The Canadian Academy of Engineering

ENGINEERING RESEARCH IN CANADIAN UNIVERSITIES

This document has been prepared by the following Task Force of the Academy.

Chairman: Gordon Slemon
Members: Pierre Belanger
Walter Curlook
James Ham
Edward Rhodes
John Roth

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EXECUTIVE SUMMARY

Engineering researchers in Canadian universities could be making a much greater contribution to the well being of the country. Improvements in our economy and our welfare are closely linked to the kinds of research and development which will improve our competitiveness and enhance the quality of our products. Achievement of these improvements will require engineering research more than any other and should be accomplished through a greater cooperation between the universities' engineering faculties, industry and the other elements of the user society.

Regrettably, much of the research conducted by engineering professors and their students is directed more toward contributing to the world's store of scientific knowledge rather than to the solution of engineering issues of significance to Canada.
A basic reason for this bias in the orientation of Canadian engineering research is to be found in the general criteria used by our universities in the recruitment, promotion, and rewards for professors. To a considerable extent, research funding agencies have employed similar criteria and have contributed to this bias.

This document has been written to stimulate discussion of this important issue by members of the engineering profession, governments, industry, funding agencies, and, in particular, faculty and administrators of Canadian universities. A number of guiding principles are advanced for consideration and as a prelude to the formulation of specific policy and program revisions.

Among the suggested principles are:

- a dedication by engineering professors to increase their contributions to the solution of present and future issues of Canadian society,

- the adoption by universities of evaluation criteria for engineering professors that are different from those applicable to many of the university's other learned disciplines, and that, while retaining respect for quality, reflect the special role of engineering in society,

- the development of programs of engineering research funding that promote a closer and more effective linkage between engineering professors and the major users of engineering research in industry, government and society.

- a major involvement of users of engineering research in the review panels of the research funding agencies and a significant involvement of these users in university evaluation processes.

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Purpose

This document sets forth some of the principles which should guide the formulation of policies on research in the engineering faculties of Canadian universities and influence the manner in which such policies are applied. The document is intended as a basis for discussion prior to the development of specific programs of implementation.

Target

The target audiences for this document are members of the engineering profession, governments, funding agencies, industry, and, in particular, faculty and administrators in Canadian universities.

What is Engineering?

- Set in a social context, engineering is a profession concerned with the creation of new and improved systems, processes and products, to serve human needs as they are expressed by individuals, communities, governments and corporations.

- Its central focus is design, an art entailing the exercise of ingenuity, imagination, knowledge, skill, discipline and judgement based on experience.

- The practice of professional engineering requires sensitivity to the physical potential of materials, to the logic of mathematical analysis, to the operational principles of processes and systems, to the constraints of human resources, physical resources and economics, and to the social and environmental context for society, now and into the future. The professional engineer may be a specialist in a particular area of expertise, but must also be a generalist.

What is Engineering Research?

- Engineering research is concerned with creating information, concepts, principles and programs on which the design and production of engineering products and systems can be based.

- Engineering research utilizes and extends the knowledge base of mathematics and of the various disciplines of the physical sciences, particularly physics, chemistry, metallurgy and geology.

- The knowledge base of the physical sciences and mathematics serves engineering by enabling the establishment of bounds for those operational principles which can be realized in both hardware and software.

- The extension of this knowledge base in engineering research occurs through studies of materials, processes and mathematical formulations that deepen understanding of what can be practically achieved. This aspect of engineering research is commonly called engineering science.

- Much of the continuing research and development in what is known as classical science is done by engineers in the context of engineering science. This research develops the understanding and insight needed for effective design.

- Engineering is not, therefore, simply applied science. It develops and utilizes a distinctive body of operational principles to be realized with materials, devices, products, processes and systems. It also draws on a range of other disciplines including economics, psychology, human relations, the life sciences and management. In its application, engineering is inherently multidisciplinary.

- In contrast, the basic objective of pure science is the discovery of fundamental knowledge and the creation of a deeper understanding of the physical world. Fundamental knowledge is distinctive in that it establishes general principles applicable over diverse circumstances. The quality of basic science is judged by its generality and verifiability. The competent judges of scientific accomplishment are other pure scientists of stature, i.e. a peer group.

- There is a continuum of research and development from basic science through applied science to engineering. Across this spectrum, the focus shifts from pure contributions to knowledge towards satisfying the immediate needs of society. The time scale for the usefulness of results becomes shorter as the production of a particular product or system is approached.

- Most pure research is carried out in universities and government research establishments. Engineering research is often performed in universities when it is pre-competitive in an industrial context and when it is of a medium-term to long-term nature. As the objectives become more competitive, more immediate, and more specifically dependent on the circumstances of end use, engineering research and development is normally carried out in industry.

Objectives of Engineering Faculties in Universities

- The research role of engineering faculties in our Canadian universities can best be seen in the context of their overall objectives. A primary objective is education:

    - to prepare students for entry into the engineering profession.

    - to provide advanced levels of education for those in the engineering profession who plan to focus on research, development, teaching and the management of technological enterprise.

    - to provide a source for the continual upgrading of aspects of the education of members of the engineering profession.

- A major objective is to contribute to the body of useful engineering knowledge and understanding through research and development, with a view to enabling the creation of improved products, processes and systems to serve the needs of society.

- In universities, the processes of engineering education and of engineering research are closely linked and interdependent. Most fields of engineering are in rapid evolution and change. A sensitivity to what is happening at the frontiers of both the sciences and the marketplace is necessary to the evolution of relevant educational curricula and programs. Involvement in research and development projects is therefore an indispensable aspect of the formation of competent engineers.

- Members of engineering faculties in universities are in an advantageous position to link simultaneously to the sources of new knowledge in the basic sciences and to the needs of the user community in industry, government and society, with a view to creating new concepts and innovating new processes and products.

- Engineering faculties in Canadian universities have a distinctive role in research and development because Canada

is an advanced, technologically-dependent society with very few, large, high-technology companies doing their product development in Canada. In the past, Canadian industry has been dominated by branch plants which typically manufactured products but did little or no research. Many of these are now moving to regions of lower costs. There is a need in Canada to develop more new ventures with special niches in the world marketplace. Engineering research can contribute substantially to the development and success of such ventures.

- A close linkage of engineering professors and students to industry can provide a valuable resource to such companies during product and process development, particularly for companies with few research and development personnel. This linkage can also provide a flow to the company of new engineering talent who, in addition to being educated in an environment close to industry, provide the best means of technology transfer from the university to industry. This linkage is of value not only to the so-called advanced technology companies but also to the broad array of companies involved, for example, in construction, forestry, agriculture, and mining.

Engineering Research in the Context of the University

- With few exceptions, engineering education and its associated research in Canada occurs in multi-faculty universities. Engineering professors and students are therefore subject to the general policies of these universities.

- The ability of engineering faculties to carry out their education and research objectives is constrained by some of these policies and practices. An understanding of these constraints is important in arriving at more effective policies for the future.

- The objectives of research in engineering faculties differ in significant ways from those of many other university disciplines. In the pure sciences and in much of the arts and the humanities, research and scholarship are characterized by an emphasis on contributing to basic specialized knowledge. The target audience for the results of such research is the world research community in the pertinent specialty. Peer groups in each specialty review research results to ensure integrity and provide judgement of quality. While the knowledge discovered may ultimately be made useful, utility is not normally a basic criterion. An additional feature of such basic research in the sciences is

that its focus is often on the seminal breakthrough which opens up new areas of investigation. These seminal breakthrough concepts usually come from a few gifted individuals.

- In contrast, the emphasis in engineering research should be, and, at its best, is characterized by:
  - a contribution to the solution of a particular real or perceived problem or opportunity in society
  - a focus on the timely and economic meeting of the needs of the user
  - a close linkage and sensitivity to the industries that are manufacturing the products and using the processes, and to the agencies that are operating the engineering systems
  - a distinctive body of innovative operational principles related to the design, synthesis, optimization and control of the hardware and software of processes, products and systems
  - an application of existing knowledge to create and improve the physical systems that serve society
  - a combining of knowledge and experience derived from many disciplines to meet the needs of a variety of groups or individuals in the user society in the most effective manner
  - a different view of specialization. While specialization is usually necessary to pursue particular foci of research, the end objective requires integration of the research results into a generalist approach to the user's problem
  - a different view of publications. Engineering research publications should be motivated by progress toward eventual practical application. The eventual primary audience for research publications in engineering should be the members of the engineering profession who have the potential to use the results in their designs and operations. Communication to other research specialists is also required for the same reasons as with basic sciences, but this should not be the sole or even the primary objective.
  - a different view of team efforts. Much of engineering research and development must frequently be done by groups or teams.

- the view that leadership in engineering research is likely to come from the gifted generalist in perceiving the needed direction for effort to serve the developing needs of society

- the conviction that the significance of engineering research depends on the impacts that newly developed or improved operational principles have on the long term quality of life in society

- Universities have set up policies and processes to measure and promote quality in the professorate. Criteria, common to all disciplines, are established for the initial recruitment of faculty, for the review processes prior to achievement of academic tenure and for promotion to full professorship. These criteria tend to be dominated by the values of the majority, i.e. the basic sciences, the arts and the humanities. It is frequently difficult in the university community to argue successfully for criteria suited to the character of those disciplines which have professional objectives arising from their close interface with areas of society. Generality in policy is favoured by central administrations, both of universities and of faculty associations.

- Although the policies of many universities may call for equal weight to be given to teaching and research in the evaluation of professors, accomplishment in research is almost always the dominant factor in practice. A major reason for this fact is that research efforts are normally well documented as an essential and funded part of the research process and can readily be measured by the acceptance of research papers in properly reviewed journals. Education is arguably the university's primary role. However, documentation of educational accomplishment, is much more subjective and therefore more difficult. Some universities have included in their policies an evaluation category of creative professional accomplishment. The same difficulty arises in providing documentation of such accomplishments acceptable to university committee personnel who are frequently not familiar with the profession.

- Since success in the university environment has become so identified with research accomplishment, the emphasis on recruiting new professorial staff tends to be focused on the doctoral research which normally precedes faculty appointment. The search is primarily for potential research stars.

- New staff members experience pressure to produce research results quickly in the first few years of their appointments in order to ensure the granting of tenure and a continued

growth of research funding. This circumstance favours specialization and the production of a sequence of small research contributions in the chosen specialty. In the current university environment, junior engineering professors would be ill-advised to address engineering research problems requiring the acquisition of major additional breadth, experience or facilities which might delay the production of evidence of research accomplishment.

- The pressures for research production are such that engineering professors must restrict the time that they can allocate to interaction with the profession, with industry, and with the user communities. Consulting, which is recognized as an excellent means of useful interaction, is discouraged by the system, particularly in the important early years.

- The perceived criteria for success in the university tend to lead engineering professors into producing research results which will be accepted by the reviewers and editors of journals, most of whom are academics or are closely related researchers. The primary target audience has become the research peer group rather than the user group. Utility of the results has too often become a neglected objective.

- To understand the effect of these university pressures, it is important to recognize that most of those being recruited to professorships in engineering are very able people who generally have outstanding academic records. They expect to succeed in their new roles and, accordingly, they act within the existing rules to advance their chances for success. If this process does not produce the results desired by those setting the objectives, the fault is not with the junior professors, but rather with the rule makers and the systemic preconceptions in applying the rules.

Engineering Research in the Context of the Research Funding Sources

- In the main, university research in Canada is funded by agencies which are external to the universities and which receive their funds from government sources. A majority of this funding is provided by the federal government, although there is an increasing involvement by some provincial governments. A small proportion of the funding comes from industry and from private agencies. In general, funds for education are provided from provincial governments and from student fees.

- The criteria employed by the major research funding agencies in making grants are similar to those of the university researchers that they fund. In an agency such as the Natural Sciences and Engineering Research Council (NSERC), the majority of the recipients of research grants are in the basic sciences. Therefore, it is not surprising that there are pressures generally to adopt the research criteria of these basic disciplines. Among these pressures are:

    - An emphasis on individual research excellence. This emphasis is highly appropriate for the basic sciences. However, it tends to discourage group and interdisciplinary research which might be more suitable for many engineering projects.

    - An emphasis on good funding for research stars, combined with a policy of dropping funding from researchers who have not produced evidence of research results in the past two to three years. This policy appears to favour incremental projects to be reported in a series of short papers, a process which is effective in many basic disciplines. In engineering, a single major publication giving a comprehensive view of an integrated project would usually be of much more value to many users.

    - The accepted reviewed paper as the primary measure of research productivity. This is usually a good criterion for the basic sciences and thus tends to be adopted for engineering disciplines as well. Generality in policy throughout an agency is simpler than differentiation.

    - Documentation and publication of research results in the form of published papers is considered as an integral part of the research process funded by the public agencies. There is no similar incentive to produce reports on engineering projects funded by industry and to have these reports evaluated by a peer group.

- NSERC has made significant attempts to address many of the issues raised in this document. Its criteria for the evaluation of the applicants and their research proposals have been extended to include internal reports, patents and evidence of industrial interaction. Applicants have been encouraged to emphasize innovation and impact. However, these measures have had only a limited effect in changing the nature of engineering research in the universities. Engineering professors have frequently seen these changes as demands for still more documentation in their grant requests. There is still a lack of sufficient incentive to shift the emphasis toward research conducted in cooperation with

industry. The professors still regard evidence of research paper production as the essential ingredient in a successful application.

- In an attempt to achieve generality of policy, the criterion of interaction with industry promoted by NSERC has been implied even in pure disciplines where it appears to be inappropriate. This circumstance, actual or perceived, has lead to the voicing of deep concerns by researchers in the basic sciences about the steering effect of such interaction. This concern has achieved much greater publicity than has the welcome that engineering researchers extend in principle to industrial interaction.

- The criteria of the universities and of the granting agencies have had a strong steering effect on both national and international engineering societies leading to a bias in many engineering journals toward science and away from comprehensive engineering criteria. Many of the editorial boards are dominated by engineering professors who have an interest in a ready avenue for publication, since this is a requirement of their success. Instead of a focus on providing the user with useful information from research results, the journals are too often seen as a means to publish contributions on which academic and research status and advancement depend.

Some Guiding Principles for Engineering Research in Universities

Canadian engineering schools have good to excellent standing. The average Canadian engineering faculty provides both better education and better research output than the average faculty in the United States of America. The best engineering departments in Canada have achieved a status comparable to some of the top ten in the USA. To build on this good base, we need policies which will produce the results to serve Canada well in the difficult, rapidly changing years of evolution ahead. Just as our industry looks increasingly to Japan for role models of quality in design and production, our engineering schools need to look at the best technical universities of Europe as role models of industry-university interaction. The following are some of the principles which should guide the development of engineering research in our Canadian universities:

- A central dedication by engineering professors to contribute to the solution of present and future problems of Canadian

society, in so far as they fall within the broad scope of the engineering profession. While science is properly international or non-national in its outlook, engineering practice is, by its nature, focused towards the communities it serves. Since engineering research must be oriented toward eventual application, it is proper that Canadian engineering professors chose to direct their efforts toward problem areas with Canadian needs in mind. The impact of this engineering research may however be made international through the efforts of Canadian companies and consultants working in an international context.

- An acceptance by university leaders that the criteria of performance applicable to engineering professors need to be different from those which pertain to many of the university's learned disciplines. These criteria should be no less stringent with respect to quality.

- An acceptance by university leaders and funding administrators that engineering research is essentially multidisciplinary, and that it frequently involves team work. Such synergistic skills of engineering researchers should be recognized, encouraged, and rewarded.

- A recognition that measures of research success which are pertinent for engineering research in universities include the discovery and initial development of potentially useful materials and processes, the innovative formulation of operational principles for the design of practical processes, products and systems which can eventually serve user needs, the creation and evaluation of exploratory designs, and the investigative study of risks and the causes of failures. Documentation and verification of these measures is more difficult to achieve than is the documentation of peer reviewed papers in the sciences.

- A significant involvement of leading users of engineering research in the processes of appointment, tenure decision and promotion for engineering professors. Such persons can ensure that the broader criteria for engineering are effectively implemented. In the past, many of the persons, external to the university, who have participated in these processes have been researchers in large industries with sophisticated research establishments. While these researchers make a valuable contribution, they do not always reflect the needs of a majority of the engineering and consulting industry.

- A clear recognition by funding agencies that engineering research should respond to criteria which are distinctly different from those of the basic sciences. The end result of an engineering research project may more properly be a design, an artifact, a process, or a system concept than a research paper.

- A major involvement of users of engineering research on the panels of the funding agencies which provide support for university engineering research. Some of these may themselves be researchers. However, the role of the non-academic persons on these panels should be mainly to assess the value and relevance of the proposed projects in the user community.

- The introduction and extension by the funding agencies and by government departments of programs which encourage linkages between engineering professors and Canadian industry in the conduct of joint research of a medium-term to long-term nature. An excellent example is the Cooperative Research and Development Grant program of NSERC.

- A recognition by industry that universities are committed to the free dissemination of research results, and are therefore not in a position to undertake proprietary research. However, pre-competitive research undertaken in engineering faculties in cooperation with industry can provide a sound basis for the innovation of competitive products and processes for the world market. In addition, consultancy by engineering professors can continue the linkage to industry in competitive situations.

- A recognition that incentives are needed to attract both engineering researchers in universities and personnel in industries to undertake cooperative projects. It is an appropriate role for governments to provide such incentives. These incentives must be strong enough to encourage approaches to universities by companies who have no previous history of such interaction, and, in some instances, no previous involvement in research and development. From the viewpoint of the engineering professor, the process must be made both simple and rewarding. For such incentive programs to be effective, there must be reasonable limits on the demands by supporting agencies for documentation in the initial application and in the regular reporting on interactive projects. A major criterion for support should be the willingness on the part of both the professor and industry to devote time and resources to the project.

- A recognition by governments that a major share of the funding for engineering research projects carried out jointly by engineering faculties and industries must come from resources provided by these governments. In general, these projects are at a pre-competitive level. The results of the research are openly available. Much of the value of the work is in the educational development of the students involved. Some of our larger firms can afford major support for research in universities. However, the financial investment

that most of our smaller emerging industries can be expected to make for this type of research is limited. While a small financial contribution by an industrial firm is a valid measure of its commitment, an investment of time by the industrial partner is frequently of much greater value in contributing to the research and to ensuring the effective transfer of technology.

- The maintenance of a broad base of support for the research of engineering professors. In the interests of good education alone, most engineering professors should be involved in some aspect of engineering research and/or practice. In the interests of an adequate supply of graduates with advanced-level education, most if not all engineering professors should be directing the work of several graduate students. Essentially all of these engineering professors involved in research and graduate supervision should receive some sustaining support. Most universities have not been in a position to provide such support from their base budgets in recent years.

- A revised rationale for the proportioning of research funds between the sciences and engineering. It should be recognized that there is a wide potential market for advanced engineering graduates in the newly-emerging, advanced technology industries on which much of our future high quality employment and prosperity depends. In contrast, the market for researchers in the basic sciences is relatively smaller and is dominated by the universities themselves.

- A revised interpretation of the role of the NSERC operating grant program as it applies to engineering. Many of the most successful engineering researchers find that their NSERC operating grant funding is frequently best used to start projects of a fairly fundamental nature and to explore their possible applications. Such projects provide good grounding for graduate students. The funding policies should be so framed that, if and when the project shows sufficient potential and relevance to attract the attention of a potential user, an industrial partner should usually be sought for the continuing, often major, development of the project. At this stage, the researcher and the industrial partner should access one of the support programs targeted for joint industrial/university research and development. With this combination of sources for research funds, the good professorial researcher can be adequately supported in carrying out major research and development efforts of national relevance. This approach relieves NSERC operating funds of the pressure to provide engineering researchers with all of their required research support.

- A reexamination of the structure of NSERC. Consideration might be given to a greater bifurcation of NSERC to permit

more latitude in interpreting the needs of engineering research and in devising mechanisms to serve these needs without impinging on the interests of researchers in the basic sciences. A basic issue in NSERC is who should be funded. The principles outlined above suggest a broad base of support with limited maximum funding from the operating grant sources for engineering professors. Beyond this base funding, the programs involving industrial and user interaction must be made the most attractive avenues for support as seen by these engineering professors. In contrast, researchers in the basic sciences frequently receive their sole research support from the NSERC operating grant program. To enhance the probability of significant breakthrough results, it may be most appropriate for NSERC to focus in the sciences on a relatively few outstanding researchers rather than to attempt a broad base in these disciplines. Such a policy is however inappropriate for engineering.

- In establishing new policies for the support of research, NSERC should take account of the fact that engineering professors work in a broad spectrum which, on the one hand, merges through engineering science with that of basic research and, on the other hand, merges with industrial product development . A significant number of professors in faculties of engineering carry out research in established areas of basic sciences which have been largely abandoned by academic researchers in the physical sciences and mathematics. Engineering professors should therefore have access to funding for which the criteria extend across this spectrum.

- Government departments at both the federal and provincial levels should become more involved in direct funding of engineering research and development to be carried out by industry and engineering faculties in cooperation. In this way, the direct involvement of the user community can be enhanced in assessing the importance and relevance of projects to be undertaken. The establishment of federal and provincial centres of excellence has provided useful experience for extension of this approach in the future.

Subsequent Action

This document has been written to stimulate discussion of the principles which should apply in formulating policies and practices relating to engineering research in Canadian universities. The Canadian Academy of Engineering invites your

comments on the issues raised and your involvement in promoting action in the continuing process of implementation.