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A Cooperative Enterprise

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A COOPERATIVE ENTERPRISE

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INTRODUCTION

I am happy to add my welcome to that of Professor Werner Soedel. Purdue University is pleased that you thought this conference important enough to come. I trust that you will not be disappointed.

Also, I add my thanks to those already expressed by Dr. Soedel to all of you who made this conference possible - the Organizing Committee, the Advisory Committee, the Session Chairman, and the authors. All were necessary and all have done an excellent job.

I was especially pleased with the lively discussions during the short course on Mathematical Modeling of Compressors. It indicates to me that industrial activity in this area is becoming more widespread.

The Organizing Committee thought that an address today on the Herrick Laboratories and this Compressor Technology Conference and Short Course would be interesting and useful to you. The task fell to me and it is a pleasant one since I have devoted the better part of the past 15 years to these or closely related areas.

The following discussion is to be considered as a case history. It should be useful to industrialist who might contemplate closer cooperation with universities, whether with Purdue or others. It should be useful also to other academics who might plan a closer cooperation with industry. I do not mean to brag about our successes, but, of course, I am proud of our accomplishments. One of the secrets of successful cooperation between universities and industry is establishing good communication. This requires good understanding of each other's requirements, objectives and attitudes. Perhaps my administrative point of view makes it possible for me not to notice our failures.

In order to better understand the emergence of the Herrick Laboratories, I believe it necessary to first understand something about the recent history of engineering education in this country. We must go back to World War II and earlier to get a proper perspective.

Before and during World War II engineering professors were generally more practically oriented than now. They also tended to be generalists as contrasted with specialists. Few had Ph.D degrees. In fact by 1941 MIT had graduated only 9 Ph.D's in Mechanical Engineering in its entire history. I am told that professors were also more closely associated with industry than now, perhaps because more of them did consulting with industry then.

By comparison to curricula of today, laboratory subjects, design and manufacturing technology were emphasized. Handbooks were an essential part of every engineering student's equipment.

Following World War II, the technological explosion was followed by many new industries - television, computers, jet engines - to name just a few. These led to many new courses of study in the universities. . Many companies formed their own research laboratories and the need for university consultants lessened. Another factor was that highly proprietary attitudes toward technology became prevalent in industry.

Major influences on engineering education were the formation of the National Science Foundation (NSF) in 1952 and the flight of Sputnik in 1957. Enormous sums of money were provided to educate engineering students to the Ph.D. level. Most of these Ph.D's stayed at the universities. Thus a trend toward specialization among faculties was started. New generations of students every three to five years exaggerated this trend. Those few Ph.D's who left the academic arena found their way mostly to the new highly technological industries. The older, more basic industries were not able to hire their fair share of the highly educated engineering talent.

At the undergraduate level, engineering curricula became highly scientific. Engineering laboratories became oriented toward demonstration of basic scientific phenomena as opposed to, for example, demonstration of equipment performance tests. Design courses and manufacturing courses were de-emphasized or even eliminated. In some cases engineering drawing disappeared from the curriculum.

With that background it is easy to see why industry and universities started to have communication difficulties and why they started to drift apart. It was in that atmosphere that the Herrick Laboratories were conceived. Before starting a discussion of the Herrick Laboratories though, we should say that the pendulum has started back. One of the causes is the decline of the aerospace industry. Another, is the recognition that U.S. industry has found it increasingly difficult to compete on the world market. Labor problems, improvement in foreign technology and world economic factors are certainly important reasons for this. Some think a contributing factor in some areas might be a failure of U.S. industry to adopt a long range view of engineering developments. Finally, the great social and political problems of our time have influenced engineering education as well.

Evidence of many changes in engineering education can be tabulated, but one of special note to graduate education is the change in position of the federal government. For example, the National Science Foundation has turned its attention to support of research which is deemed "relevant" -- that is, relevant to today's great problems. RANN (Research Applied to National Needs) is a new and financially significant part of NSF. Programs funded by NSF can be either university programs, industry programs, industry programs, or cooperative ventures.

So the stage is set for the emergence of industrially oriented university programs again. Now we begin to see many kinds of cooperative programs between industry, universities and government. I am sure the situation in Europe is similar. My recent sabbatic leave in England brought me in contact with university groups established by the Ministry of Technology at the University of Southampton and the University of Strathclyde in order to establish a close working relation with industry. I understand that there are simlar examples at the Universities of Leeds and Swansea. I also know that Professor Bjorn Qvale, formerly with us at the Herrick Laboratories but now at the University of Denmark, is trying to establish a strong industrial link. I mention these to indicate that what I describe here has some relevance to our overseas friends.

THE R. W. HERRICK LABORATORIES

Returning to the Herrick Laboratories history, we note that it started about fifteen years ago, and was conceived even earlier during the 1950's. Remember, at that time industry sponsored research was virtually nil, and government sponsored research was quite large and relatively easy to obtain. Why would a university professor want to fight the "easy way?" Small grants and small research contracts from industry did not look very attractive in comparison with big money from government. Perhaps it was the conservative mid-western attitude that looked unkindly at federal research funds. Perhaps it was a recognition that a laboratory was needed which would introduce advanced degree students to the engineering challenges and opportunities of our basic industries. Certainly there are other reasons, but in the main I think these are the two major reasons which prompted Professor W. E. Fontaine (my predecessor) to start the Herrick Laboratories. He was influenced and helped greatly by many industry friends, most notably Curtis Brown of Tecumseh Products and Bill Haines of Honeywell. Of course the name of the laboratories is in recognition of the large financial contribution of Ray. W. Herrick of Tecumseh Products.

Bill Fontaine was one of the - shall I say - "old school" professors more "problem-oriented" than "discipline-oriented" in outlook and research attitude. This was a necessary ingredient when we consider that at the time we were faced with some different attitudes. On the academic side the prevalent feeling was that universities were above applied research, that involvement with industry would have to be much too specific and could not be either long term or fundamental. On the industrial side we had the attitude that success is measured by profitability, and that the academics were (and perhaps still are) much too sheltered from the real world of industry to have a proper sense of urgency and business-like approach in their work. Bill Fontaine saw no reason to share either of these attitudes and gathered around him faculty of like mind. He conceived a graduate research program with work principally centered around the climate control industry.

Because of the belief that a good laboratory experience was needed in addition to the theoretical studies already emphasized, his first task was to obtain funds for the capital investment required. State schools like Purdue were spending their money primarily on their undergraduate laboratories. Research laboratories were almost exclusively financed by federal funds. In this case the initial funds came from Ray Herrick. Purdue, by providing the original section of the building and some matching funds, made the start of this large cooperative venture possible. The formation of an Industrial Advisory Committee nurtured the cooperative spirit. As a result, industry collectively matched Ray Herrick's magnificent gift with money and equipment. Two government agencies, the National Institute of Health and the National Science Foundation, came along with grants for the two specialized environmental laboratories - the climate controlled chambers and the acoustic chambers.

This spirit of cooperation continues now when we are embarking on yet another expansion. This time, we shall be building a noise and vibration laboratory. It shall be semi-anechoic, that is, with a hard floor and acoustically nonreflective walls and ceiling. The laboratory and the first several years of research will be cooperatively finance by the National Science Foundation, industry and Purdue. Nearly half of the funds will come from industry and about one third from NSF.

When complete, this over 2000 square foot addition will bring the usable floor space of the entire Herrick Laboratories to approximately 35,000 square feet. The proportion of funds for the entire Herrick Laboratories from industry, the federal government, and Purdue is fairly similar to the proportion for the new laboratory addition. If this ratio seems strange to you (that is, not as much government funds as you might expect) the ratio will seem even stranger when we consider the funds for the research programs themselves.

Except for the research programs of the Animal Science Department in the climate controlled chambers, nearly all of the sponsored research has been suggested and/or funded by industry. Typically the ratio of industry research contracts to government grants has been 90% or more. I am told by colleagues in other universities, and friends in industry and government that this is unique. A walk through our laboratories will reveal the large influence of industry on our research programs. A "handson" experience for most of the students is in evidence, balancing the theoretical approach prevalent and necessary in the classroom. Even those theses which are in themselves theoretical or solely analytical are motivated by practical needs of industry.

Professor Fontaine's and his industrialist friends and advisors dreams have certainly come true. Over forty different industrial concerns besides four government agencies have sponsored research, with contracts; many have come back for continuations.

Forty-nine graduate students were registered at the laboratory for the MS or Ph.D degrees during this past 1973-74 year. A few are company employees who have been sent to the University to study at the laboratory for an advanced degree. Thesis subjects required the application of many basic scientific subjects including in particular: the thermal sciences and fluid mechanics, stress analysis, control theory, vibrations and acoustics, mathematics and optimum design theory, and basic measurement principles. Applications were varied; dealing, for example, with engines and vehicles as well as compressors, heating ventilating and air-conditioning equipment, automotive tires and mufflers and even a special noise project on jet engines. Perhaps the common thread that permeates these research activities lies in the approach to their solution. Most programs employ a blend of modeling, experimentation, identification and simulation techniques to discover the basic behavior of the system studied. For those interested, we have a list of students in residence, their thesis subjects, a list of the more than 150 theses completed and many other informational materials in brochure form.

We are often asked about those unique features which have made the Herrick Laboratories successful. So perhaps some discussion along these lines is appropriate. Frankly I'm not certain what the unique features are, but I think I do know some of the important features. The most important is the attitude of the faculty and support of that attitude by the school administration. The faculty must have a practical professional outlook and be somewhat entrepreneurial in their activities. Each must be specialist enough to have a reputation in a particular field, but generalist enough to be able to work on a broad range of applied problems. Of utmost importance is the ability to communicate with industrialists. Although these attributes may appear desirable by all, I submit they are not shared by all professors. I believe that they are requirements for those professors who are to be successful in a laboratory like the Herrick Laboratories.

Students working on industrial research contracts have two masters - the sponsor and the graduate school. They must produce reports for the sponsor and a thesis for their advanced degree. The thesis and the reports are not often identical. If they are completely different, efficiency is very low. The trick in picking research topics is to make the overlap in the sponsor's objectives and the thesis objectives large. This requires a number of mutual understandings. The first of which is an appropriate period of time for the project. Usually this is somewhat longer than would perhaps be considered normal in an industry environment. Of course there are benefits to offset this longer time. Overlap in objectives is usually a function of proprietary restrictions. The university must be willing to accept the fact that competition at the marketplace may require some commercial security on work of an applied rather than fundamental nature.

Cooperation between industry and universities in research programs also requires an understanding about patents. The inability to find a mutually agreeable position about patents has often stopped a research program before the contract is signed. But I wonder how many times the "patent problem" (or for that matter, the "proprietary problem") has been used as a convenient excuse, when for other reasons more difficult to explain, a company wanted to say no to a proposal. Patent clauses should be derived from the patent positions already established or from potential contributions to future patents. When these are understood, the financial worth should be able to be assessed - and then the agreement is ready to be drafted. In my opinion that is the point when the attorneys should become involved, not before. In short, there must be mutual understanding of both positions from which to negotiate. There must also be flexibility in the attitude of industry and the universities to allow for some negotiation.

There are, of course, many other details we could speak of. Our students and facilities are worthy of note. The laboratory spaces are purposely large open areas rather than small individual rooms. We think it necessary to have the facilities arranged so that the students can share their instruments and other equipment. It helps foster a spirit of cooperation that makes it possible to get the job done with a minimum of capital investment. Industry seeks our students for employment after their experience of answering to an industrial sponsor while meeting the scientific requirements of the graduate school.

I hope you are starting "to get the idea" that it is a good thing for industry to have cooperative research ventures with university laboratories. To be more specific, the fact that we are here today indicates that the results of university research can have a beneficial impact on industrial sponsors. I am convinced that many of our research results have found their way into company designs or design procedures. The hope that this will occur every time must remain the primary reason for sponsoring research. However there are other reasons as well that may not be so obvious.

Usually it takes considerable time for new technology to be applied in industry when based on research results from universities. Consider the customary chain of events. After a professor gets an idea for some research, he develops a proposal which he usually submits to a government agency. Time for this plus the customary review procedure may mean that as much as two years can elapse before funding. If the graduate students are immediately available, another year for the MS degree to three years for the Ph.D can elapse before the thesis is presented. Availability of Ph.D theses through University Microfilms and announcements in abstracting journals may take another year. Alternatively, the preparation of a technical paper, submission to a technical society or journal with their review policies may also take as much as a year or two before the paper appears in print. In either case, industry is only then ready to recognize the work's relevance to their needs, and have their engineers start study in order to master the work. It is easy to visualize eight years before industry might start on the application of results after research was initially conceived. Contrast that to the rapid knowledge transfer from university to industry that results from a sponsored research effort. In this case the proposed research has already been recognized to be relevant. The development of the work statement and proposal can occur simultaneously and directly between the company and university. With good reporting and other communications, the transfer of knowledge can occur simultaneously with the research work. Years are saved.

The professor who assumes the role of principal investigator is the most important person in the system. A personal relationship between him and personnel in the sponsoring company is established during the research program. This leads to all sorts of side benefits. For one thing, the company now has a specialist who knows the company, its products and personnel well and yet who can bring a different perspective to their problems. This is somewhat like a consultant, but perhaps more like a member of the company's team. I've seen this relationship work wonders on the attitudes and performance of engineers assigned by the sponsor to monitor the research.

Some companies sponsor research with a contractual relationship rather than with fellowships or grants because they see advantages with respect to hiring students. A better understanding of the opportunities and abilities of employer and student result from the more frequent contact. Students know the company, its products and its personnel. If hired by the sponsor, their experience usually makes them immediately productive.

What kind of projects are good candidates for university cooperative research contracts? I think they fall into one or both of the following categories. First, those which require the expertise or facilities of a particular laboratory. Even if a company has the expertise, it may not be able to use it on the particular problem in question at that particular time. Secondly, those which can be termed high risk, long range feasibility studies of new technology. Within these categories, we are often asked to make a study of existing designs or procedures to promote a better understanding of them - or to attempt a generalization of apparently disconnected experiences into a more unified set of principles. In other words, to aid the translation of "art to science".

CONTINUING EDUCATION ACTIVITIES

Another most important area of activity is our "formal" continuing education activities. In the last four years we have run a dozen short courses or conferences on noise control and compressor technology. I say "formal" because we are always involved in continuing education of company employees during our frequent contacts with sponsors. This October (1974) we shall branch out into another area related to our expertise - "Improving Efficiency in Heating, Ventilating and Air-Conditioning Systems and Components". This Compressor Conference, as with others, involves cooperation between university, industry and technical societies. In the case of the October conference we also have the cooperation of the Federal Government, the National Bureau of Standards, because of their strong activity in energy conservation measures and because of the national character of the conference. Cooperation from them comes in the form of a sizeable grant which will help pay the costs of the conference and thus help keep the fees down.

I think that a word about conference costs may be in order. The cost of this Compressor Technology Short Course and Conference will probably be between $20,000 and $30,000. I won't know exactly until all the bills are in. Yes, in this period of inflation, actual costs can be that high even with author prepared mats and the cooperation obtained from professional societies and others in the form of help with publicity and travel. These high costs are the reason that technical societies cannot develop many such speciality conferences separate from their usual meetings. Cooperation among all groups therefore is needed in order to keep the costs down. A little arithmetic shows no one is making money on this conference. I shall be happy to know we are not in the red when all the accounting is complete.

Why are these costs so high? Well, firstly, they must cover the cost of printing the proceedings and texts. Publicity, especially in the form of direct mailings, is another major item. Finally, it is necessary for the University to release some time of the professors, especially for the work associated with the short course texts and conference proceedings. In our case, the state of Indiana requires that Purdue recover appropriate portions of the salaries of these people.

Finally with respect to costs, state institutions are not allowed to make any money on the average with such ventures. Fees are established with simple arithmetic by dividing the estimated costs by the estimated attendance. To make sure this philosophy works, the State Board of Accounts does detailed audits of our business procedures and accounts. By the way, this philosophy and accountability holds true for all of the Herrick Laboratories operations.

I really think it more important to talk about the other aspects of this Compressor Technology Conference than the budget. In developing the conference the Advisory Committee was interested in the following goals:

(1) Bring together recognized authorities to present review papers.

(2) Bring together recognized authorities to present current practice papers as well as state-of-the art of research papers.

(3) The development of proceedings which can be used by compressor designers as a reference manual.

Obviously, to achieve these goals it is necessary to have the greatest cooperation between industry, the university community and the professsional societies. To a great extent the proceedings of the 1972 Compressor Conference is being used as a reference manual. Our Advisory Committee believed the other goals were met as well by that conference. Thus, they recommended another this year. Personally I believe that we will again produce another useful book of proceedings and again meet the other objectives.

This year cooperation from professional societies has been even better than before. Thanks are due again to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Central Indiana section of the American Society of Mechanical Engineers (ASME). In addition we welcome the cooperation of the Design Engineering Division and the Fluids Engineering Division of the ASME and also the Compressed Air and Gas Institute.

Cooperation from our colleagues at other universities has been good. Papers based on work at eleven universities, nine from overseas, will be presented.

Industry again has been cooperative. We hope that this reflects their assessment of the worth of our conferences. Twenty-four companies (including four from overseas) have submitted papers. Industrial papers are necessary if we are to have a good balance between science and practice. In 1972 papers from industry represented 60% of those in the proceedings. This year the number has dropped slightly to nearly 55%. In my opinion, to be a success, future conferences should have a greater proportion of industry papers - not a lesser proportion. Industry benefits more from these conferences than professors do. Industry benefits cannot continue unless industry contributes.

Professor Soedel, as chairman of the Organizing Committee speaks in the Foreword of the Proceedings about "sensing some reluctance on the management level of some companies to encourage publications by their engineers." He speaks of the advantages of having one's work stand the scrutiny of one's peers - of satisfactions derived from recognition - of an opportunity for management to compare its technical position with its competitors - of the time for preparation of manuscripts - and of the role that company review boards play in publications. If industry does not encourage their staff to publish, then how can the academic community be aware of recent developments in industry?

If these conferences and other cooperative technical activities in our professional societies are considered useful to industry, then industry must support them. If industry does not, these activities will certainly degenerate into sterile, academic exercises of small value to industry. Each of you in industry should encourage your company to cooperate with strong technical contributions - not only at our Compressor Conferences, but at other worthy technical informational activities of universities and technical societies.

THE HERRICK LABORATORIES COMPRESSOR PROGRAM

I think it appropriate to comment on the Herrick Laboratories Compressor Research program. It started slowly in the late 1950's with studies of noise and fatigue life - primarily of compressor valves. I remember well my first trip to Ted Rundell's office at Tecumseh Products Company. Ted was vice-president in charge of engineering. How naive I was when I thought it would be a simple thing to apply my experience from the jet engine industry to "simple" refrigerator compressors. I proposed to simply apply strain gages to the compressor valves while they were operating in situ - then relate stress levels to fatigue life, and frequency content to noise. I need not bore you with details, but we soon found out that the fatigue life of the gages was much below that of the valve material - that the space needed by the gage and wires significantly changed the small clearance volume - that the fatigue life of the wires and solder connections was a significant factor - etc., etc. We almost gave up after several months of frustration, but succeeded adequately (several minutes of compressor running time then) to obtain reproducable results. They were feeble results by today's standards but they provided design insight not available by other means at the time. Those measurement techniques have been improved considerably and now, I venture to say, are a part of the development process in virtually every company producing refrigeration compressors (and probably other types of compressors, too).

To be fair, I should caution that there are still some compressor valve configurations which tax the most competent strain gage installers. Further, we are still trying to predict the life of valves from strain gage measurements with only limited success. Although a design change was made for noise reduction even from those first measurements, the general problem of measuring vibrational and acoustical energy flow through a compressor from source to receiver is still a matter of research.

To show just how simple minded I was in the beginning, I thought that only a few theses would be needed to produce a mathematical model adequate for stress and performance predictions. Over a decade later and many, many theses later (elsewhere as well as at the Herrick Laboratories) we still are devoting much research effort to compressor modelling and much time to this subject at this conference. But here also, though our successes were limited in scope, they were adequate to be used and are used today by some compressor designers.

Since starting our compressor research program some fifteen years ago we have produced 50 theses on, or related strongly to, compressors - 19 Ph.D and 31 MS theses. With the exception that some of the later ones have not yet been released from the confidential list because of agreements with sponsors, the Ph.D theses are available from University Microfilm, Inc. and the MS theses through the Purdue Libraries Inter-Library Loan Desk.

With respect to valves, our program has been quite extensive. In the vibration and reliability (or stress) area, we have worked on both reed and plate valves. Failure studies have been concerned with flexural and impact stresses as well as materials. Mode shapes have been studied experimentally and theoretically by both the Rayleigh-Ritz and finite element methods. Regarding experimental stress analysis, photostress, Moire and photoelastic methods have been used - but the bulk of the work has been with strain gages. Simulation models (i.e. enlarged models) and scaling problems have also been used.

Additionally we have worked in the area of flow through valve assemblies. This has been in connection with flow and drag coefficients and noise radiation. The dynamics of the flow in the valve and port area were also considered in some studies.

Noise and vibration of compressors has been another area of considerable study. This includes vibration isolation externally and internally - also shell vibration, and radiation from the shell and secondary surfaces. Energy flow from the cylinder area to the noise radiating surface is also a matter of current research.

Thermodynamic studies of compressors and systems has been another area of study - including various heat exchanger studies - losses within the compressor - gas properties -system studies - and many others.

An area of large concern has been gas pressure oscillations. These oscillations occur within the plenums, between the shell and the compressor body - and along the connecting pipes. They give rise to noise, can cause mechanical failure by exciting vibration of parts - and can interfere with performance. Special attention to these problems should be made when multi-cylinder compressors are used. Prediction of these oscillations and their dependence on design parameters and operating conditions is an area we have studied extensively.

Another area of study has been the kinematics of various positive displacement compressors. This included some design studies of motors and studies of the interaction between the compressor and motor.

SUMMARY

I hope you now have a better understanding of what the Herrick Laboratories are and how they came to be. In my opinion they are truly a cooperative enterprise with industry primarily but also with the federal government and professional societies. To continue to provide service to industry they must continue to be supported by industry. I envision other similar university laboratories with a strong industrial involvement to emerge. I think that will be good for engineering education, for industry, and for society. Perhaps this discussion will help those who contemplate similar ventures.

Not too long after our first feeble successes with compressor research, Ted Rundell predicted that a new design text would come out of those humble beginnings and that I would be the author. I argued that I did not think so. I believed that I could not write such a design text, because I did not have the broad industrial experiences necessary to qualify as a good compressor designer. Well, of course, both of us were partially right. These two books of compressor proceedings (the 1972 and 1974 editions) in a way do act as a substitute for the text he predicted. Also note that except for a few papers, I did not write these books - you did!