THE RELATIONSHIP OF THE ENGINEERING COLLEGES TO THE DEFENSE PROGRAM

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The part being played in the defense program by the engineering colleges cannot be reported completely by one person because each institution is contributing in ways appropriate to its location, staff and facilities; it *is* possible, however, to present a general view of the situation together with some of emergency measures adopted to meet the increasing demands made upon these institutions.

In a recent issue of "Military Engineer," Charles P. Summerall, formerly Chief of Staff of the United States Army, wrote as follows:

"Modern warfare is the greatest engineering operation in which mandkind has ever engaged. The employment of machines driven by a prodigal expenditure of mobile mechanical power has multiplied a thousand-fold the range, speed, and destructiveness of the implements of war; and has correspondingly added to the magnitude and complexity of the technical problems involved. In the vast total effort that is modern war, there must be mobilized all the skills, techniques, and productive capacity of science and technology to construct and operate a gigantic assembly of machines against an enemy who is equipped with a like assembly of weapons. It can well be that victory will be with the combatant who possesses superiority in technical skill. The change in the tempo and magnitude of miltary operations is the direct result of the mechanized equipment that engineers have put into the hands of soldiers; and, while strategy and command remain the function of the soldier, the engineer has emerged as a key figure in modern warfare. It is urgent that he play the role which destiny has cast for him. Without superlatively good engineering in the national war effort there will be no military victories. . . . The increasing responsibility of engineers in national defense does not end with implementing the nation and its armed forces for the shock of war. Their role in the theatre of operations has ceased to be a mere auxiliary function. Before the days of mechanization, the work of engineers in combat was characterized by makeshift and temporary expedient; now, both in preparation for war and in actual military operations, there must be projected the highest degree of technical skill. The effective employment of the intricate mechanisms now used in war —ranging from the flying fortresses of the air to ships that range the ocean bottom — can not be left to unskilled or hastily trained operatives. The skilled commander will make his dispositions and assign objectives to the mighty array of men and machines that make up his army, but the engineer must follow through to assure that these machines function. It is true that the essentials of the art of war have not changed, nor has the importance of the courage and will to win of the individual soldier lessened, but it is equally true that the introduction of mobile mechanical power to operate a vast mechanical military force of incredible speed, range, and hitting power has made of a battle a joint military and engineering operation. The technical skill with which the mechanism of battle is operated may be the determinant. That this indispensable superiority be achieved is the function of the engineer in battle."

This statement emphasizes the importance of the engineer in both his civilian and military capacities.

Although engineering students form a large percentage of the reserve officers commissioned through the R.O.T.C. units, the engineering colleges do not directly participate in military training. For this reason, I will consider only the civilian functions of the engineer in the defense program.

Scientists are inclined to regard engineering as the mere application of the physical sciences but this conception is incomplete for professional engineering also involves the restraints and limitations imposed by psychological, economic, and social considerations. It is true that engineering education deals largely with science and its quantitative application but, following his formal education, the engineering graduate must serve what amounts to an apprenticeship in order to gain the practical experience necessary to round engineering judgment. The engineering diploma is less a certificate of competence than a permit to start learning engineering practice. This necessary combination of experience and formal education in the development of a professional engineer is a formidable obstacle to an abrupt increase in the number of engineers available to the defense program.

ENGINEERING ECONOMICS

The aim of engineering design, at least in peace time, is to produce machines, processes, and structures which are no more expensive than necessary to perform the desired function with, of course, adequate factors of safety to offset uncertainties in the quantitative specification of this function. To do less results in failure and to do more reduces profits. In the defense program, cost does not play so direct a part in design but a limitation of similar character comes into play. To design beyond the requirements specified is to deny needed materials and labor to other items in the program. In a nation working to the limit of productive capacity in order to supply armament, the greatest offensive power will be achieved by proportioning the number of items of each kind to the military requirements and by designing each item so as to require a minimum of labor and materials. The tempo and the objectives of engineering for defense are different but the principles and methods remain essentially unchanged and the time necessary to prepare for professional responsibilities cannot be materially shortened without impairing the competence necessary to conserve productive capacity. Deficiencies in men and materials are already apparent and the engineer should design even more economically for war than for peace.

Undoubtedly, you are familiar in a general way with the duties performed by engineers. Starting from a quantitative statement of the desired characteristics of the machine, process, or structure, preliminary theoretical or experimental studies may be necessary to decide on the general features of the design. Next comes a detailed consideration of every component part, resulting in drawings which present not only the dimensions but also the materials, tolerances, surface finishes, and all other specifications necessary for fabrication. The production engineers study these working drawings to determine the operations necessary to form each part, schedule the use of existing plant facilities, design special tools as required, and plan the sequence of assembly and the installation of accessories. A good illustration of the volume of engineering work necessary in defense industries is the fact that a typical heavy bomber is made up of approximately 25,000 different parts, each one of which represents a quantitative prediction that it will be adequate and at the same time be as light as possible. As many as 8,000 separate drawings may be necessary to inform the production department of what is required in the construction of a plane of this size.

In engineering design, a functional division of labor is possible. Details are worked out by draftsmen, computers, and other sub-professional workers and engineering design departments provide opportunities for men of varying skill and experience but there is in each industry a limit below which professional skill cannot be safely diluted.

Mechanization of warfare has increased the number of workers necessary to supply each man on active duty. A quantitative statement on this point must stem from somewhat arbitrary definitions but various estimates are roughly in agreement on a present ratio of about eighteen. The ratio of engineers to production workers depends on the industry and the production volume. Considering the engineering department as a whole, including sub-professional workers, the ratio in aircraft plants is around fifteen but is decreasing as production grows. In shipbuilding and in industry generally, the proportion of engineers is much smaller. Taking these figures in connection with the immediate production goal of 50,000 airplanes and 130,000 airplane engines, 40,000 guns, 300,000 machine guns, 380 naval vessels, 200 cargo ships, and 200 cantonments, to mention only the major items requiring a labor force running to millions, the reason for concern over the supply of engineers becomes apparent.

DEMAND FOR ENGINEERS

Because engineering design precedes production, the maximum demand for engineers should be felt early in the defense program and it is expected that the peak will be reached this year. An indication of the number required is provided by a forecast prepared by the Ordnance Department for the period July 1941 to June 1942. The figures are as follows:

Inspectors of ammunition, explosives, and material	7700
Tool and gage designers	105
Chemists and chemical engineers	840
Mechanical engineers and draftsmen	350
Metallurgists	35
Total	9030

The Ordnance Department represents only one segment of the governmental requirements for technical men in civilian capacities. A survey of the aircraft industry around New York City indicated a need for 5,000 engineers. Another estimate gives a total of 40,000 additional engineers needed for the country as a whole, after allowing for all possible shifts from non-defense to defense industries. The 1941 graduating class of recognized engineering schools will not exceed 14,000, of which about 4,000 will be taken by the Army and Navy. The experience of the engineering colleges this year in placing their graduates substantiates the conclusion that the present demand for engineers is two or three times the supply and may shortly prove to be much greater.

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The situation which has developed points clearly to the conclusion that, so long as engineers are needed and students are available, the greatest service the engineering colleges can perform is to continue their normal function. No other activity, however much its publicity value may appeal to administrative authorities, should be allowed to impair their capacity to educate men for professional engineering. Not only should they continue to perform their normal function but strenuous efforts should be made to improve instruction by placing greater emphasis on physical science and the analytical and experimental procedures required for its application while limiting specialized curricula and descriptive courses. Experience is better gained in practice than in the lecture room while the practicing engineer seldom has the time to master a subject involving analytical procedures. The transition from one field of specialization to another, necessary in the defense program, is not difficult for engineers well grounded in fundamentals and the return to normal engineering pursuits after the emergency will be equally facilitated.

PRODUCTION KNOWLEDGE NEEDED

Among the fundamentals which the defense program has shown to be inadequately treated in engineering education is a knowledge of the manufacturing and assembly procedures by which engineering designs are converted into finished products. Being common to all branches of engineering and susceptible to analytical treatment, this subject should be raised from the semi-vocational level in which it now appears frequently in engineering curricula. Many of the bottlenecks in the defense program can be traced directly to failure on the part of the designer to visualize the production process.

A common fallacy in the mind of the layman is the belief that the productive capacity of any given plant is the same regardless of the product. Differences in the permissible leeway, or tolerance, the arrangement and the relative numbers of different kinds of machines, the experience of the workers, and other factors may make difficult a transition to a new product. Careful study of existing facilties has resulted in many conversions from peacetime manufactures to their military counterparts but a large percentage of the armament is being produced in new and specialized plants. For example: it was proposed early in the defense program that abandoned automobile plants be reconditioned for the manufacture of airplanes but investigation showed that even the newest plants were unsuited to the purpose because the accuracy, number, and arrangement of equipment for automobile production do not correspond with the requirements of aircraft. In addition to the design function itself, much engineering work must be performed in preparing for and carrying out the production program but the engineering colleges have not sufficiently stressed this important function, with the result that a large majority of production executives are not college graduates.

EMERGENCY MEASURES ADOPTED

In order to meet the deficiency in engineers, the engineering colleges have adopted a number of emergency measures which will supplement the normal supply of new graduates.

The first need in many neglected or under-developed fields, such as naval architecture and explosives, was for experienced men to assume control of major divisions of design and production. The scarcity became acute immediately because there had been little opportunity during the previous twenty years for engineers to follow these specialties. It is indicative of the need that the civil service age limit for naval architects was raised to seventy more than a year ago. Although it was obviously impossible to *develop* experienced men, the engineering colleges through their formal or informal employment machinery were able to assist in locating the few men available. A similar activity aimed at assisting engineers to find positions better suited to their education and ability. During the years of the depression, many engineering graduates were unable to find suitable employment and a number of institutions circularized their alumni to find men who wished to transfer, either to a different industry or to more responsible positions in other companies. This adjustment of employment served to meet a part of the early need but it no longer represents a substantial supply and probably should not be encouraged at this stage of the program except where the transfer is from non-defense to defense industries.

One suggestion made when the scarcity of engineers first became apparent was that graduation of engineers be speeded up by omission of vacation periods and *non-essential* courses. The attitude of the Army, Navy, Office of Production Management and the Office of Education was not favorable for the reason that the emergency was likely to continue for some time and the regular curricula should not be altered. Practical difficulties of scheduling in large institutions would be serious but not insurmountable. The most serious objection to this plan is that a majority of engineering students must work during the summer if they are to continue their education. Much of this summer work is now in defense industries; these students make a direct contribution to defense and the experience gained compensates for the delay in graduation. Another consideration is that this speed-up program results in only one additional class, after which the number of graduates per year is unaffected.

THE E.D.T. PROGRAM

The most spectacular, and probably the most effective, work of the engineering colleges to date has been the Engineering Defense Training (E.D.T.) program authorized by Congress and directed by the U. S. Office of Education. Parallel to the governmental program at vocational level, the law provides for either pre-employment or in-service training at college level without cost to the student. Recognized engineering schools offer these courses to meet local defense needs and are reimbursed for expenses incurred. Within limitations imposed by the Congressional Act and the regulations of the Office of Education, the colleges administer the program. A recent tabulation showed that 137 engineering schools were offering 1500 courses to 95,000 students, a majority of whom were already employed. Subjects covered range through the whole field of engineering but courses in mechanical or industrial engineering predominate. The subject matter of these courses is generally characteristic of local industry or the lack of it. In the industrial areas, persons competent to take these engineering courses are generally employed and are unable or unwilling for financial reasons to enroll in full-time courses. The in-service program meets the need here for up-grading to permit greater engineering responsibilities. In regions remote from the defense industries, full-time programs appear to be feasible as preparations for migration to the defense production centers.

In California, E.D.T. courses are being offered by the California Institute of Technology, Universities of Santa Clara, Stanford University, University of Southern California, and the University of California. Between four and five thousand students are enrolled. The great majority of these students are employed in the aircraft plants and shipyards. With the exception of the University of California program, these courses are offered "on campus" with a large percentage of the instructors drawn from the faculty. In addition to classes on the Berkeley and Los Angeles campuses, the University of California offers courses at Mare Island Navy Yard, San Francisco, Burbank, Inglewood, Downey, Huntington Park, and San Diego.

The University of California program at San Diego is a typical example of the work done under the Engineering Defense Training program. Thirty-two sections of sixteen courses in such subjects as lofting, drafting, aerodynamics, aircraft inspection, analytical mechanics, strength of materials, airplane structures, metallurgy and aircraft power plant installation attracted a total enrollment of 1250 students of whom 850 were in attendance at the last count. The engineering population of San Diego probably does not exceed 2500. The prevailing working week for engineers is 50 hours and many of the students, particularly the newer employees who need this instruction most, are assigned to the engineering night shift, an arrangement made necessary by lack of space.

The usual course in the University of California program consists of one two-hour meeting per week plus approximately

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four hours of outside work. Students and instructors have been discouraged from attempting more than one course because of their arduous schedule of full-time employment. With few exceptions, the instructors have been drawn from industry. Frequently, the instructor is the senior engineer in the subject treated and the class is made up largely of his own subordinates. As teachers, these men are surprisingly competent, making up for their lack of experience by enthusiasm and knowledge of the subject. Recruiting almost one hundred instructors for predominantly lecture courses in a period of six weeks might easily result in embarrassing situations but, with the aid and support of the companies concerned and many hours of conversation with the prospective appointees, selections were made which resulted in a quality of instruction very nearly equal, on the average, to that in the regular engineering courses of the University.

In setting up these Engineering Defense Training courses, the immediate defense need has been given consideration and the courses have been outlined so as to carry the students as far as possible in the time available. Most of the students are subject to calls for overtime work and it was decided that scheduled class hours should be devoted as much as possible to lectures on fundamental principles followed by outside problem assignments which the students could work out as time permitted. The student's place of employment and his associations with other engineers working in the chosen field of study were expected to provide the practical examples of the principles discussed. Few of the courses have been devoted to descriptions of equipment and procedures.

The effect of this program will not be evident immediately but there are some indications of its success. Changes of assignment and promotions are known to have resulted directly from ability demonstrated in these courses. As a result of requests from the companies concerned, student grades and instructors' recommendations are submitted to the personnel offices on written request from the individual students. Senior engineers report that their supervisory work has been simplified because of the knowledge gained by their subordinates. It has been argued that student interest in these courses is not sufficient proof that they meet a defense need. The best answer I can give to this criticism is that students who spend 50 hours per week on the engineering night shift and then devote six to eight hours more to a study show a seriousness of purpose which cannot be ignored and I am sure that the knowledge these men gain is improving their regular work.

POST-EMERGENCY UTILITY

One aspect of the Engineering Defense Training program which deserves greater emphasis is the part which these courses may play, if properly planned and executed, in the transition to other employment after the emergency. My original conception of the function of the program was to aid graduate engineers to transfer to defense industries by giving them concentrated courses covering the special limitations and procedures of their new field of employment. However, examination of students' biographies has shown that this function should be secondary and that the primary objective should be that of up-grading men who have completed one, two, or three years of college work, or who have acquired equivalent knowledge through experience. A relatively large group in the University of California program are men who, in their enthusiasm to learn aeronautical engineering quickly, have been misled into studying at technical institutes offering miscellaneous facts about engineering rather than engineering principles. The technical background of these men is sometimes appalling in the light of their responsibilities. The objective of this program is to meet the immediate and urgent needs of defense. It is my contention that this need is most effectively met by a judicious combination of knowledge immediately useful with fundamental principles of engineering to fill out an irregular and inadequate technical background and thus permit a lifetime of truly professional work.

Research and experimental investigations at the engineering colleges have expanded with the increase of industrial activity but research directly related to defense is surprisingly limited. Individual faculty members have been taken for full-time technical employment in government laboratories but the colleges, as such, have not been called upon generally to mobilize for defense the staff time and facilities available, after meeting the primary requirements of instruction. Questionnaires regarding the qualifications of the staff and available equipment have consumed enough time in the aggregate to complete several research projects. Institutions which volunteered their assistance have encountered what seemed to be the implication in many cases that their effort aimed to serve their own advantage. There is no question but what the engineering colleges would be willing to divert their staff and facilities from present research activities to urgent defense problems, even without additional financial support if they were provided with an authentic statement of desirable projects. The engineering colleges are in a position to render assistance by research, testing, inspection, and consultation but somehow they must be informed of the problems to be solved.

My remarks have dealt with the work of the engineering colleges, a small segment of the defense program. To appraise accurately the importance of their activities requires a view of the program as a whole, which is difficult to obtain under rapidly changing conditions. On the basis of experience thus far, it appears that the greatest contribution which the engineering colleges can make will result from maintaining unimpaired their capacity to develop competent professional engineers.