The second chapter only briefly takes up the educational issues because, Reynolds explains, these "external" interests gave way after 1930 to a concentration on "internal," or organizational, matters. Primary among these was attracting and holding a wider membership. The desire for this led to a watershed in 1930 when the AIChE dropped the constitutional requirement that members be proficient in chemistry. Unaffected by the watershed, membership growth was slow. Numbering 344 in 1920 when 6,000 students were enrolled in chemical engineering programs, the AIChE reached a mere 812 members by 1930. By 1937, only 1,500 chemical engineers belonged.

Reynolds's remaining chapters follow the internal activities, proceeding in a predictable fashion to the end of the 1970s. And herein lies the problem of Reynolds's history. Whereas chapter 1 introduced the fundamental issues of the engineering society—membership definition and disciplinary definition primarily—the author's final three chapters turn to organizational matters that are no less common to the technical society but are decidedly less fruitful in the telling of the story of the profession.

Even in the first chapter, only one paragraph is devoted to curricular content and only a slight attempt is made to establish the social and economic bases of the founders. Thus, the reader gains little knowledge of the nature of the work of chemical engineers or of the broader purposes of the AIChE. It is to be expected, perhaps, when the author labels educational concerns "external" and organizational matters "internal" that the basic social and economic questions will go unexplored.

This is not to fault Reynolds's choice of the material he does provide. For here, in 129 pages, is an account of the organizational activities of one of the nation's major engineering societies during its first seventy-five years. Joining recent works on mechanical and electrical engineers, it has thus contributed to our knowledge of the development of engineering societies in the 20th century. However, one must regret that the last two chapters were not given over to the author—along with time and support—so that he could have pursued the critical disciplinary and socioeconomic issues introduced in the first chapter.

A. MICHAL MCMAHON*

To Engineer Is Human: The Role of Failure in Successful Design. By Henry Petroski. New York: St. Martin's Press, 1985. Pp. xiii + 247; illustrations, bibliography, index. $16.95.

The "3-2-1-blast off" countdown had become a shibboleth for today's children and adults, who took technological achievements as a

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matter of course. It was associated with the triumph of space technology. Then in January 1986 the unthinkable happened—the space shuttle *Challenger* exploded, and, in less than two minutes, the unbridled confidence in faultless technology was also destroyed. This and other recent disasters have shaken public confidence or at least called into question the safety of contemporary engineering. The response to failures such as in Three Mile Island in Pennsylvania and in the Ukraine has been a deep-seated public anxiety regarding nuclear power stations, despite the efforts of government officials and expert engineers who give assurances of their safety. In a similar way, structural engineers have had to calm fears about the safety of a wide range of structures—bridges, hotel skyways, and large-span roofs—while, at the same time, they have had to seek to understand how failure could possibly occur with today's sophisticated technology.

Numerous articles, discussions, and books have recently been published on engineering failures on a case-by-case basis. Henry Petroski's book does indeed deal with engineering failures and, in this sense, is part of the current literature on the subject, but it is much more than a catalog of the collapses, explosions, and other accidents that have made the headlines. Recognizing that, despite the pervasive influence of technology on modern society, the public knows little about engineering, Petroski, with missionary zeal, sets himself the task of explaining to the lay reader where failures fit into the entire engineering enterprise.

Like a good humanist, engineer Petroski starts with the human condition and uses childhood experiences to demonstrate that all of us, in an existential way, know about the methods of engineering. The plot quickly thickens as he explores the concept of engineering as a creative activity, distinct from scientific enquiry, and the role structural safety and failure play in the design process, where both engineers and the public live in a world of acceptable risk. Uniting the discussion on the process of design with the case studies of failures is the idea that the primary purpose of engineering design is to obviate failure. This is achieved not by the so-called scientific method but rather by considering each design as a hypothesis which is validated by testing it against a series of individual failure criteria. These should include all expected loading conditions to which a structure will be subjected during its life. Thus, in a paradoxical way, the design process is advanced by failure if the causes are well understood and used to test future designs. Although not discussed in the book, engineering research must play a role in advancing design methods by simply explaining the cause of specific failures. The history of suspension bridges provides excellent examples of how a basic design can be shown to be perfectly safe under all expected static loads yet collapse under certain inexplicable wind conditions. It was not until after the Tacoma Narrows collapse that aerodynamic instability was identified as a failure mode for long-span suspension bridges.

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Not all failures are the result of defective designs: they may be caused by construction errors or faulty materials. Petroski concludes his book with a useful classification and discussion of the various causes of structural failures under the headings of limit states, random hazards, and human errors. In the case of limit states failure may occur because of overloads, understrength structural components, movements such as the settlement and deterioration of the structural elements, or combinations of these. Random hazards that may not have been considered in the design include fire, floods, explosions, earthquakes, and vehicle impact. Human error may result from a mistake in the engineer's calculations or from a lack of understanding of the behavior of the structure under load. On the other hand, many recent failures have been attributed to poor construction practice, the use of inferior materials, and inadequate construction details on shop drawings prepared by the contractor. Thus, there is an increasing recognition that the lack of clear lines of responsibility and of effective inspection during construction have led to an unnecessarily large number of failures.

Amid all the cited cases of accidents, collapses, and failures, it is most refreshing for the author to herald the Crystal Palace of 1851 as an exemplar of the best in engineering design and construction. This exhibition hall was a revolutionary structure in its use of an iron skeletal frame and glass curtain walls, yet it was entirely successful as an engineering design, in part because of the meticulous field testing of structural components and the careful consideration of how it would behave under static and wind loads. We also can learn a great deal from our successes.

This book should find a wide audience, since it is a rare instance of a work that appeals to the general reader, practicing engineers, and historians of technology.

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