EUROPEAN CONTRIBUTIONS TO AMERICAN ENGINEERING EDUCATION: BLENDING OLD AND NEW

Bruce E. Seely
Michigan Technological University

1.- Introduction.

As the 20th century comes to a close, one of the most striking developments, at least from the perspective of an American historian of technology, is the position of international leadership accorded U. S. engineering schools such as MIT and Stanford.[1] To some observers, this development is simply part of the general technological strength of the United States. But to others, the impressive record of 20th century engineering accomplishments that includes building the first atomic bomb and going to the moon represents some-thing more, something akin to proofof American uniqueness. This manner of thinking was born in the American political revolution of the 1770s and reinforced by the isolation provided by the 3000-mile moat of the Atlantic Ocean during the 19th century. Applied to technology, this thinking led many Americans to view their record of invention and innovation as proof of an innate technological capability aptitude, which was labelled "Yankee ingenuity". This inventive aptitude, in turn, explained the growth of industry in the United States after 1800. Charles Goodyear, Thomas Edison and Henry Ford especially were celebrated as incarnations of this ideal.[2]

Historians of American technology have long known the shortcomings of "Yankee ingenuity" as an explanation for American technology. Most of us are uncomfortable with claims of national uniqueness in the arena of invention and innovation. We accept that national "styles" of innovation or technology exist, but also look for continuity and similarities.[3] "Yankee ingenuity" is an especially weak explanation for the development of American engineering education. Certainly features that reflect the particular and unique circumstances of the United States can be found in the growth of technical education in the U.S., but I will suggest that American

[1] This paper is based upon a presentation made by the author at an International Symposium: *Tècnica, Ciència i Universitat: reflexions de final de segle*, sponsored by the Centre de Recerca per a la Història de la Tècnica, Escola Tècnica Superior d'Enginyers Industrials de Barcelona, Universitat Politècnica de Catalunya, September 26, 1996. The author thanks to Professor Guillermo Lusa Monforte, Universitat Politècnica de Catalyuna, and his colleagues at the *Centre de Recerca per a la Història de la Tècnica* for the opportunity to participate in that gathering on the occasion of the 25th anniversary of the founding of the University. Much of the research on which this paper rests was supported by the U. S. National Science Foundation, Program for Studies in Science, Technology and Society: grant number SES-8711164 and SES-8921936.

[2] Examples of this thinking can be found in WILSON, Mitchell (1954) *American Science and Invention: A Pictorial History*, New York, Bonanza Books; COOK, Donald E. (1962) *Marvels of American Industry*, Maplewood, NJ, C.S. Hammond & Co.; and several books by Roger BURLINGAME, including (1938) *March of the Iron Men: A Social History of Union through Invention*, New York, Charles Scribner's Sons; and (1940) *Engines of Democracy: Inventions and Society in Mature America*, New York, Charles Scribner's Sons.

[3] For examples of national styles of innovation, see HUGHES, Thomas P. (1983) *Networks of Innovation: Electrification in Western Society, 1880-1930*, Baltimore, Johns Hopkins University Press.

engineering education rests upon a solid foundation borrowed from Europe. European influences were most evident during the first halves of the 19th and 20th centuries, while more original experimentation took place during the second halves of both centuries. As a result, engineering education in the United States reflects a blending of European elements with American conditions.

2.- The British Tradition.

In America in 1800, a student interested in engineering would have found no school with a course of study in this field. Not surprisingly, the entire profession of engineering was very weak. This was most evident in the effort to construct a 27-mile canal from Lowell and Boston in Massachusetts after 1793.[4] Few engineering projects in the new nation even approached the scale of this Middlesex Canal. Loammi Baldwin, a cabinetmaker and surveyor, was the company's engineer, but he and his workers were quickly overmatched by the demands of the project. They had difficulty excavating through rock and their canal bed leaked; they did not know how to design or construct the locks or the valves to let water into them. Worst of all, the surveying was so inaccurate that in one six-mile stretch the work was 41 feet off level!

The company soon turned to a British expert for help -- William Weston. An immigrant with no formal schooling, Weston experience on British canals left him better prepared for engineering work than almost any American. He ultimately assisted every large civil engineering undertaking in the U. S. during the 1790s, from a waterworks in Philadelphia to a canal on the Potomac. Weston visited Baldwin for eight weeks July 1794 and taught techniques like puddling the canal bed with clay to hold water, and showed Baldwin materials like natural cement mortar and new instruments and surveying tools. Weston encouraged Baldwin to build the locks of stone. Despite this sound advice, the canal was never successful.

This experience was repeated on other early American engineering projects and tells us much about the new country's technical capabilities. As historian Elting Morison observed, this difficulty "suggests that what knowledge of engineering existed was held in the minds of a few widely separated men; that the network for the retention and distribution of the available information was an unstable coalition of personality and accident; and that the means for enlarging the body of knowledge were insufficient and randomly assembled."[5] This situation changed only slowly. For many years, Weston and other apprentice-trained English engineers like Benjamin Latrobe were the models for Americans.[6] And like their British teachers, Americans earned their living as private, independent consulting engineers.[7] For example, Loammi Baldwin, who was an

[4] On the construction of the Middlesex Canal, see MORISON, Elting E. (1974) *From Know-how to Nowhere: The Development of American Technology*, New York, Basic Books, 18-36.

[5] MORISON (1974), 34.

[6] On Latrobe, see STAPLETON, Darwin (1982) "Benjamin Henry Latrobe and the Transfer of Technology," in PURSELL, Carroll W. (ed.) *Technology in America: A History of Individuals and Ideas*, Cambridge, MIT Press, 34-44; also STAPLETON, Darwin (ed.) (1980) *The Engineering Drawings of Benjamin Henry Latrobe*, New Haven, Yale University Press.

[7] The British tradition of apprenticeship may still be most clearly seen through Samuel SMILES, *Lives of the Engineers* edited with an introduction by Thomas Parke HUGHES (1966), Cambridge, MIT Press; also BUCHANAN, Angus (1986) "Education or Training? The Dilemma of British Engineering in the 19th

inexperienced cabinet maker when he started on the Middlesex Canal, later built a solid engineering reputation by learning from his difficulties. In the 1820s and 1830s he helped construct the canal and railroad across Pennsylvania.

Other Americans learned the craft of engineering while helping to build the Erie Canal, which opened in 1825 after eight years of construction. The canal stretched 363 miles from the Hudson River to Lake Erie, transforming communication between the Atlantic coast and the Midwest. As importantly, perhaps, it has been labelled America's first engineering school.[8] One noted Erie Canal alumnus was John B. Jervis. Born in 1795, he was working at his father's saw mill when an invitation came to join the construction project as an axeman in 1817. Within a year he was the surveying team's rodman; later he ran levels. In 1819 Jervis was appointed resident engineer for a 17-mile section, indicating that he had learned to survey, make estimates, draw maps and profiles, and manage projects. During the winters, he had read about mathematics, mechanics, hydraulics, architecture, carpentry, and mill-wrighting. By 1823, Jervis was supervising engineer for a 50-mile section of the canal that had opened.

Jervis had an outstanding career as one of the leading engineers in the country. He resigned from the Erie Canal in 1825 to join the team building the Delaware & Hudson Canal. Although listed as second-in-command, Jervis did most of the design work, including the plans for a section of steam railroad. Then from 1830-1833 he was chief engineer of the Mohawk and Hudson Railroad, before becoming chief engineer of the Chenango Canal from Binghamton to Utica, New York. But his most memorable work began in 1836, as chief engineer for the Croton Aqueduct, a project designed to carry water to New York City from a dam 41 miles north of Manhattan. Jervis designed the dam, the masonry aqueduct channel, bridges, tunnels, weirs, reservoirs, and other components. The project was dedicated on July 4, 1842 at a cost of $12 million. It supplied water to New York for more than a century.[9]

Over the next three decades, Jervis's engineered a number of railroads and other large projects. He was the model apprentice-trained engineer, and he did his part to bring others into the profession through the same route. He steadily advanced young men who worked with him into positions of greater responsibility. Jervis favored those from rural areas, comfortable with the rigors of outdoor living. Above all, he stressed practical experience as the primary method of learning to be an engineer. Latrobe and Baldwin felt the same way. Baldwin's staff, for example, always included young men who paid Baldwin $200 per year to learn engineering skills. In return Baldwin paid his "young gentlemen" for the work they performed.[10] And every mechanical engineer of this time went through an apprenticeship in a machine shop. Indeed, as Americans

Century," in KRANZBERG, Melvin (ed.) *Technological Education - Technological Style*, San Francisco, San Francisco Press, 69-73.

[8] Information on the Erie Canal can be found in TAYLOR, George Rogers (1951) *The Transportation Revolution, 1815-1860*, New York, Holt, Rinehart and Winston, Inc., 32-37; and CALHOUN, Daniel H. (1960) *The American Civil Engineer: Origins and Conflict*, Cambridge, MIT Press, 24-37.

[9] Information on Jervis can be found in LANKTON, Larry D. (1977) "The `Practicable' Engineer: John B. Jervis and the Old Croton Aqueduct", *Essays in Public Works History*, nº 5, September 1977; also JERVIS, John B. (1971) *The Reminiscences of John B. Jervis: Engineer of the Old Croton Aqueduct*, Neil Fitzsimmons, ed., Syracuse, Syracuse University Press; LARKIN, F. Daniel (1990) *John B. Jervis: An American Engineering Pioneer*, Ames, Iowa State University Press; and in MORISON (1974), 37-67.

[10] CALHOUN (1960), 47; STAPLETON (1982), 42.

visiting England reported, this avenue remained the standard way of entering the field.[11]

3.- Borrowing from Europe: West Point and Polytechnics.

Even John Jervis recognized, however, that field experience alone could not make one a good engineer. In 1830, he complained to James Renwick of Columbia College that even among the most eminent American engineers "there is doubtless a great deficiency in scientific knowledge. This in great measure may be attributed to the limited education of... those who were considered engineers without ever having made much inquiry into reason or principles of what they have been doing or its applicability to other situations."[12] At that time, those who sought more knowledge had to learn on their own, as Jervis had. The only obvious alternative was to attend the United States Military Academy at West Point which was the first engineering school established in the country. West Point was founded in 1802, and into the 1820s can be considered the only formal engineering school in the United States.[13] But like the apprenticeship models, the military academy drew upon a European pattern for inspiration, in this case the French engineering schools of the late 1700s.

West Point initially was the army's school for artillerists and engineers, established to end reliance on European technical advisers.[14] During the debates about the school's founding, George Washington and others proposed that the school function as a national university and train engineers for civilian and military purposes. But West Point began as a small-scale enterprise tightly tied to the army's needs; the first group of cadets numbered only 10. In 1817, however, Sylvanus Thayer was appointed superintendent and began building an engineering school modeled exclusively on French institutions.

Thayer's decision was almost natural, given the relationship the American army had developed with French officers during the American Revolution. French engineering schools, a product of the centralizing tendencies of that country's monarchy, were quite uniquely strong.[15] The École des Ponts et Chausees in 1747, and then the École des

[11] One account of a visit to Henry Maudsly's shop in England is in FERGUSON, Eugene S. (ed.) (1965) "The Early Engineering Reminiscences (1815-1840) of George Escol Sellers", *Bulletin of the United States National Museum*, nº 238, 108-115; see also CALVERT, Monte A. (1967) *The Mechanical Engineer in America, 1830-1910: Professional Cultures in Conflict*, Baltimore, The Johns Hopkins University Press, 43-62.

[12] Quoted in LANKTON (1977), 11.

[13] As we will see below, other institutions of higher learning offered some form of engineering instruction after the 1820s, but it remains true that West Point was the only school that made engineering its first priority until the 1830s or so.

[14] The best source of information on West Point is MOLLOY, Peter M. (1975) *Technical Education and the Young Republic: West Point as America's École Polytechnique, 1802-1833*, Ph. D. diss., Brown University.

[15] The development of French technical education is treated in ARTZ, Frederick B. (1966) *The Development of Technical Education in France, 1500-1850*, Cambridge, MIT Press. A marvelous recent study is PICON, Antoine (1992) *L'invention de l'ingénieur moderne: l'École des Ponts et Chausées, 1747-1851*, Paris, Presses de l'École Nationale des Ponts et Chausées. See also WEISS, John Hubbel (1982) *The Making of Technological Man: The Social Origins of French Engineering Education*, Cambridge, MIT Press; and MOLLOY (1975).

Mines in 1793, were established to improve both the relevant technologies and instruction. Perhaps as important, graduates of these institutions became part of the state bureaucracy, further enhancing their prestige. The Revolution strengthened French educational institutions, especially with the foundation of the École Polytechnique in 1794. The performance of French military engineers under Napoleon demonstrated the value of French schools, and as historian John Weiss notes, "In the century that followed, the Polytechnique became a model for engineering schools throughout Europe."[16]

Americans, too, leaned heavily on the French model. Several American army officers studied at the Ecole Polytechnique; several others visited Paris on inspection trips. In 1815, Thayer was one of those delegated to observe French schools and also to purchase a library for the Military Academy at West Point. By the end of 1816, he and another officer had purchased more than a thousand French books and several hundred charts. In addition, the two made contact with the École's faculty and gathered classnotes and textbooks.

When Thayer was recalled from Paris in 1817 to become West Point's superintendant, he launching a complete reform by borrowing heavily from the French. Historian Peter Molloy argues that Thayer did not copy blindly, but adopted "French theories to his plans for West Point without turning the Academy into a French school."[17] But his basic goal was a school resembling the Ecole Polytechnique of 1795-1804, a period when it had been "a real engineering school."[18] His plan was similar to Gaspard Monge's of 1794 for the Polytechnique: "produce technologists for either military or civil service." To do so, Thayer reduced the time devoted to military training and drill, as had the Polytechnique. He adopted French textbooks exclusively, although he downplayed the role of the abstract sciences in favor of attention to problem solving. The books he had been buying for two years became a French-style reference library. He also adapted a French administrative structure for West Point, complete with regional examination centers and subjects found in French schools. Finally, Thayer borrowed the École's policy and hired only Academy graduates as instructors. Other elements of Thayer's West Point reflected American circumstances, such as the creation of non-advanced courses to accommodate the poorly-prepared American students. Still, the debt to the French engineering school was obvious to all.

West Point was important for a couple of reasons. First, it successfully introduced formal engineering schooling to the United States. Indeed, West Point itself provided a model that other schools, including the Virginia Military Institute and the Citadel, copied after they were established about 1840. Even the Norwich Military Academy, organized in 1820, was a response to West Point, although its founder opposed many of Thayer's reforms. These examples highlight a more lasting legacy of Thayer's reliance on French models. Even today, American engineering education

[16] WEISS (1982), xv; see also 13-16. Another scholar who dealt with the impact of French technical education is FOX, Robert (1995) "Les regards étrangers sur l'École Polytechnique, 1794-1850", in BELHOSTE, Bruno *et al.* (ed.) *La France de X. Deux siècles d'histoire,* Paris, Econimca, 63-74. An English translation of this paper, as well as several other of Fox's papers on French technical education during the 19th century can be found in his book, (1995) *Science, Industry, and the Social Order in Post-Revolutionary France*, Brookfield, VT, Variorum.

[17] MOLLOY (1975), 388.

[18] MOLLOY (1975), 389. This and following information is drawn from 388-392.

retains a tone and style that separates it from classical learning. Engineering students follow a hierarchical, often rigid curricula, that reflects the French pattern of engineering as a uniformed service of the state. These military and bureaucratic overtones, although less overt in the United States today, still influence engineering education.[19]

But the most important legacy of West Point was the way it met Thayer's goal of training engineers for civilian projects. After Congress passed the General Survey Act in 1824, the President could appoint army engineers to private projects and they routinely surveyed routes for canals and railroads for the states and private corporations. They worked, for example, on the Chesapeake and Ohio Canal and the B&O Railroad. Even after the act was repealed in 1838, army engineers surveyed every trans-continental railroad route across the Great Plains and through the Rocky and Sierra Nevada Mountains. Many engineers served in the army just long enough to establish a reputation, and then resigned to enter private practice. Of 940 West Point graduates from 1802-1837, 231 were private civil engineers at some point in their career; in 1837 alone at least 100 former West Pointers worked on civilian projects. Perhaps the best proof of their reputation was the hiring of Major George Washington Whistler as advisory engineer for the St. Petersburg to Moscow railroad in the late 1830s.[20]

A formal rivalry never developed between West Point graduates and apprentice-trained engineers. Each contributed to the solution of difficult engineering problems facing an expanding country. But it was clear that army engineers possessed a different kind of education that proved especially useful in tackling and planning larger projects. Even so, after 1840, the influence of West Point slowly declined in American engineering, in part because of Thayer's policy of hiring only Academy graduates. Other factors included the end of the policy of assigning Army engineers to civilian projects. But a central reason was the emergence of other engineering schools.

Most of the new schools were in the polytechnic mold, a title that suggests another link to French technical education, namely the École Polytechnique as it evolved after Monge. As one historian put it, "the insight of the Ecole Polytechnique in Paris [was] that all technical work had a common basis in method, mathematics, and science".[21] In practice, the polytechnic idea of professional training in technical fields meant the establishment of schools separated from existing universities. The U. S. was not alone in borrowing this French concept, for Germany during these same years also built polytechnics that later became Technische Hochschulen.[22] But American

[19] This point is made in FERGUSON, Eugene S. (1992) *Engineering and the Mind's Eye*, Cambridge, MIT Press, 74.

[20] Statistics from CALHOUN (1960), 43; other information on the activities of West Point graduates on 37-43.

[21] MANEGOLD, Karl-Heinz (1978) "Technology Academized: Education and Training of the Engineer in the Nineteenth Century", in KROHN, Wolfgang; LAYTON, Edwin and WEINGART, Peter (ed.) *The Dynamics of Science and Technology, Sociology of the Sciences*, vol. 2, Dordecht, Holland, D. Reidel Publishing Co., 141.

[22] On German education, MANEGOLD (1978), 137-58; BRAUN, Hans-Joachim Braun, "Technological Education and Technological Style in German Mechanical Engineering, 1850-1914" in KRANZBERG (1986), 33-40; and KÖNIG, Wolfgang (1986) "Science and Practice: Key Categories for the Professionalization of German Engineers", Ibid., 41-47. For the earlier period, see FARRAR, D. M. and PACEY, A. J. (1974) "Aspects of the German Tradition in Technical Education", in CARDWELL, D. S. L. *Artisan to Graduate*, Manchester, Manchester University Press, 11-22.

polytechnics also showed the influence of the British self-improvement approach to education, especially the working man's institutes. The two threads were visible at the most important American polytechnic, the Rensselaer School. When its doors opened in 1824, this school promised to train students and teachers in science and its applications for farming. The first lectures on civil engineering were added in 1828, and in 1835 a one-year program in civil engineering appeared for those with a bachelor's degree. Not until 1850 did the Institute abandon its original programs and devote itself to engineering, copying explicitly the École Polytechnique and the newer École Centrale des Arts et Manufactures. Its new purpose was "the education of the architect, the civil engineer, constructing and superintending engineers of mechanics, hydraulics, gas works, iron works, etc., and Superintendents of those higher manufacturing operations, requiring for this successful prosecution strict consideration of the scientific principles..." As it sought the best way to prepare engineering students, RPI was a crucially important model for other American engineering schools, and the change of its name in 1861 to Rensselaer Polytechnic Institute simply made official what the school had become.[23]

Following RPI's example, the polytechnic movement in the U. S. expanded significantly. Other schools included the Polytechnic College of Pennsylvania, founded by chemist Alfred Cooper, who in 1849 had established a lab of industrial chemistry in Philadelphia. The following year Cooper toured Europe, including Paris and Liebig, and in 1853 opened the school to provide specialized, professional training for those destined for careers in engineering and manufacturing. Brooklyn Polytechnic, organized in 1855, had similar roots. Each school attempted, in the words of historian Terry Reynolds, "to break away from the mainstream of the American collegiate tradition with its broadly based, liberal arts curricula."[24] But like the military schools, the polytechnics drew heavily on European models in attempting to introduce formal engineering education into the United States.

4.- Americans and Practicality.

In about 1850, the pioneer period in American engineering education ended, as opportunities for formal technical instruction increased dramatically. A period of American experimentation began, with less reliance on European models. A central element in the American story of engineering education has been enormous diversity and a variety of approaches. Given the nation's size, as well as the decentralized government that drastically limited the influence of central authorities (education by definition was a matter for the states), the lack of a single approach to engineering education is not surprising. The experiments shared, however, a desire to combine British apprenticeships with French schools, for no matter what form American engineering schools took, they sought to provide a practical education.

One strategy was to graft technical education onto existing American colleges.[25]

[23] On RPI, see REZNICK, Samuel (1967) *Education for a Technological Society: A Sesquicentennial History of Rensselaer Polytechnic Institute*, Troy, NY, Rensselaer Polytechnic Institute, quotation from 83-84. See also GRAYSON, Lawrence P. (1993) *The Making of an Engineer: An Illustrated History of Engineering Education in the United States and Canada*, New York, John P. Wiley & Sons, Inc., 32-33.

[24] REYNOLDS, Terry S. (1992) "The Education of Engineers in America Before the Morrill Act of 1862", *History of Education Quarterly*, 32, Winter 1992, 459-482.

[25] The following section rests heavily on REYNOLDS (1992).

This step was taken in a surprising number of schools after 1825, in part because many traditional colleges faced a compelling need to attract students. But rather than develop full engineering courses, they added to the classical curricula the one area of formal learning required of every engineer -- mathematics and trigonometry for surveying. The results might be labeled "partial courses," for they often included a few classes, lectures, and other activities, but did not lead to a bachelor's degree. Interestingly, historians of engineering education have almost completely overlooked these programs, usually concluding that no more than half a dozen engineering schools were in existence before 1850. In fact, these partial programs provided many more opportunities for formal engineering schooling than usually supposed.[26] As early as 1832, Washington College in western Pennsylvania hired a West Point graduate to teach civil engineering and other classes as required. Princeton College and New York University were among the most prominent schools to create partial programs; many southern colleges did the same. By 1856, the University of Pennsylvania awarded certificates to those who completed its partial programs in several scientific and technical fields.

After 1850, even more schools further expanded opportunities for technical study in American colleges. Some, including Yale and Harvard in the late 1840s and Dartmouth in 1851, formed separate scientific schools to offer technical education in a parallel curriculum. Others, like Wesleyan College, Denison College, and Allegheny College (all in the midwestern U. S.) accommodated technical education through programs leading to a general science degree. But eventually, many traditional colleges turned these general curricula into specialized degrees. The University of Michigan was typical of the state colleges that added new departments and courses in the technical fields, doing so as early as 1837. During the 1850s, the universities of Illinois, North Carolina, and Iowa, as well as the University of Rochester and New York University followed this second option. And after 1860, another 25 institutions of higher learning expanded their technical offerings in this way.[27]

The effort to bring professional education into traditional colleges was less often followed in Europe, where separate schools for technical education predominated. But even more uniquely American were two developments of the 1860s -- the land-grant approach to education and the technical institutes. Both illustrated the democratic ideals, as well as the limited educational support structure, of the United States. Both also showed the continuing importance of practicality as a determinant of American technical education.

Land-grant schools were one of the first experiments aimed at promoting a

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[26] For example, GRAYSON, Lawrence P. (1977) "A Brief History of Engineering Education", *Engineering Education*, 67, 246-64; and McGIVERN, James G. (1960) *First Hundred Years of Engineering Education in the United States (1807-1907)*, Spokane, WA, Gonzaga University Press, present the traditional position. REYNOLDS (1992), 468-69, expands sharply the number of schools that offered some form of engineering instruction; see also GIANNINY, O. Allan (1988) "The Overlooked Southern Approach to Engineering Education: One and a Half Centuries at the University of Virginia, 1836-1986", in HARTMAN, Howard L. (ed.) *Proceedings of the 150th Anniversary Symposium on Technology and Society, Southern Technology: Past, Present and Future*, College of Engineering, University of Alabama, Tuscaloosa, March 3-4, 1988.

[27] RUDOLPH, Frederick (1962) *The American College and University: A History*, New York, Vintage Books, ca. 240-245.

democratic-style of higher education.[28] In 1862, Congress passed legislation (the Morrill Act) providing federal support for one college in each state to encourage the agricultural and mechanical arts. Each state was given 30,000 acres of federal land for every Congressional representative to support a school dedicated to the agricultural and mechanical arts. This focus on the useful arts was widely interpreted to mean highly practical instruction, thereby separating A&M schools from traditional colleges. These schools were intended to attract students from the middle and working classes. Eventually the intent was broadened to include connecting science and practicality, but all this happened slowly. Most states did not form schools until about 1870; some started new colleges while others gave the funds to existing institutions. Moreover, the quality of instruction could be quite low. Texas A&M, for example, admitted students with a ninth grade education and offered basic courses on carpentry and blacksmithing, devoid of any theoretical content.[29] And since agricultural concerns predominated at first, some land-grant institutions were labelled "cow colleges."

As they grew, however, land-grant colleges had an impact out of proportion to the relatively small amounts they received from the federal money.[30] Engineering education especially benefited. Several important engineering schools, including Penn State and MIT, received their start with land-grant funds. Others engineering programs received a big boost, and at several midwestern state schools, including Ohio State, Purdue, Illinois, and Wisconsin, engineering programs soon enrolled more students that the agriculture colleges. And by 1900, the great majority of American engineering students were enrolled in A&M schools. (See Table 1) Cornell, New York's land-grant school, was much the largest engineering college in the country, and probably the best.

TABLE 1. Engineering enrollements, 1900.

	Land-grant colleges	All schools
Mechanical engineering	3.398	4.459
Civil engineering	1.964	3.140
Electrical engineering	1.617	2.555
Mining engineering	822	1.261
Architecture	292	489

SOURCE: DALBY, W. E. (1903) "The Training of Engineers in the United States",

[28] The classic treatments of land-grant schools is EDDY, Edward D. (1957) *Colleges for Our land and Times: The Land-Grant Idea in American Education*, New York, Harper & Brothers; and ROSS, Earle D. (1942) *Democracy's College: The Land-Grant Movement in the Formative Stage*, Ames, IA, Iowa State University Press; see also RUDOLPH (1962).

[29] See DETHLOFF, Henry C. (1975) *A Centennial History of Texas A&M University, 1876-1976*, 2 vols., College Station, Texas A&M University Press.

[30] In 1890, an extension of the act provided annual federal payments to land-grant schools, but still in small amounts.

Proceedings of the Institute of Naval Architects, 45, 39.

The other American experiment in engineering education was the technical institute. These served mechanical engineering, whose practitioners resisted book-learning longer than many civil engineers. Mechanical engineers believed first-hand knowledge of machine tools, gained through a shop apprenticeship, was a basic requirement of their education, but over time, the need for more class room work was recognized. Technical institutes attempted to satisfy both positions: most of the day was spent in the machine shop, but classes were held in the basic fundamentals in science, math, and engineering. No time was given, however, for general education or humanities classes. Worcester Polytechnic Institute (WPI), established in 1868, may have been the most famous of these schools. Its curriculum revolved around shop work, with students working alongside real machinists. Stevens Institute also attempted to bring mechanical engineering into an academic setting. Founded in 1870, Stevens with a $600,000 legacy from Edwin A. Stevens, the trustees ordered a practical education strictly for mechanical engineers. Stevens also placed emphasis on shopwork, although not to the extent as WPI. Even Cornell's mechanical engineering program was built around shop work until the 1880s.[31]

The institutes and the land-grant colleges had in common a strong emphasis on practical, technical education, a trait shared with engineering programs at every American college. The emphasis -- and the amount of time spent -- on gaining hands-on experience with tools and machines differed only in degree. Thus every engineering student, even electrical engineers, learned to survey; all learned to draw. Field trips were common in many courses, and might include riding a steam locomotive to measure its efficiency, working in a model textile factory, or investigating the details of a street railway system. Faculty were expected to have been practicing engineers before they became teachers, and many spent summers working for businesses or governmental agencies, tackling real engineering problems. When on campus, almost all faculty were fully engaged in teaching, with little time for research. Laboratory courses were designed to introduce students to the techniques and equipment they would use after graduation; laboratories were therefore not seen as centers for the development of new knowledge or technologies.[32] In part, the explanation for this style lies in the close ties many schools developed with local and regional industries that wanted students prepared for jobs. But a continuing belief in apprenticeships also was a factor. In an on-going debate during the second half of the 19th century among engineers and teachers concerning the place of theory and practice in American engineering schools, the proponents of hands-on experience usually prevailed.

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[31] Information on WPI from THURSTON, Robert (1893) "Technical Education in the United States", *Transactions of the American Society of Mechanical Engineers*, 931-33; TAYLOR, Herbert Foster (1937) *Seventy Years of Worcester Polytechnic Institute*, Worcester, Davis Press, Inc.; and TYMESON, Mildred McClary (1965) *Two Towers: The Story of Worcester Tech, 1865-1965*, Barre, MA, Barre Publishers. On Stevens Institute, see CALVERT (1967), 49; and Stevens Institute of Technology (1945), *Stevens 75th Anniversary, Commemorating 75 Years of Accomplishment in Engineering Education*, Hoboken, NJ, Alumni Association of Stevens Institute of Technology. On Cornell, see CALVERT (1967), 87-107; and BISHOP, Morris (1962) *A History of Cornell*, Ithaca, Cornell University Press.

[32] See HITCHCOCK, Embury A. (1939) *My Fifty Years in Engineering: The Autobiography of a Human Engineer*, Caldwell, ID, 75-78, 91-112; MCMATH, Robert C. *et al.* (1985) *Engineering the New South: Georgia Tech, 1885-1985*, Athens, GA, University of Georgia Press, 81-88; and Cornell University, *Annual Report of the President (1899-1900)*, 53.

5.- Changes at the Turn of the Century.

By 1900, the French textbooks had long since disappeared from American engineering schools. This did not mean, however, that American engineers ignored events in Europe. Engineering journals contain many reports by individual engineers on their travels to Europe, to international meetings, and to worlds fairs and engineering congresses. Most visitors commented favorably on the theoretical tone of European engineering schools, and noted how different conditions were in the U. S., especially in terms of student preparation. The Americans also noted wistfully the greater social status enjoyed by their European colleagues.[33] Class-room instruction had replaced apprenticeships as the normal way to enter the engineering field by this time, and many engineers hoped college degrees would provide them with social recognition and position comparable to that enjoyed by professionals in law, medicine, and the ministry. One strategy recognized early throughout American higher education was to emulate German universities, where the search for knowledge had become a primary purpose, thereby making research the measure of excellence, especially in the natural sciences. Like other American academics, engineering faculty eventually moved in this direction, once again borrowing from Europe.[34]

Few observers at the end of the 19th century failed to note that engineering education had developed differently in Europe than in America. The more abstract scientific studies apparent at the Ecole Polytechnique as early as the 1810s continued to develop, leading to greater emphasis on mathematical expression and the development of theory.[35] And similar developments occurred in German universities. Americans might claim some credit for developing analyses of bridge trusses, but this was not usual, according to historian Monte Calvert.

> *"Mechanical engineering emerged in Europe before it did in the United States, and it was also in Europe that the theoretical basis was created. Thermodynamics was first explored by French and German engineers and scientists. Strength of materials was another subject of direct concern to the mechanical engineer, and here the basic work was done by Navier, a Frenchman. Elastic theory likewise was developed in France by Poisson. Experimental work in the stress on machine parts was done by Weisbach in*

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[33] See, for example, (1869) "Technical Education in France", *Van Nostrand's Engineering Magazine*, 1, 405-06; BARNARD, Henry (1872) *Military Schools and Courses of Instruction in the Science and Art of War*, New York, E. Steiger (reprint ed., Greenwood Press, 1969); (1880) "Technical Education in England, France, and Germany", *Van Nostrand's Engineering Magazine*, 22, 253-56; SWAIN, George F. (1893) "Comparison between American and European Methods in Engineering Education", *Proceedings of the Society for the Promotion of Engineering Education*, 1, 75-117; and (1895) "Engineering Schools in Germany", *Engineering News*, 33 (April 4, 1895), 221-222.

[34] This idea is developed fully in GEIGER, Roger L. (1986) *To Advance Knowledge: The Growth of American Research Universities, 1900-1940*, New York, Oxford University Press. He includes in his discussion information about engineering colleges.

[35] One sees this point clairly from FOX, Robert "Education for a New Age: The Conservatoire des Arts et Métiers, 1815-1830", in CARDWELL (1974), 23-38; see also MANEGOLD (1978) and SEBASTIK, Jan "The Introduction of Technological Education at the Conservatoire des Arts et Metiers", in KRANZBERG (1986), 26-32.

> *Germany. A Scottish engineering professor, Rankine, studied fatigue in metals and the basic science involved in the workings of the steam engine. America had no scientist-engineers to rival these pioneers until late in the nineteenth century"*.[36]

And the same could be said of electrical engineering and most other fields. American accomplishments in some fields of civil engineering awed the world by 1900, but the designs of the alternating current turbines for the Niagara Falls hydroelectric station were dependent upon the work of Swiss and German engineers more comfortable with the language of mathematics.[37]

By the last decades of the century, some Americans called for adopting the newest European approaches to engineering education. Robert Thurston was perhaps the most articulate spokesmen for change.[38] After graduating from Brown University in 1856 with degrees in civil engineering and philosophy (science), he joined the Navy and taught mechanical engineering at the Naval Academy in Annapolis. He thought much about engineering curricula, and according to Calvert, "Thurston's theory of what engineering education should be was primarily a blend of French and German ideas. From France came an emphasis upon math and science and the concept of the high-level professional school; from Germany came the practice of setting up schools to train technical personnel at all levels, with the research institution at the top".[39] For thirty years, at Stevens Institute beginning in 1871 and then at Cornell University's Sibley College of Mechanical Engineering after 1885, Thurston promoted his ideas. He enjoyed an enormous advantage over many American colleagues, for Cornell had the highest entrance standards of any American engineering school. As a result, it was much easier for Thurston to stress that engineering students should be learning the fundamental principles of math, science, and engineering that could later be used to solve problems. He reduced the emphasis on practical skill with machine tools, stressing instead calculation. Real world experience was not ignored, but Thurston assumed that the final training of the student would come after graduation on the job, not at the college. Finally, Thurston constantly pressed his administration and benefactors to add laboratory facilities for real research. His greatest desire was for a hydraulics laboratory, but the list of his publications indicates that he gave attention to strength of materials, the production of iron and steel, and steams engines and boilers.

Thurston's ideas were widely echoed by his colleagues, despite Cornell's unique advantages. Palmer C. Ricketts, president of RPI from 1893 to 1934, complained in

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[36] CALVERT (1967), 52-53.

[37] This point is made in HUNTER, Louis (1979) *A History of Industrial Power in the United States, 1780-1930*, Volume One: *Waterpower in the Century of the Steam Engine*, Charlottesville, VA, University of Virginia Press, for the Eleutherian Mills-Hagley Foundation, 390.

[38] On Thurston, see CALVERT (1967), 45-57; and especially THURSTON's *The Mechanical Engineer: His Preparation and Work; An Address to the Graduating Class of the Stevens Institute of Technology*, New York, 1875.

[39] CALVERT (1967), 47; see also MARSTON, Anson (1900) "Original Investigations by Engineering Schools a Duty to the Public and to the Profes- sion", *SPEE Proceedings*, 8, 237; and Records of the College of Engineering and the Papers of Robert Thurston, Department of Manuscripts and Archives, Cornell University Library, Ithaca, NY; and Cornell University, *Annual Report of the President, (1896-1897)*, xl-xli; (1897-1898), 42-43.

1893 that the curriculum imparted "a smattering of so called practical knowledge". Engineering colleges, he charged, turned out "surveyors, and those of mechanical engineering, mechanics, rather than engineers".[40] Even so, most American colleges changed their curricula and practices very little, beyond adding new classes in new fields. Faced with the pressure of rapid technological change, American engineering professors generally moved slowly to bring research and theory into their classrooms. As usual, the diversity of institutions hampered efforts to change, as did the uneven preparation of students and the weight of tradition. Moreover, the desire of industry for graduates who could step right into jobs never disappeared.[41] It is instructive that the University of Cincinnati introduced the first cooperative education program in 1907, in which students spent alternate semesters working in industry and attending classes.

Even in 1920, the report of French observer Maurice Caullery, who toured American universities, echoed Ricketts.

> *"There is nothing in the United States comparable to the preparation in our courses of the École Polytechnique or the École Centrale. The first-year students, the freshmen, of the engineering schools, are very weak. It is none the less true that the American engineer gives abundant proof of all the qualities which are expected of him. What is asked of him is `not to be a savant, but a practical man, a businessman and a financier. His art is not only to adapt the forces of nature to the use of man, but to do it economically... The engineer must not build a find bridge with costly details, difficult to execute, in the desire of leaving a monument behind him.' He is first of all a man of action"*.[42]

But at about that same time, Thurston's ideals were beginning to be more widely implemented. It happened very slowly, and quite unevenly. But even more obviously than in the 19th century, both the inspiration for, and the agents of, change came from Europe.

6.- European Engineers and American Colleges, 1920-1960.

In part, complaints from within the American engineering community forced adjustments. Quite simply, rules of thumb and common sense were no longer enough for dealing with many of the science-based technologies engineers designed, produced, and managed. A survey of American engineers in the 1920s produced one comment that claimed, "the American is lacking in a good solid grounding in the elements of

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[40] REZNICK (1967), 256. For an overview of changes in American engineering education that began in the late 19th century, see REYNOLDS, Terry S. and SEELY, Bruce E. (1993) "Striving for Balance: A Hundred Years of the American Society for Engineering Education", *Engineering Education*, 82 (July 1993), 136-51; also SEELY, Bruce E. (1993) "Research, Engineering, and Science in American Engineering Colleges, 1900-1960", *Technology and Culture*, 34 (April 1993), 344-386.

[41] NOBLE, David F. (1977) *America by Design: Science, Technology, and the Rise of Corporate Capitalism*, New York, Alfred A. Knopf, makes this point one of his central theses; see especially chapters 2, 8, and 9.

[42] CAULLERY, Maurice (1922) *University and Scientific Life in the United States*, trans. James Haughton Woods and Emmet Russell, Cambridge, Harvard University Press, 121-22; quotation from George Swain, engineering professor at Harvard, *Science* (January 2, 1910), 81-93.

engineering mechanics, physics, chemistry, and the natural laws by which the world goes around... I feel it is primarily the duty of the faculties of our American universities to eliminate as far as possible the shop courses, the so-called research courses, and in fact, all so-called practical work and concentrate all effort in preparing the foundation to better advantage".[43] But this goal had been articulated by Thurston and others before. Why did change finally begin in the 1920s?

The timing was clearly connected to the arrival of a number of European- born or European educated engineers in the United States after World War I. And they brought with them new approaches to engineering, primarily a belief in the utility of mathematics and a greater willingness to develop a theoretical base for engineering. One of the most important Europeans engineers in this regard was Stephen Timoshenko, a Russian immigrant who arrived in the United States in 1922. Working at Westinghouse Electric, he later recounted that he was stunned at the poor preparation of American engineering students.

> *"I was amazed at the complete divorce of strength-of-materials theory from experimental research. Most of my students had done no work whatever in mechanical testing of materials with measurements of their elastic properties. The newer methods of calculating beam deflection and investigating flexure in statically in determinate cases had not been taught them at all. In the face of so feeble a background [I offered a course given sophomores in Russia.]"*

After joining the faculty of the University of Michigan in 1927, his complaints did not change: Students knew nothing about the physical properties of building materials, allowable stresses, and fatigue in metals.[44] But Timoshenko also began to change this, transforming the study of strength of materials, structural mechanics, and dynamics -- especially vibration -- in American engineering schools, effectively placing this work on a mathematical footing. He devoted his career in the United States to this goal, beginning with the informal seminar he started at Westinghouse Electric in Pittsburgh during the early 1920s. After he moved to the University of Michigan as a faculty member, he then launched an enormously influential summer school in mechanics in 1929; this ran into the mid 1930s. After he moved to Stanford in the mid 1930s, he continued to change engineering education, especially through his textbooks.[45]

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[43] HIGBIE, H. H. (1932) "Research in Engineering Colleges of Interest to Industry", *Journal of Engineering Education*, 23 (October 1932), 154. Such concerns also were found in the massive study of engineering education conducted during the 1920s, and usually labeled the Wickenden Report. See REYNOLDS and SEELY (1993), 138-140.

[44] TIMOSHENKO, Stephen P. (1968) *As I Remember; The Autobiography of Stephen P. Timoshenko*, Princeton, Van Nostrand, 253, 280. On Timoshenko, see "Stephen Prokofievitch Timoshenko, 1878-1971", *Stanford Engineering News*, nº 82 (May 1972). Timoshenko's role, and that of his textbooks, is also acknowledged in EMMERSON, George S. (1973) *Engineering Education: A Social History*, Newton Abbott and New York, Crane Russak, 289-290.

[45] See TIMOSHENKO (1968); "Stephen Prokofievitch Timoshenko"; TIMOSHENKO, Stephen and LESSELS, J. M. *Applied Elasticity* (Pittsburgh, Westinghouse Night School Program, 1925; London, Constable and Co., 1928); TIMOSHENKO, Stephen (1929) *Vibration Problems in Engineering*, New York, D. Van Nostrand Company, Inc.,; TIMOSHENKO, Stephen (1934) *Theory of Elasticity*, New York, McGraw-Hill;TIMOSHENKO, Stephen and MACCULLOUGH, Gleason H. (1935) *Elements of the Strength of Materials*, New York, D. Van Nostrand Company, Inc.; TIMOSHENKO, Stephen and YOUNG, D. H. (1940) *Engineering Mechanics*, New York, McGraw-Hill; TIMOSHENKO, Stephen (1940)

Only the California Institute of Technology had really adopted an approach to engineering that matched Timoshenko's by 1930, and even then it is doubtful he would have been satisfied. Physicists Robert Millikan and George Ellery Hale, who embraced the new vision of scientific engineering, had founded Caltech in part to make "engineering grow out of physics and chemistry".[46] Among the first faculty they hired was the "strongly theoretical" Theodore von Kárman, a Hungarian engineer who showed Americans a scientific orientation to aeronautical engineering, mainly though the mathematical analysis of problems. Crucially, von Kárman introduced American engineers to German engineer Ludwig Prandtl's contributions in fluid dynamics, especially boundary layer theory. And he trained a generation of aeronautical engineers.[47]

With people like von Kárman, Caltech embraced the new engineering, but most American engineering schools moved more slowly. Only MIT made an attempt at a complete transformation, and even that began in the 1930s after physicist Carl Compton became president. Most schools witnessed more subtle change, as individual European engineers or their students, brought the new approaches to America. At the University of Illinois, Harald Westergaard played an important, thus less visible role in civil engineering. Having completed his preliminary education in Germany with Prandtl at Göttingen and August Föppl at the Technische Hochschule in Münich, he came to Illinois from Denmark in 1914 to do graduate work. He earned Illinois' first Ph. D. in theoretical and applied mechanics, and remained to teach structural theory and the theory of elasticity. As a participant in Timoshenko's summer school in Michigan, he helped other faculty learn, and also was an effective consultant/researcher. He developed a theory of pavement slab behavior for the federal government's Bureau of Public Roads in the 1920s, and calculated stresses caused by large dams in the 1930 for the Bureau of Reclamation. He moved to Harvard in 1936 and became dean of engineering in 1937, determined to make Cambridge a center for theoretical and applied mechanics.[48]

Theory of Plates and Shells, New York, McGraw-Hill; and TIMOSHENKO, Stephen (1953) *History of the Strength of Materials*, New York, McGraw-Hill.

[46] Quoted in WISE, George (1985) *Willis Whitney, General Electric, and the Origin of U. S. Industrial Research*, New York, Columbia University Press, 262.

[47] See KARGON, Robert H. (1977) "Temple to Science: Cooperative Research and the Birth of the California Institute of Technology", *Historical Studies in the Physical Sciences*, 8, 3-31; VON KÁRMAN, Theodore with EDSON, Lee (1967) *The Wind and Beyond: Theodore von Kárman, Pioneer in Aviation and Pathfinder in Space*, Boston, Little, Brown, 122-126, 146-159; HANLE, Paul (1982) *Bringing Aerodynamics to America*, Cambridge, MIT Press,; and GORN, Michael H. (1992) *The Universal Man: Theodore von Kárman's Life in Aeronautics*, Washington, DC, Smithsonian Institution Press. The description of von Kárman is from KOPPES, Clayton R. (1982) *JPL and the American Space Program: A History of the Jet Propulsion Laboratory*, New Haven, Yale University Press, 2.

[48] Westergaard's career can be followed in his professional papers and correspondence, which are deposited in the Harvard University Archives, where they are under restricted access. See also *Who's Who in Engineering*, 5th ed. (1941); 7th ed. (1954); (1950) "Harald Westergaard", *Yearbook - American Philosophical Society*, Philadelphia, American Philosophical Society, 339-342; KINGERY, R. A., BERG, R. D. and SCHILLINGER, E. H. (1967) *Men and Ideas in Engineering: Twelve Histories from Illinois*, Urbana, Univeristy of Illinois; *Harvard University Gazette* (December 16, 1950), 80-81; and (1974) "Harald Westergaard", *Dictionary of American Biography*, supplement 4, New York, Cahrles Scribner, 873-874.

There were many others who helped transform American engineering education and practice. Civil engineer Karl Terzaghi, who helped develop soil mechanics, taught at MIT from 1925-1929 and Harvard after 1938. The American Society of Civil Engineers has honored his memory with an annual lecture in his name.[49] C. Richard Soderberg, a Swede who studied at MIT in 1920 and worked at Westinghouse in the 1920s and 1930s, joined the MIT faculty in 1937. A specialist in machinery design with special attention to vibration, Soderberg taught theoretical mechanics before moving into the administrative hierarchy. He served first as department head in mechanical and aeronautical engineering and then as MIT's dean of engineering in the 1950s.[50] Max Jakob, who fled Nazi Germany in 1937, brought crucial understandings of the theory of heat transfer to the Armour Research Institute, including the approaches of Ernest Eckart, who himself arrived from Germany after World War II.[51] And the list could be extended. For example, the contributors to a memorial volume on mechanics dedicated to von Kárman in 1941 included Westergaard, Boris Bakhmeteff, Max Munk, A. L. Nádai, Richard von Mises, even Albert Einstein and colleagues from the Institute of Advanced Studies.[52]

A few Americans who studied in Europe also helped transfer the European style of engineering. Morrough P. O'Brien, later dean of engineering at California (Berkeley) in the 1950s, introduced fluid dynamics, especially as applied to coastal engineering, after spending more than a year in Europe in the late 1920s. L. M. K. Boelter, who taught at Berkeley from 1918 until 1941, played a similar role in heat transfer by introducing Eckart's work through a set of highly influential lecture notes.[53] But the main carriers of new styles of engineering were Europeans, and change was slow.

In the end, American engineering finished this transformation after World War II, and did so rather quickly. But it was completed in a way that again reflected a blend of European approaches and American conditions. One spur to change came from those

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[49] See TERZAGHI, Karl (1960) *From Theory to Practice in Soil Mechanics; Selections from the Writings of Karl Terzaghi*, New York, Wiley; and Boston Society of Civil Engineers (1965), *Contributions to Soil Mechanics, 1954-1962*, Boston.

[50] See C. Richard Soderberg Papers (1914-1979), MC-23; also Soderberg Interview, MIT Oral History Program, MC 393; and a personal reminiscence/autobiography entitled *My Life*, all in the Institute Archives and Special Collections, Massachusetts Institute of Technology, Cambridge, MA. See also National Academy of Sciences, *Memorial Tributes*, Washington, DC, National Academy of Science, 1984, vol. 2, 267-271.

[51] See JAKOB, Elizabeth "Max Jakob: Fifty Years of His Life and Work"; and DAWSON, Virginia "From Braunschweig to Ohio: Ernest Eckart and Government Heat Transfer Research", both in LAYTON, Edwin T. and LIENHARD, J. (ed.) (1988) *History of the Heat Transfer Division, Essays Honoring the 50th Anniversary of the ASME Heat Transfer Division*, New York, 87-116 and 125-137; also LAYTON, Edwin T. (1989) "Innovation and Engineering Design: Max Jakob and Heat Transfer as a Case Study", in KRANZBERG, Melvin *et al.* (ed.) *Innovation at the Cross Roads Between Science and Technology*, Haifa, 132-152.

[52] See (1941) "Theodore von Kárman Anniversary Issue", *Applied Mechanics*.

[53] See (1988) "Morrough P. O'Brien: Dean of the College of Engineering, Pioneer in Coastal Engineering, and Consultant to General Electric", College of Engineering Oral History Series, University of California at Berkeley, 13-16, copy in Bancroft Library, University of California, Berkeley; and KREITH, Frank "Dean L. M. K. Boelter's Contribution to Heat Transfer as Seen Through the Eyes of his Former Students", in LAYTON and LIENHARD (1988), 117-124.

engineers who had watched physicists fill many of the crucial positions in war-time atomic bomb and radar research labs, and reap the lion's share of the credit for those technical accomplishments. Driven by "physics envy," engineers like Stanford's Frederick Terman were determined not to take a back seat to scientists again. He overhauled Stanford's curriculum to place more emphasis on scientific and mathematical fundamentals and developed interdisciplinary research programs on the cutting edges of science and engineering. Federal funding was essential to his success.[54]

Terman was not alone. Many schools created new degrees in engineering science, for example. The University of Illinois launched a degree in engineering physics in the early 1940s, taking advantage of the location of the physics department within the College of Engineering. Cornell created a program in engineering science in 1946, as did Stanford. By 1959, at least three additional schools offered such curricula, while seven schools awarded engineering physics degrees. All limited these programs to their brightest students. Penn State, for example, created an honors course in engineering science in 1953-54.[55] But in 1955, a study of engineering education endorsed such changes for all students. The Grinter Report called for additional course work in fundamental science and mathematics, arguing that this prepared engineers for rapid technological change better than courses in specific areas of engineering and design. By the mid 1960s, engineering science curricula were in place in engineering schools across the country. Symbolizing the embrace of change was the abolition in 1960 of Purdue's summer surveying camp, a hallmark of its civil engineering program since 1914.[56]

But underlying these and other related changes was a crucial and unique element -- massive amounts of funding for research from the United States government. Initially the largest supporters were the Office of Naval Research and the Atomic Energy Commission, but soon all branches of the military were backing the largest expansion in research in history. The decisions were driven by the fear that the next war would allow no nation time to recover, so the United States had to achieve a

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[54] This effort can be followed in archival records documenting the development of the engineering school at Stanford University after the war, especially the papers of Frederick Terman. See also TERMAN, Frederick E. (1976) "A Brief History of Electrical Engineering Education", *Proceedings of the Institute of Electrical and Electronic Engineers*, 64 (September 1976), 1.399; LESLIE, Stuart W. (1987) "Playing the Education Game to Win: The Military and Interdisciplinary Research at Stanford", *Historical Studies in the Physical Sciences*, 18 (January 1987), 56-88; LESLIE, Stuart W. (1993) *The Cold War and American Science: The Military-Industrial Complex at MIT and Stanford*, New York, Columbia University Press; BRYSON, Effie G. (1984) "Frederick E. Terman", *IEEE Spectrum*, 21 (March 1984), 73; and LOWEN, Rebecca S. (1997) *Creating the Cold War University: The Transformation of Stanford*, Berkeley, University of California Press.

[55] BEZILLA, Michael (1981) *Engineering Education at Penn State: A Century in the Land-Grant Tradition*, University Park, PA, 172-174.

[56] On the 1955 report and its impact, see GRINTER, L. E. (1956) "Report on the Evaluation of Engineering Education", *Journal of Engineering Education*, 46 (April 1956), 25-63; American Society for Engineering Education (1968) *Goals of Engineering Education: Final Report of the Goals Committee*, Washington, D. C.; DOUGHERTY, Nathan W. (1968) "Foundation for Our Future", *Journal of Engineering Education*, 58 (May 1968), 1.019-1.031; BRYSON (1984); KLINE, Ronald R. (1984) "Origins of the Issues", *IEEE Spectrum*, November 1984, 38-39. On Purdue, see KNOLL, H. B. (1963) *The Story of Purdue Engineering*, West Lafayette, IN, 251-254, 260-261.

state of constant preparedness in terms of technological development, and by the connected tensions with the Soviet Union that were soon labeled the Cold War. But military officials also believed that the had to support not only research on narrowly practical studies, but also much broader, fundamental work in the engineering sciences that would pay off in the future.[57]

For the first time, American engineering schools had a patron interested in and committed to work that required the new approach to engineering. Indeed, military agencies funded research in computers, materials, rockets and jet propulsion, nuclear power, and other fields that could not be pursued except through the new approaches to engineering. The older fashion of practical education had to give way, for scientific theory and practice were becoming ever more tightly intertwined as the entire pace of technological change accelerated. In many instances today it is not easy to tell the differences between a scientist and an engineer. As a result, every aspect of engineering began to change. Doctorates were now expected of academic engineers, and many of them never set foot outside the doors of a university, or inside a business corporation. Theory clearly mattered as much, if not more, than practice. Graduate students were vital, too, as the workers who conducted much of the research. Other changes were not always what their sponsors had hoped for. Eric Walker, dean of engineering and later President of Penn State University, and Solomon Cady Hollister, long-time dean of engineering at Cornell, had both promoted the new approach to engineering in the late 1940s and early 1950s. But by the 1960s, both were unhappy at development of a style of engineering science that was increasingly divorced from real-world design problems and from industry. But all of these changes demonstrated that the research university finally had arrived in American engineering schools. By utilizing the lever of federal funding for basic research, academic engineers brought into existence the style of engineering education they had long talked about.

7.- Conclusion: Where are We Today?

In the 1990s, the United States seems to dominate the world of engineering education. Intriguingly, there appears to be no substantial gap between the best American and European engineering research institutions. Engineering science matters everywhere, so that theory stands higher than practice. And until very recently, the level of research funding, the majority of it from the U. S. government, had increased rather steadily, with the only dip in the curve coming in the early 1970s as the initial space program wound down. All is not perfect in the American paradise, however, and the problems that have appeared here are not limited to this country. First, I suspect that many American engineering researchers are for the first time in decades worried about declining levels of research support. While those outside the U. S. may have more experience with this difficulty, American engineering faculty have not yet identified a justification of research to replace the logic of the Cold War for huge expenditures in science and engineering. Second, issues related to the impact that the shift to graduate study and research has had on undergraduate instruction are appearing much more often in engineering journals.[58] For the moment, the numbers of students from other

[57] The best short accounts of these developments are KEVLES, Daniel J. (1978) *The Physicists: The History of a Scientific Community in Modern America*, New York; and LESLIE (1987).

[58] See, for example, FERGUSON, *Engineering and the Mind's Eye*; and DURFEE, William K. (1994) "Engineering Education Gets Real", *Technology Review*, 97 (February/March 1994), 42-51; and MASI,

countries who seek to study engineering at American colleges and universities suggests that the difficulties are yet small. The reputations of schools like MIT, Stanford, and the University of Illinois or Penn State are still such that American engineering education remains the best in the world.

The current popularity and attraction of American engineering schools for non-U. S. students suggests, however, that the basic pattern that appeared in my account of the patterns of development of engineering education continues to strike some resonant chords. That is, the relationship of U. S. engineering education to the rest of the world is still a live and important concern. It is obvious, however, that in important ways, the basic relationship has been reversed since the end of World War II.

In 1800, it seemed inappropriate to many citizens of the United States that the nation's military should be dependent upon French and British engineers. As a result, the nation set out to develop its own system, ultimately blending European and American approaches. The result was a heterogeneous system that included MIT, Illinois, Michigan Tech, and Texas A&M. But now, one might ask what it means to have the U. S. pattern so dominant in the engineering world, and is even now educating many of the best students from other countries. A couple of questions come to my mind. Is engineering a social enterprise, rooted in American culture, history, and society, and connected over the longer sweep to Western culture? Can it be separated from those contexts? This issue assumes importance when we think about those non-U. S. students, who arrive with their own cultural and social background. What do we expect of them? As undergraduates, at least, they must meet the minimum requirements for work in the social sciences and humanities -- usually about 25 percent of a student's course work -- which are supposed to provide a general education. But from personal experience, I know that many non-U. S. engineering students are hopelessly lost, struggling to comprehend, in a second language, material that is given a low priority by even many American engineering students. And foreign-born graduate students almost never have to venture outside their engineering sub-specialty field. It appears that U. S. schools accept their non-U. S. engineering students, teach only technical data, formulae, techniques, and so forth. When they complete their studies, they almost certainly have concluded that engineering and technology are activities almost completely divorced from culture -- technical challenges of vital importance, but rarely subject to broader social factors.

The outcome of this development seems to me a vital question for all who are engaged in educating engineering students. I believe it is a situation that comes into focus a little better if we look to history for a some guidance. The pattern of my story makes very clear that engineering education can not develop apart from the culture and society its graduates are meant to serve. American engineering professors never could simply borrow ideas or approaches from Europe; they had to adapt and modify the French and British style to fit the circumstances of the United States. The sponsors of the symposium for which this paper was originally prepared entitled this paper "America, Land of Engineers". It may be that the U. S. has come to merit that title at the end of the 20th century, but if it has, Europeans had much to do with this situation. But we should not forget the process of adaptation that was always at work, even as American engineering schools now sit in a position much like that held by the French schools of the late 1700s.

C. G. (1995) "Re-engineering Engineering Education", *IEEE Spectrum*, 32 (September 1995), 44.