, the total of the organization, GM needs mathematicians. But how many mathematicians does the Pontiac manufacturing division need? Maybe one maybe none but you can't operate that way. And the division may not even know it's a mathematical problem they have. So somewhere there has to be some central oversight that says, "Hey we do." And this institution has that. It sits around and says, "What kind of departments do we need?" Well we need physical oceanography and stuff. This department does that, I've heard you guys do it. What kind of skill do we now need that we didn't need the last year that we have to have somebody around. And by the way, at least in industry, and to some degree here, you do other stuff. We used to develop cars, we worked on how you manufacture cars we had the guys coming in with the door rib and like the Navy comes in here and says, "We have this funny? what do we do about." It keeps an eye on what the rest of the world is doing in absentee?. It was memory, you know? I actually had to tell somebody, "Yeah, we used to have a guy who knew about grease but he retired. But I can probably find you somebody in the universe." Okay you do an education in training, now if you read the literature on industrial R and D labs it tells you it's all about product development. Either they're lying or they don't understand.

Two management systems I've learned: one is well known. That's David Packard, the Packard of Hewitt & Packard, and he's written a book and talked about it and he calls it management by walking around. That is how do you know what actually is going on. Story: Sonabuoys, everybody here knows what a sonabuoy is. And at one point in the history there were three companies making sonabuoys. Two aerospace biggies and a third company that no one quite understood how it got the contract because it was in the business of making cheap radios. And sonabuoys were then made in, I think, five or ten thousand item lots of which they would take a sampling of like a hundred and take them out and fly them and drop them to qualify them with the rest the lot. Very good practice. Everything is going along fine and suddenly one day aerospace biggy's sonabuoys are not qualified. And whoops aerospace biggy number two sonabuoys are not qualifying. And the radio manufacturers are chugging on their sonabuoys that qualify. So it got pretty bad for a while and the Navy wasn't getting any sonabuoys so they came around and said – they always come to R and D when this stuff happens – "Would you go off and look?" So I had a guy on my staff named Peter Waterman go. He was a radar engineer from NRL originally. And so the other thing this audience he was a Vermont man, very skeptical. So peter went off on a two week trip to see what was going on and came back and said, "Well boss, it's like this. Aerospace biggy number one, I come into the place and they immediately show me into the management information center. And they show me all the records and where they keep track of everything but after a while I get to look, and everything looked like it was kind of stale. Like it was two weeks old and I couldn't get it. So, you know, after a while I left there and went to biggy space number two and same deal with the management information center. So then I went to the radio company and I went into a kind of dinky little office with an old, ripped chair and two guys sitting there were talking away about the business and finally I said, 'Where is your management information center?' And they said, 'What's a management information center?'" And he said well you're supposed to have this and describes it. So, "My brother and me, we don't have time for that we have to spend all our time walking up and down the production line making sure its being done right."

This one is my own recent formulation. It is called management by asking questions. So what questions? The first, most important question you have to ask is, "So what's going to go wrong?" Nobody wants to tell you what's going to go wrong, then there are others who once said why? and other things are left out. So if this thing breaks how are you going to get inside it and fix it? Who's the guy who is going to have to get inside it and fix it? Who doesn't have your funny tool that you made up? In the course of my life I have been made responsible for a couple of ships that had to carry very heavy objects. The autonomous transducer that is fifty to a hundred tons, well we took a ten thousand ton tanker and cut a sea chest through it. So in one of these cases I'm hearing all of the designs and so on and just for the hell of it I say, "So what happens if the spring breaks?" "Don't worry about the spring breaking, it has a factor of such" After a while I said, "Humor me." Go away, tell me what happens with the spring. So the next day I get called to the project office and everybody is kind of gray and they say, "Well boss if the spring breaks, and we assumed it was sort of in the middle because its fairly deep, if a waves comes up the line and when it gets to the thing that holds it, the thing that holds it jumps up and comes down, and breaks the ship. And it goes to the bottom. However, now that we've look at it, it's very easy to fix. You put a damper in here. Always ask what can go wrong, what are the issues, which is something of an issue here, with respect usually to the Navy or some other customers.

Okay so now I solved the problem, I have this piece of equipment, how do I hand it over, what do I do? And the usual solution is you've got this patent, that you've got all the paperwork, put it in an envelope, and you send it to them. That is useless. In the end either somebody who actually understands has to go, if for no other reason than the tacit knowledge, but actually to make it clear what you actually did. We all have the experience with the computer stuff and the telephone stuff where it does everything. It says, "Push this button." And you look, "What button? Oh! That's the one. Right." So you have at least that, so you have to send somebody or you have to bring somebody in and give them a course and you have to keep being available. So we had this problem in the GM labs and somebody noticed that the best people for this were the guys who'd left the labs and had gone to the division. And we didn't have that happening very much so we invented a way to have it happen more. We hired people from the labs who didn't want to really have a research career. They really wanted an operating division career. But they had the right kind of background, in the end we sort of settled down on about a master's level, engineering usually. And they came into the lab and if we had something going with the division – you know, next year we're going to finish this and then we're going to send it over there – they worked on that project anywhere from six months to a year and a half and at the end of it they got a promotion and they were sent down to that division and they're the guy carrying the new technology and that really worked. It was very hard to get people from the divisions into the research labs. Mostly they didn't have the same kind of education and they weren't all that interested. You had to find people who kind of bridge the gap.

Now I mentioned the matrices but here is an example of what I try to think about. So, all of this simultaneously. You've got an engine block and you're working on an engine block. And each of these fit into an engine so it can't stick out and you got this long thing and it's got a match to a power train and it's got to go in the vehicle with fuel and all that and the vehicles got to drive and so on and eventually you're up there. But also it's made out of something. Iron and carbon that came from somewhere and it came from some place originally ore, iron, carbon, it helps to know all this. And what's going to happen to it when you throw it away? Well that's of some importance. Matter of fact, this loop, that loop, actually goes all the way around for a track? GM when I was there was running the world's largest ferris foundry company – like twice the size of US Steel – because it made all the engines and the transmissions and so on. It bought no steal, or iron. It ran entirely on the clippings from the sheet steel that was bought to make the vehicles. Both, what is called engineer scrap, namely you can only use so much of a sheet of steel no matter how clever you are. So you've got all that left over and then there is scrap and old engines and so on. No iron, which was fascinating. You threw in other stuff. You know, you put it out somewhere and so on and you could do that. It went through a cupola with the right chemistry.

By the way that is an interesting side story, a cupola is about ten stories high sometimes, eight stories high. And in the top of it you put either ore, or iron, or steel, or whatever. And you add the coke and you add the lime and this and that, silica sand. And you've got gas burners and it all melts down and at the bottom out comes caste iron. It turned out nobody actually understood the thermodynamics, thermo-performance and chemistry of this thing. It was one of these trade things. You built the new on with some improvements over the last one and my conclusion was that a Sumerian bronze-smith from about 2000 B.C. would come into the plant, be appalled by the size, not quite understand the fuel, but realize what was going on. And when the guy went over and looked in, he knew exactly what he was looking at. So the guys had spent about two years, they borrowed one that was down and measured the temperatures for the first time and it was the same kind of thing. You had to move the gas jets down a little bit and put a little more of this in. And it was very interesting. So knowledge is very fascinating.

So how do you find out? I wanted to know whether the GM research paid the rent. You know, we were funded centrally and in principle the divisions thought they were taxed in order to run us. Nobody knew where the number came from. It went up and down every year, not having anything to do with us except of failure, but business was good, and we had the right boss, we got some more money. I concluded you can't say how many projects have succeeded. They are of all of different sizes and shapes, and what does that mean anyway? And you don't even know what the success rate ought to be. You know, how good should projects be and since you have things like the zinc alloy that was a failed project and a successful project and I don't know what all that means. And then I had a NASA center director once, we had a meeting with all the other directors, he came in and said, "Everything my lab did last year was successful!" And I said, "So you're going to try something else?" Which was unfair because he ran a very good lab he just had a funny idea of what we wanted.

So my thing was that the organization should pay the rent, that is the GM research labs should be paying its rent. Now, what did we do? Well, what we did was, I went to every department and said, "Give me a list of the projects last year that you transferred to a division. You know, just slice off a year, don't worry too much about any facts and give me a list of things. And give me your estimate, which I won't believe, but your estimate of the value of it to the division." What we used that for was because we got 150 things on the list and we used their estimate to rank order which ones we to take seriously. So we ended up with about 16 allegedly big ones. And then I got the financial officer for the labs to go to the financial officer in the division and say, “Hey, our guys say you’ve got this and it was worth such and such, what do you think it was really worth?” So out of the 16 we had 12 that looked like they were real and they had two properties, three properties really.

One was they were worth a lot of money. The guys in the division thought that they were worth a lot of money. They had staying power. That is they were going to go on and be a savings, it wasn’t just well we are going to save a little this year but it won’t matter. They were something that was going to go on and save us money. And mostly they were productional manufacturering. We couldn’t follow an improvement to a car to find out what it was worth. Suppose you improve the combustion chamber of an engine. Well, by the time they make the engine, there is an improved combustion and they fiddled with the starting and they fiddled with this and they fiddled with that. And you can’t figure out what it’s worth to the car. But you go on a production line and they take five people off the line, you know what it means. In the sample here we have 12 projects out of 120 and we ran them for a six year project life. Which was the GM standard, and even if it went for infinity years you did your value estimates on six years. And we computed an internal rate of return. You take the future cash flow, you discount it back to the present by whatever you think the discount rate is, and that gives it a value for the six years, and you divide it by six so it’s an annual value. Then in the denominator of the sum of the twelfth project we put the entire cost of the lab for the year. So it was a lower bound it was other stuff and that gave us an internal rate of return of 70%. And what an internal rate of return means to financial people is that’s equivalent to the percentage rate that you would get in the bank if the bank were giving you 70%. So did we pay the rent? Oh yes, we paid on all the other investments like that. So incidentally, we went to the financial people and said, “Hey, next time you’re worrying about this and that, we’ve got two answers. One, the research labs doesn’t make a profit, it’s a cost center, it says so right here. And two, that’s sort of 180 million, we can’t find that in the bottom line. It’s a 26 billion dollar company. Mind you the books were kept at 12 significant figures. Nevermind.

This is kind of a valedictory comment. The Navy’s research community can be as marvelous as possible but that doesn’t mean the knife is going to work for us. There are too many ways to screw things us. That’s enough.

Questions?

I actually have a comment, just an observation. The Navy now is implementing, for instance, in these reach back cells that the Navy has come out where they do run oceanographic and acoustic models, and they send information out in fleets, they do that sort of synthetic alumni thing. There are people who have been at the reach back cell who are on the operations officer's staffs, the commanding officer's staff for fleets, and those are the people who…

Well the military services have always been fairly good at that. In the sense that they are all started with education. And they tend to keep track of people's experiences and what they like to do. There was an interesting guy?. I did some studies in the state department, where they don't do that. State department won't take anything you know and put it into the planning for where you want to go. In fact to the extent that when Kissinger was secretary of state he made a rule that says, "Regional and area experts are not to be assigned more than once for their region" they go native. To which the answer is, "Isn't that nice, now I know where I can get a friendly native.

It was interesting seeing your experiences as associate director of applied research at WHOI because we don't have anybody with that exact title now I was wondering if you could expand on what that was.

Well, remember when this was. This was 1955 to 77, and Paul Fye and I cooked up the title and the job because we thought it would sort of move things into more application oriented stuff. Roughly speaking, most of the institution didn't want to have anything to do with it. And there were some people who were working with the oil industry; there was the same crowd who had been working with the Navy all along who didn't need any particular encouragement or discouragement; but as for other people, thinking about, "Gee, where is there out in the world of industry and government organizations, that this stuff might be useful for." Nobody wanted to think about that. I logged it as a failure more or less. There were a few things that happened. But I was here for what, two years? I think we managed some interdisciplinary stuff. Charlie Hollister got the bug to study a bunch of things in ocean bottoms and continental slopes and that's where the stuff about – I don't know what to call them, he called them "storms" that was a little violent – actually I guess some of it was gyres, the small vortices coming close to the slope and making trouble. That came out of that. And he did a lot of work on deep ocean disposal of nuclear waste which is probably still a very good idea but nobody wanted to take it very seriously. I think he might have made something out of it but he got off into other activities and he died pretty young. So nothing much happened there. It was not one of my great successes, or our great successes. A lot of people plain just "we don't do that" we do pure research stuff. I didn't make the sale.