MATH DERIVED, MATH APPLIED

THE ESTABLISHMENT OF BROWN UNIVERSITY'S DIVISION OF APPLIED MATHEMATICS, 1940-1946

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"Is it coincidence that the founding of the École Polytechnique just preceded the beginning of Napoleon's successful army campaigns? Is it coincidence that fundamental research in ship construction was assiduously prosecuted in Britain during the period just before 1900, when the maritime commerce of that great nation held an assured position of world leadership? Is it coincidence that over the last quarter century airplane research at Göttingen and other German centers was heavily subsidized and vigorously pursued and that in this war German aviation has come spectacularly to the forefront? Is there a lesson to be learned here in America from the consideration of such concurrence?"

—R.G.D. Richardson, April 1943
American Journal of Physics

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INTRODUCTION

At the beginning of the twentieth century, American mathematicians were sure that applied mathematics would never be as prestigious as pure mathematics. Even a master applied mathematician's most complex mathematical technique would pale in comparison to a pure mathematician's simple and logical proof. After all, as mathematician Godrey H. Hardy said, pure mathematics gave rise to the "finest imaginations" and "innovative methods" by studying the nature of numbers and systems of mathematical relations for its own sake, whereas applied math forced applied mathematicians to work in a practical, "humdrum way."[1] This was so, given that applied mathematics is the study of problems grounded in the physical, real world. Techniques arising from this discipline are used as tools for other sciences such as physics or engineering.[2] Because of this prejudice, applied mathematics had no place in American research and universities for most of the first half of the twentieth century.

With the outbreak of World War II, new military, industrial and technological demands dramatically overturned this bias. The production of planes, artillery, and machines demanded ever more efficiency and intricate equations. Due to the mathematical background required, engineers and other practical scientists generally lacked the training to fulfill this task. With that realization, in 1940 the opportunities for applied mathematics opened up, developed and prospered, particularly at Brown University in Providence, Rhode Island. Under the direction of Roland George Dwight Richardson, Dean of Brown's Graduate School, applied mathematician

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[1] Godfrey H. Hardy, *A Mathematician's Apology* (Cambridge, MA: Cambridge University Press, 1992), 135.

[2] The distinct differences between pure and applied math are still debated today. But on a very broad level this is the agreed upon distinction between the two.

William Prager, and other esteemed mathematicians, the University pioneered a program providing formal training in applied mathematics.

This thesis, covering the years 1940-1946, examines the rise of applied mathematics in America through the 1946 establishment of Brown University's Division of Applied Mathematics in the Graduate School, the first applied mathematics department in the country. The systematization of applied mathematics at Brown began in a wartime environment that altered both the status of applied mathematics in American academia and the institutional structure of Brown University. It was a world where industrial entrepreneurs, government officials, university administrators, mathematicians, engineers, and physicists rubbed shoulders. In a time of progressive technology and war that called for more technical expertise, the applied mathematics initiative at Brown placed applied mathematics at the crossroads of academia, government, and industry and made it a well-respected discipline in its own right.

Interwar Times

The status of computing machines in America: that is what Wilhelm Cauer, a young *privatdozent*[3] for applied mathematics at Germany's Göttingen University, intended to study when he submitted his application for a fellowship with the Rockefeller Institute in 1929. If he received a fellowship, the funding would support his studies as a visiting scholar at the Massachusetts Institute of Technology. His colleague Richard Courant, a renowned mathematician in his own right, enthusiastically supported Cauer's request. Yet the initial response from the Rockefeller Foundation towards Cauer's application was discouraging:

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[3] A *privatdozent* was a teaching fellow hired under the German university system. It is comparable to a senior lecturer in today's university system.

> As you know, the fellowships in Natural Sciences of the Rockefeller Foundation are limited to pure science. The fact that Dr. Cauer has been and still is interested in the applied aspects of mathematics is a matter which may place his application outside of the present fellowship program.[4]

The Rockefeller functionaries expressed reservation about Cauer's project, concerned about its practicality and lack of abstract rigor; it was a study that involved analyzing a specific problem rather than undertaking basic research, pursuing "pure" science and extrapolating general principles.

Dismayed by the philanthropic institution's bias against the application, Courant nevertheless proudly defended the "pure scientific purpose" of Cauer's intended study. His efforts paid off; the Rockefeller Foundation's reply from its office in Paris was much more promising. However, it also echoed previous concerns the organization had about Cauer's research:

> This application is to permit Dr. Cauer to spend a year in America, devising his time to Professor Bush and Tyler at Cambridge and Professor Carson in New York.
>
> As you know, Professor Carson is with the American Telephone and Telegraph Company, a private and industrial corporation, and we will be very reluctant to consider sending a fellow to such an institution. As you know, our fellowships are designed for the development of young scientists rather than for the completion of a given problem.[5]

The Rockefeller Foundation not only reiterated its reservations about Cauer's intended course of study in the United States, but also cited the reason for their hesitation; the Foundation was reluctant to have an academic working in collaboration with a corporation. They believed there needed to be a strict separation between the corporate and academic world. Only after Courant had taken the time to show how Cauer's project was a study in the pure sciences did the

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[4] W.J. Robbins to Richard Courant, 17 August 1929, Courant Papers, Bobst Library, New York University.

[5] W.E. Tisdale to Richard Courant, 20 November 1929, Courant Papers, Bobst Library, New York University.

Foundation officially approve his application. It took all of Courant's diplomatic skills to secure the fellowship for Cauer.

The case of Wilhelm Cauer reveals that the Rockefeller Foundation—like other institutions—did not respect applied mathematics as a discipline, although they eventually granted Cauer his fellowship. Indeed, correspondences between the two parties over the application continued over the nature of his proposed study. On 12 January 1930, the Rockefeller Foundation had its final exchange with Cauer in Göttingen, where the Foundation's board attempted to redirect his research in the direction they wanted. The fellowship card for Cauer noted: "Is only cultivating such mathematical ideas, which, partly direct, partly by employment with numerical apparatus, lead to solution of important purely scientific problems in numerical and graphical respect."[6] The card outlined how Cauer's work would be a project that added to the field of the general sciences, not just devoted to solving a particular problem. The Foundation remained steadfast in its opinions over how Cauer's project should proceed. Indeed, only a few "applied mathematicians" were included in the fellowship program, and they did not officially figure as such.[7]

As this account implies, before the 1930s in America anyone who wanted to pursue university work in applied mathematics—the use of mathematical techniques used in the application of mathematical knowledge to solve specific problems in other domains like physics, engineering, or electronics—would experience difficulty. Mixing disciplines was frowned upon.[8]

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[6] A.T. to Richard Courant, 11 January 1926, Courant Papers, Bobst Library, New York University.
[7] Karen Parshall and David Rowe, *The Emergence of the American Mathematical Research Community, 1850-1900* (Providence, RI: American Mathematical Society, 1994), 65.
[8] The theme of a marginalized applied mathematics in the interwar U.S. is frequently evoked in commemorative literature such as Rees (1980), Lax (1989), and Prager (1972). Historical studies

And by nature applied mathematics is cross-disciplinary. Among the plethora of sub-fields studied are operations research, statistics, business management, economic theory, computer science, and the more technical aspects of engineering.[9] Thus the field did not attract the interests of those whose primary interests were in mathematics, where the properties of functions, number theory, and the study of shapes and space are analyzed. With a few exceptions, there was little trace of applied mathematics in the universities of America; few problems were handled, few disciplinary lines crossed, and few formal classes taught.

American mathematics up until the 1940s could be characterized by its success in the pure aspects of its discipline. American mathematicians concentrated their efforts on basic research that added to the general principles of the field. Their endeavors to do so shaped the mathematics departments at institutions such as Harvard and Princeton. With strong institutional support, significant progress was made in the study of the calculus of variations—a form of mathematics that deals with the extremizing functionals, the "the function of functions"—and modern, abstract algebra—the study of algebraic structures such as groups, rings and vector spaces.[10]

The researchers of these institutions took pride in the abstract rigor of their research. In the 1930s, English mathematician Godfrey H. Hardy gleefully made a toast: "Here's to pure mathematics! May it never have any use."[11] Others expressed hope that pure mathematics would

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have added several nuances to this picture, such as Hanle (1982), Reingold (1981), and Hunter (1999). The last reference contains helpful information on how transatlantic contacts facilitated the creation of the community of American mathematical statisticians.

[9] Philip Davis and Reuben Hersh. *The Mathematical Experience* (Boston, MA: Birkhäuser Boston, 1981), 83.

[10] Parshall and Rowe, *Emergence of the American Mathematical Research Community*, 436.

[11] Godfrey H. Hardy, quoted in Morris Kline, *Mathematics: The Loss of Certainty* (New York, NY: Oxford University Press, 1980), 295.

continue to dominate intellectual inquiry. One authority at the University of Chicago claimed: "Thank God that number theory is unsullied by any applications."[12] It seemed applied mathematics would never be able to make itself a respectable discipline in the eyes of mathematical professionals and to university departments.

Only in Europe did applied mathematics receive any admiration and respect from professors and researchers. Germany's Göttingen University was among the European institutions providing abundant support for the discipline. Undoubtedly, the researchers at the institution were at the fore of producing seminal research in the sciences and mathematics. As an example, mathematician Hermann Minkowski had proven in 1907 that Albert Einstein's special theory of relativity could best be understood in a four-dimensional space.[13] But another highlight of the university's sciences and mathematics was the Mathematics Institute built in 1930. The school emphasized basic research in the applied and received substantial support.[14]

Both internal and external events soon altered the course of American and European mathematics dramatically. Shortly after Hitler became Chancellor of Germany in January 1933, the Nazis dissolved the once-mighty Mathematics Institute at Göttingen.[15] Had it not been for a few resolute figures within the German mathematical community, the whole enterprise might have fallen completely to the political machinations of Ludwig Bierberbach, a mathematics

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[12] Ibid.
[13] Scott Walter, "Minkowski, Mathematicians, and the Mathematical Theory of Relativity," in *The Expanding Worlds of General Relativity*, vol. 7 of the *Einstein Series* (Boston, MA: Birkhäuser, 1999), 47.
[14] Reinhard Siegmund-Schultze, *Mathematicians Fleeing from Nazi Germany: Individual Fates and Global Impact* (Princeton, NJ: Princeton University Press, 2009), 45.
[15] Constance Reid, *Courant in Göttingen and New York: The Story of an Improbable Mathematician* (New York, NY: Springer-Verlag, 1976), 43.

professor who sought to "purify" German mathematics by ideological means.[16] The political instability in Göttingen, and the rest of Europe, spurred an unprecedented migration of prominent intellectuals, particularly in the sciences and mathematics.

Just before America's entrance into World War II, R.G.D. Richardson, American mathematician and Dean of the Graduate School at Brown, concentrated on securing positions for mathematicians, engineers, and physicists fleeing wartime Germany. At the time, Brown was a relatively small university compared to, say, the grand research institutions Harvard, Princeton and the University of Chicago. Among the talented individuals who arrived at Brown was William Prager, a German émigré who had served as a *privatdozent* at Göttingen and a professor at the University of Istanbul. He, and many other European applied mathematicians, served as a foreign stimulus for the establishment of applied mathematical research in America, particularly in cultivating a program not at Harvard, Princeton, or Chicago, but at Brown. Particular circumstances and accidents of history form part of our story of Brown's Division of Applied Mathematics. But Brown, as we shall see, was more than just a passive recipient of good fortune.

Historiography and Methodology

It certainly is possible to say that European applied mathematicians were the primary agents developing Brown's initiative. European émigrés like William Prager, Richard Courant, and Theodore von Kármán—other important figures in the history of applied mathematics—were possibly the only scholars capable of instructing a new class of applied mathematicians. Historian of mathematics Reinhard Siegumund-Schultze explores this view of history in his *Mathematicians Fleeing Nazi Germany*. His argument, with special reference to European

[16] Ibid, 43.

applied mathematicians, maintains that the "actions of the scientists [fleeing Europe] in these periods had an enormous impact on the future path of their disciplines."[17] Only those few had the expertise to influence their occupations.

Siegmund-Schultze has not been the only historian to place special emphasis on the mathematician's role in developing an applied mathematics department. In the same vein as Siegmund-Schultze, a similar reading is found in the works of historians Amy Dalmedico Dahan and Constance Reid. Dahan refers to German mathematicians and their research collectively as "la figure symbolique" for American applied mathematics' development, whereas Reid makes special reference to the research methods of German émigré Richard Courant.[18] Like Reid, historians John L. Greenberg and Judith R. Goodstein pay special attention to the efforts of a single mathematician, albeit in their case to Hungarian Theodore von Kármán, in building up applied mathematics in America.

Taken together, these histories incorporate a traditional view of the history of mathematics that historian Michael Stolz labels as "internalist."[19] Such accounts are "internalist" because the historians aim at reconstructing the development of mathematics in the work of an individual expert or in the discussions of a group. David E. Rowe and Karen Parshall's *The Emergence of an American Mathematical Research Community, 1850-1900*, incorporates this methodology as well, writing only of mathematical concepts being built upon one another by other mathematicians. Their discussions contain detailed analyses about the meaning of the mathematical symbols created and used by mathematicians. Thus we often perceive a picture of

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[17] Siegmund-Schultze, *Mathematicians Fleeing from Nazi Germany*, xix.
[18] Amy Dahan Dalmedico, "L'essor des mathématiques appliquées aux États-Unis: l'impact de la Seconde Guerre mondiale," *Revue d'histoire des mathématiques* 2 (1996): 172.
[19] Michael Stolz, "The History of Applied Mathematics and the History of Society," *Synthese* 133 (2002): 43.

applied mathematics belonging to the realm of the sciences, one that is untouched and unaffected by people without a concrete connection to the discipline. These narratives thereby attribute, at times even enshrine, the development of American applied mathematics—and the creation of Brown's Division of Applied Mathematics by extension—entirely to scholars with mathematical training and expertise.

It is easy to represent this transformation of the discipline as isolated from culture and disconnected from the discipline's place in the world at a specific instance in time. Indeed, the emergence of a new discipline entails constituting a stock of theoretical knowledge, shared questions of inquiry, standard research methods, and a scientific community—all of which would not concern anyone but an applied mathematician. But such an approach is also inherently limited, due to the complex conditions that give rise to key events in the development of scientific knowledge. Though a critical influence, emigrating scholars, bringing their own research methods and ideas, did not solely cause the emergence of Brown's applied mathematics program. New technologies were not derived just from mathematical ideas. Neither the analysis of the logic behind mathematical thinking nor the sole emphasis on an interacting group of applied mathematicians fully explains the dynamic and complex cluster of events that led to the institutional development of an applied mathematics department at Brown. Another image is needed.

My intent in this thesis is to place the development of Brown's Division of Applied Mathematics, a history that has never been constructed or explored thoroughly before, within a relevant, extra-mathematical context. In combining the internal technical history within this extra-mathematical context, the significance of applied mathematics' institutionalization is enhanced when we realize that its development constitutes a cultural event, not just an intellectual one. World War II saw the reversal of a decades-long discrimination against a discipline long shunned by philanthropic institutions and academic scholars in universities. Brown's initiative legitimized applied mathematics' existence, and led to changes far beyond the walls of the University. We are able to, then, perceive a more complete picture about the development of applied mathematics.

So how, in the middle of the twentieth century, in a time of war, was Brown able to establish an applied mathematics program that led to its institutionalization as a department? What was its impact and what did the establishment of an applied mathematics department mean for Brown as an institution? Applied mathematicians and the mathematical concepts they developed remain critical historical actors to our story. But by taking into account other outside agencies that concerned themselves with the applied mathematics initiative at Brown—in particular businesses, the military and the government—we can further elucidate the importance of applied mathematics to the history of higher education.

Reading the archives of Richardson, Prager, and other important figures involved with erecting Brown's applied mathematics department in the 1940s reveals the struggle to make applied mathematics acceptable to the previous parties who had dismissed it. Sifting and reading through the correspondences, reports, and memorandums of businessmen and government officials complicates the story further.

Brown University's Division of Applied Mathematics arose because of university ambitions, the demands of war, the needs of industry, and the ingenuity of science. It was an affair for individual mathematicians, university administrators, government officials, and businessmen. Amidst this cacophony of voices, this thesis aims to show how the development of Brown's Division of Applied Mathematics became a matter of coordinating the languages of science and technology. The story of applied mathematics is not a forward march of scholars vying for applied mathematics' utility; it is a story in which engineering, business, commerce, mathematics, and war came together for both practical and idealistic reasons. At every moment systematizing applied math was both practical and ideal: about improving technology and industry and about expanding the influence of Brown University.

Order of Argument

Because the formulation of an applied mathematics department in America cannot only be tracked from a nuclear group of mathematicians, engineers and administrators, our story will switch back and forth between national and local narratives. Chapter 1, "From Dysfunction to Unity," anchors the history of American mathematics in the history of American universities. Before 1940, there had been no systematic endeavor in the United States to train applied mathematicians in their own right. Earlier attempts to do so were met by disapproval both from the government and academics. This chapter explores the origins of academic and governmental acknowledgement of the need for a research program devoted to studies in applied mathematics, and how it came to be located at Brown University. Confronting a staggering increase in the technicality of industry, entrepreneurs were increasingly frustrated by a lack of resources to meet their demands. So too were governmental authorities, as they stepped up the pace of increasing American defense. These various demands came to a head in 1940 through the confluence of multiple influences from government, industry, and academia.

Frustrated, indeed infuriated, by a lack of initiative from other parties, Brown lobbied to develop a new program, determined to put a stamp of rigorous education and research on the new world order of applications. Brown President Henry Wriston and Dean Richardson also saw an opportunity to expand the research capabilities of Brown, leading to the Division of Applied Mathematics' predecessor, the Program of Advanced Instruction and Research in Mechanics.

Chapter 2, "Meeting the Challenge," picks up on the initiative brought up by Richardson and Wriston. The chapter centers on the successive sessions of applied mathematics held in the summers of 1941 and 1942. Each was referred to as the "Summer Session" of the Program of Advanced Instruction and Research in Mechanics. This chapter explores how Brown successfully demonstrated the importance of the summer sessions to other American institutions, and how the program's research was tied to the demands of war. The colloquia served as a model for eminent mathematicians and engineers evaluating the program, helping to assure the emergence of applied mathematics as a discipline distinct from engineering, physics, and mathematics. It takes us close-in to show that the evaluators recognized the efforts of Richardson, Wriston and Prager, and were convinced of the program's significance.

In Chapter 3, "Expanding Horizons," the emphasis shifts to a particular instance of the development of an applied mathematics department: the establishment of an applied mathematics journal from 1942 to 1943. Although the training of mathematicians at the research level represents a critical ingredient in the historical process documented here, the actual formation of a department—an interacting group of scholars linked by common interests—required more than just advanced training in mathematics. They also had to validate their work to the rest of the academic community through their publications. The establishment of the *Quarterly of Applied Mathematics* accomplished this. This encouraged increasing emphasis on research as an officially sanctioned and supported endeavor in the emerging university setting and, by intimate association, to the emergence of an applied mathematical community. Thus the relationship of the applied mathematics program at Brown to other emerging initiatives is also explored. These efforts resulted in the creation of an outlet for research-level mathematics and a specialized professional society.

The final chapter, "Applied Mathematics Established," further examines the growth of Richardson and Prager's project and its lasting influence on Brown University. Beginning from 1944 to 1946, Chapter 4 describes the formal establishment of the Division of Applied Mathematics at Brown University in the Graduate School. It explores how members of this generation of research-oriented mathematicians were able to fit comfortably into the academic setting and continued to garner support from outside of universities through government work and industry. As intellectual researchers, they revealed that the importance of their work was not limited to their scholarly field. Their expertise dealt with abstract math and tackled practical problems of society. In doing so Brown lay at the forefront of a new movement. On one side lay the vast modern university infrastructure of government-sponsored grants and a growing movement in academic research towards applications. On the other, a new sense of the mission of pragmatic knowledge emerged.

This is the story of how Brown University arose, unequaled, at the intersection of knowledge and power, cultivating applied mathematics.

CHAPTER 1
From Dysfunction to Unity, 1940-1941

In March of 1941, R.G.D. Richardson, Dean of the Graduate School at Brown University, circulated a memorandum to faculty at other American universities. Addressed to physics, mathematics, and engineering department heads, the memorandum announced Brown's plan to establish an applied mathematics program. After years of futile attempts to bring applied mathematics to the fore of intellectual inquiry among scientists and mathematicians, Brown now called into existence the first applied mathematics program in America. The "Program in Applied Mechanics," as Richardson initially called it, would supplant the myriad professional organizations' and disciplines' attempts to focus on applied mathematics, to establish mathematical foundations for the sciences and defense, and to "remedy America's inadequacies in industrial mathematics."[20] At last, both practical and theoretical aspects of significant mathematical problems would be explored.

That Brown was prepared to host a slew of prominent scholars in the sciences and mathematics under the common umbrella of applied mechanics by the summer of 1941 was surprising, given the lack of interest previously displayed by mathematical professionals and Brown's status as a relatively small, traditional institution. Scientific professions, ranging from

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[20] R.G.D. Richardson, "Memorandum Concerning the Establishment of Courses in Applied Mechanics at Brown University," 18 March 1941, Courant Papers, Bobst Library, New York University. Throughout this thesis I will interchange applied mechanics with applied mathematics. Applied mechanics serves as a part of applied mathematics, where mechanics stresses the mathematics being applied. Applied mechanics deals fundamentally with fluid dynamics and elasticity, both of which are basic to general considerations of design and structure. In its applications in engineering, it bears directly upon such immediate problems as aeronautics, ship construction, ballistics and the detection of submarines and planes.

military research and industry to physics and engineering, had previously struggled to establish applied mathematical research of their own. But as a field that remained on the fringes of mathematical research, funding for applied mathematics, whether from government or philanthropic institutions, had been limited. Despite this unpromising environment, however, Brown managed to generate broad support for formulating applied mechanics instruction. But why was it that neither mathematics nor physics and engineering departments took up the cause to promote applied mathematics research? What confluence of cultural events created an environment such that academic, government, and industrial circles came to accept the need for a new program in applied mechanics at Brown?

My argument in this chapter is two-fold. First, Brown's timing was right: the argument that applied mathematics was an indispensable tool for American commerce and development finally convinced industry and government to support Brown's endeavor. In a progressive, increasingly technological world engulfed by war, the nation was ready to support a new curriculum that would utilize advanced mathematics for practical purposes. In the eyes of the administrators organizing Brown's applied mathematics initiative, the program would serve as ostensive justification for this national enterprise. Brown's reasons for contributing to this enterprise, however, were prompted by very different reasons.

Second, I contend that Brown's own self-interest, as defined by its leaders, especially President Henry Wriston, were a driving force behind the adoption of the applied mathematics program. Brown sought to be at the forefront of institutions developing systematic research and training in applied mathematics. Brown already had a graduate school, but adding this program was a major first step toward making Brown a major research university.

The Plight of Applied Mathematics

We begin with the situation of mathematics at the turn of the twentieth century, for understanding this period reveals that various facets of society—industry and military—concerned with technology sought a new class of mathematicians that required a new mathematical discipline. In the 1910s and the 1920s, graduate offerings in American mathematics departments multiplied and grew. Universities were eager to attract the cream of American talent with a program of instruction that emulated, even rivaled, German institutions like Göttingen University. But American universities embraced the German organization of higher education, in which work was self-consciously divorced from practical application and pure research was emphasized instead.[21] American universities aspired to gain the authority and credibility German research institutions had cultivated over the centuries. Thus courses were fashioned to teach aspiring mathematicians the modern and popular topics of their field: the theory of functions, higher plane curves, and number theory.[22]

These subfields of mathematics reflected the fixation on pure research—the abstract and the rigorous. So strong were these predilections that they were incorporated into the intellectual fabric of mathematical investigation. Proofs relied solely on logic and the sturdiness of algebra alone.[23] Not an analogy, not a single diagram sullied a page of any publication. With these complex topics, mathematicians paid little to no attention to the applied aspects of their discipline.

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[21] Jonathan R. Cole, *The Great American University: Its Rise to Preeminence, Its Indispensable National Role, Why It Must Be Protected* (New York, NY: PublicAffairs, 2009), 17. For more background on the role model Germany served for American higher education, see Siegmund-Schultze (2009).
[22] Parshall and Rowe, *Emergence of the American Mathematical Research Community*, 367.
[23] Ibid, 250.

Unlike mathematics, engineering and physics embraced the practicality of their scientific fields. Physics was perceived, in the words of one history, as "the invention and manipulation of concepts, using mathematics where necessary, to simplify the understanding of known physical phenomena, and to predict new phenomena."[24] The field was grounded in the real world, concerned with real, concrete environments. Engineers, too, were a growing class of scientific professionals, trained with an esoteric body of technical knowledge to apply to problems demanding technical expertise: the mining, metallurgical, mechanical, electrical, and chemical.[25] They were technological pioneers who oversaw the construction of bridges, canals, and railroads. Their occupation demanded mathematical prowess within a progressive, technological-savvy world.

For instance, stimulated by heavy World War I production, American engineers and entrepreneurs had worked to improve airplane production and aerodynamics. Yet most of these designs were carried on with little analytic or mathematical understanding of the theory of lift, drag, or airfoil.[26] These aspects of plane construction, complex in nature, were critical to building safe and efficient aircraft. Where mathematicians stood as masters over mathematics, understanding and manipulating the intricacies of numbers, engineers appeared approximate and imprecise.

Here lay an underlying problem within the mathematical community of the first few decades of the twentieth century—mathematical disunity. Mathematical professionals, ranging from teachers and professors to engineers, physicists, and mathematicians, came from a wide

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[24] M.D. Fagen, ed,. *A History of Engineering and Science in the Bell System: Volume 1 The Early Years (1875-1925)* (New York, NY: The [Bell Telephone] Laboratories, 1975), 7.
[25] Paul Hanle, *Bringing Aerodynamics to America* (Boston, MA: MIT Press, 1982), 3.
[26] Ibid, 24.

variety of mathematical backgrounds. For scientists who required mathematical training, the ambition was to educate technical experts who would be, in due time, able to meet the demands of the practical world. On the other hand, mathematics departments concentrated on schooling an elite group of pure mathematicians with priorities not necessarily grounded in the real world.

"Convenience" and "convention." These terms arose again and again in pure mathematicians' abstract logical proofs. Mathematical theories were derived using conventions, a uniform set of clearly stated definitions. Convenience arose from deriving airtight proofs devoid of excess symbols or functions. The proof of the Riemann mapping theorem, for example, exemplified this critical spirit of analysis. The Riemann mapping theorem states that an arbitrary, simply connected region of a plane can be mapped onto a circle.[27] It is a statement that requires rigorous, analytical thinking in order to prove it. In 1900, American mathematician William Osgood produced a proof of Riemann's theorem, albeit rather raw in form. Over the next decade the proof was altered using Riemann surfaces—a one-dimensional manifold[28]—only to be simplified by excluding Riemann surfaces.[29] The proof was deduced using proper mathematical rules. The reader followed the mathematician's convincing demonstration of a mathematical statement. No *ad hoc* math, inductive, or empirical arguments were invoked.

Yet these same terms, "convenience" and "convention," were also reflected in the less-than-ethereal concerns of real-world engineers, physicists, and even automobile manufacturers.

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[27] The official statement of the Riemann mapping theorem is that if U is a non-empty simply connected open subset of the complex number plane C which is not all of C, then there exists a biholomorphic mapping f from U onto the open un it disk.

[28] A manifold is a modeled topological space. A line is a one-dimensional manifold. A sphere is a two-dimensional manifold, since it can be represented by a collection of two-dimensional maps.

[29] J.L. Walsh. "History of the Riemann Mapping Theorem," *American Mathematical Monthly* 80:3 (March 1973): 275.

Engineers, for instance, were constantly concerned with finding ways to reduce the cost of electric street lighting. This involved finding shortcuts by maneuvering the electrical circuits used to power the streets of cities.[30] Here was convenience that mattered to a techno-driven and industrialized society. The electrical engineer and the physicist tackled these problems by applying well-established mathematical equations. Their duties did not involve deducing the best mathematical method from which to proceed. Rather, armed with the mechanical knowledge he already had, the mechanic worked with the physical, concrete objects or systems.

By the late 1930s, however, government and businesses such as the automobile and airline industries had a grander vision for creating convenience and developing their resources. Corporations wanted to find alternative ways of increasing production, and the military wanted to develop quantitative models for planning large-scale military action.[31] Industrialists and military officials requested the formulation of a workable mathematical theory that modeled social groups or economic behavior. These objectives required a more advanced mastery and expertise in mathematics that engineers lacked. Indeed, mathematical training was deficient in those who were not pure mathematicians. Engineering educators had even seriously doubted whether engineering students should learn calculus, with some schools opting to exclude it from their engineering curricula. Educators reasoned that calculus merely served as a "cultural embellishment" for engineers.[32] In the eyes of the educators setting the curricula, advanced mathematics was rather unimportant to an engineer. So when demand grew for highly trained

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[30] Edward T. Layton. *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession* (Baltimore, MD: Johns Hopkins University Press, 1986), 162.
[31] Mina Rees, "The Mathematical Sciences and World War II," *The American Mathematical Monthly* 87:8 (October 1980): 618.
[32] Layton, *Revolt of the Engineers*, 4.

mathematicians to fill positions and solve problems that engineers were not trained to handle, new programs became necessary.

Ironically, professional mathematicians who were well equipped and qualified had little interest in dealing with real world applications. Pure mathematicians remained concerned with their own research, ignoring the pleas of the practically minded. A certain prejudice towards applied mathematics could be discerned within the mathematical community of the 1930s. Reflecting on that time, applied mathematician William Prager pointed out (in 1972):

> [The] number [of professional mathematicians interested in applications] was extremely small. Moreover, with a few notable exceptions, they were not held in high professional esteem by their colleagues in pure mathematics, because of the widespread belief that you turned to applied mathematics if you found the going too hard in pure mathematics.[33]

As Prager's comments suggest, few mathematicians were willing to switch their specialties to more socially driven or practical concerns. So the situation called for a new profession that could apply mathematics rigorously in the real world.

Before the 1940s, despite the emerging needs of government and industry, attempts to systematically produce a group of applied mathematicians were fragmented and sporadic. The federal government set up its own experimental and research laboratories in the 1920s, aiming to improve aeronautical research. The Langley Laboratory, under the direction of the government's National Advisory Committee on Aeronautics, aimed to improve the scientist's mathematical capabilities.[34] The government did not want to wait for universities to alter their curriculums. Also, American corporations set up industrial laboratories of their own in the 1920s, training

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[33] William Prager, *Quarterly of Applied Mathematics*, 30:1 (1972): 1.
[34] Reinhard Siegmund-Schultze. "Military Work in Mathematics 1914-1945: an Attempt at an International Perspective," in *Mathematics and War*, ed. Jens Hoyrup et al. (Basel, Switzerland: Birkhäuser Verlag, 2003), 41. This organization was the predecessor of the National Aeronautics and Space Administration.

experts and conducting basic research; corporations doing so included General Electric, General Motors, and American Telephone and Telegraph.[35] Here lay an early pattern of American mathematics that placed academic research in the university and practical work in businesses and the economy.

Bell Telephone Laboratories was among the most active industrial corporations seeking to produce its own class of mathematicians. A premier research and development facility, Bell Labs was influential in technology, developing a wide range of revolutionary technologies including fax transmissions and transmitted television images in the 1920s.[36] Even as part of an efficiency- and profit-driven corporation however, Bell Labs had established its own Mathematical Department in 1928. Here seminal research was carried out in areas such as statistical quality control of industrial production.[37] At first glance, Bell Labs researchers seemed to believe in their abilities to educate the new class of researchers they needed, a belief that seemed improbable given the lack of academic training. But we must realize that at the time, Bell Labs' actions would not necessarily have been viewed as impractical. After all, the lives of engineers in industry and pure mathematicians remained unconnected. Research produced in industrial labs did not circulate among academically trained mathematicians, and thus did not influence the interests of mathematicians in universities. After over ten years of having a research lab of its own, Bell Labs understandably was not eager to abandon their program and appeal to universities for systematized training in applied mathematics. They kept mathematical training in-house

[35] Siegmund-Schultze. *Mathematicians Fleeing From Nazi Germany*, 178.
[36] Denis Bayart and Pierre Crépel, "Statistical Control of Manufacture," in *History and Philosophy of the Mathematical Sciences Volume 2*, ed. I. Grattan-Guiness (Baltimore, MD: Johns Hopkins University Press, 1994), 5.
[37] Ibid, 4.

Among the top business executives that emulated these ideas was Thornton C. Fry, Mathematical Research Director for Bell Telephone Laboratories. He coordinated and taught advanced topics in mathematics to his employees. As early as 1929, employees attended "Out-of-Hour Courses." There, workers seeking advanced mathematical knowledge read from textbooks written specifically for them. Fry's *Elementary Differential Equations* was one example.[38] In these courses, mathematical problems specific to industry were on the agenda. Readers of Fry's texts would have found an extensive range of subject matter in applications: the law of mass action in gasses and solid materials, the flow of current—the rate at which electricity is transported—in an electrical network and the conduction of heat.[39] These topics reflected Fry's penchant for thoroughly integrating a mathematical approach into the mechanistic disposition of industry. Unlike regular math textbooks, Fry's text framed math with real-world problems that preoccupied and stumped the leading engineers and physicists of the day.

Bell Telephone Laboratories, however, did not subscribe to this regimen for long. Fry's text assumed a strong mathematical background in calculus. Because some students lacked that background, the "Out-of-Hour" courses did not work and was rendered an economic waste. Students reading Fry's textbook would have found electricity being put into integral form for no apparent reason.[40] Thus Bell Labs' training was unproductive, taking up the time and money of the employees. At the rate it was being taught, Fry's program was not sufficient to produce the class of mathematicians that industry needed.

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[38] Thornton Fry, *Elementary Differential Equations* (New York, NY: D. Van Nostrand Company, 1929), v.
[39] Ibid, 45.
[40] Ibid, 46.

The 1930s were a period of frustration for industries, government, and the mathematical and scientific community. A large fissure in the form of mathematical training separated pure mathematicians from scientists. Analyzing how individuals and companies attempted to resolve this problem, we can understand the consternation of someone who realized the instability of his field—mathematics—and remained unsure of how to resolve the problem. Consequently, this fragmented community of scientists and mathematicians attempted to fix the issue in its own way. But the ineffectiveness of these short-lived solutions made business executives and scientists alike realize that more action was necessary.

The Case for Industrial Mathematics in Academia

This was how things stood for Thornton Fry in 1940 when he realized that industry was incapable of providing necessary technical training in mathematics. Applied mathematics was an immediate concern and it held his rapt attention. He acknowledged that institutions of higher learning should have the responsibility of educating a new class of mathematicians. But he also needed some means to express these views to the public. So when the federal government's National Research Council, spurred by the likelihood that the United States would become involved in World War II, commissioned the National Resources Planning Board to write a report on research in industry and its service to society, Fry jumped at the chance.[41] In December 1940, as Germany and Britain continued to exchange bombing raids, the Board submitted to the 77th Congress a review of industry's conditions entitled, "Research—A National Resource."[42] Among the many reports within this compendium was Fry's 38-page report. "Industrial

[41] Frederic A. Delano to the President, 4 April 1941, National Research Council, in *Research: A National Resource* (Washington, D.C.: Government Printing Office, 1941), vi.
[42] Ibid, 268.

Mathematics," which not only showcased the importance of mathematics and the lack of mathematical expertise in society, but also made clear that some standard curriculum in applied mathematics was needed.

Fry wrote a first draft of his report in spring 1940. In it he detailed the mathematical problems applied mathematics could resolve. But before having any industrial and governmental authority read the report's content, he sought the services of Theodore von Kármán, an esteemed aeronautical engineering professor from the California Institute of Technology. Writing to von Kármán April 26, Fry requested: "I would regard it as a great favor if you could find time to read it over, and criticize it as severely as you see fit."[43] The language of mathematics was foremost among Fry's concerns and he made conscious efforts to consult an expert scientist before an administrator or a businessman.

After Fry spent a week in nervous anticipation, von Kármán replied. His letter expressed enthusiasm for Fry's reasoning: "I read with very great interest your excellent report on Industrial Mathematics. I believe this report is not only a very readable and instructive essay, but also means a great service to the whole profession."[44] But the returned copy of Fry's draft was not without its corrections. Von Kármán also added:

> I personally would perhaps emphasize a little more the methods of approximation based on the fundamental mathematical ideas, as successive approximations, direct methods of the calculus of variation, etc. […] Concerning the theory of flutter,[45] I feel that calling the

[43] Theodore von Kármán to Thornton Fry, 26 April 1940, Theodore von Kármán Collection, 57:14, Caltech Archives, Pasadena, California.
[44] Theodore von Kármán to Thornton Fry, 6 May 1940, Theodore von Kármán Collection, 57:14, Caltech Archives, Pasadena, California.
[45] Flutter is a phenomenon encountered in flexible structures subjected to aerodynamic forces. This includes aircraft, buildings, telegraph wires, and hanging signs. Flutter occurs as a result of interactions between aerodynamics and stiffness on a structure's surface. It results in vibration motions that can cause structural failure.

> simplifying assumptions violent goes perhaps a little too far. As a matter of fact, flutter calculation has become in the last years more and more a routine thing, and it seems that in spite of the simplifying assumptions, we get quite good results by the mathematical theory.[46]

Minute and subtle as they were, such corrections were critical for Fry's campaign for applied mathematics. He did not want to omit or misrepresent any highly technical mathematics. He not only wanted future readers of his report—business executives, scholars, and government officials—to be convinced of the need to nurture applied mathematics, but to also have no one question or dismiss his argument on the grounds of faulty reasoning.

Fry's remarks in his 1940 "Industrial Mathematics" report about a lack of support for applied mathematics were not, therefore, exaggerated speculation. Here was a well-established business authority, by far one of the most famous and influential in industry, reporting on a need to reform education. All around him he envisioned the potential for applied mathematics. His 38-page tract spelled out America's need to employ applied mathematics for business and industry.

Upon first glance, government officials would first have read about the flaw of pure mathematicians: "the typical mathematician is not the sort of man to carry on an industrial project. He is a dreamer."[47] A mathematician is characterized by his habits of thought, constantly thinking of his individual research. To be useful, the mathematician in industry must be versatile. Since he functions as a consultant, he must be able, and willing, to talk to his clients in their own terms; he, not they, should put their problems into mathematical terms. Pure

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[46] Theodore von Kármán to Thornton Fry, 6 May 1940, Theodore von Kármán Collection, 57: 14, Caltech Archives, Pasadena, California

[47] Thornton Fry, "Industrial Mathematics," *The American Mathematical Monthly* 58:6 (June 1941): 4.

mathematicians lacked the interest and skill that Fry believed mathematicians in industry needed to develop.

Fry then proceeded to illustrate an ideal image of what the "industrial," applied mathematician could accomplish: "The typical [applied] mathematician feels great confidence in a conclusion reached by careful reasoning. He is not convinced to the same degree by experimental evidence."[48] Fry did not mean to differentiate applied mathematicians from scientists by saying mathematicians avoid evidence. Rather, he perceived applied mathematicians as preferring a whole picture in which experimental evidence and theoretical ideas mutually supported each other. Whereas the engineer and the physicist necessarily created experiments to produce new technologies, the applied mathematician could accomplish the same task relying on the deductive reasoning that mathematics provided.

Principles of economics and efficiency dominated Fry's appeal for industrial support of applied mathematics. "Throughout the whole of industry," Fry contended, "research is becoming more complex and theoretical, and hence the value of consultants in general and mathematical consultants in particular, must increase."[49] Simple theories of supply and demand required a new class of mathematicians. Their employment could reduce labor costs and avoid unnecessary experimentation. Thus the field of applied mathematics, and the technicians it produced, promised to bring flexibility, the flexibility of trained applied mathematicians being put to use in multiple occupations. This was the true advantage of the change Fry advocated.

But throughout the report, Fry also pressed the importance of applied mathematics to realms beyond the commercial sphere. Though his report's title specifically referred to industry,

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[48] Ibid, 2.
[49] Ibid, 10.

Fry was not exclusively interested in advancing his own private profession. Instead—this is the crucial point—Fry created an image of a new kind of mathematician, trained in universities, serving the nation, especially in wartime. Fry had to appeal to administrative and government authorities by illustrating the economic benefit to employing expert mathematicians. The employment of applied mathematicians would reduce the amount of military experimentation required.[50] Space could be saved, and budgets minimized. Labor costs could be reduced and unnecessary mathematics avoided. Fry strengthened his argument by pointing out the severe shortage of qualified experts: "As of 1939 an estimated 100 to 150 workers fit the characterization of the industrial mathematician."[51]

As the industrial executive, Fry concluded his report by calling for a long-overdue reassessment of the United State's education system. Towards the conclusion, he lamented: "There is nowhere in America a school where this [applied mathematical training can be required. No school has attempted to build a faculty of mathematics with such training in mind."[52] Here Fry left little doubt about the obligations he expected universities to meet. It was within universities that students began choosing their career paths and took the necessary coursework. It should therefore be within the same institutions that applied mathematics instruction be administered. Such an objective would demand more than just planning courses, conceded Fry, but it still remained unacceptable that industry and government "have had to make such a shift as might be with ersatz mathematicians culled from departments of physics and

[50] Ibid, 9.
[51] Ibid.
[52] Ibid, 31.

engineering."[53] Fry was ever more certain that some schools should institute an applied mathematics program. In his eyes, such institutions of higher education would serve as bridges between the world of abstract, complex mathematics and the practical concerns of electricity, telecommunications, and military movement.

In his December 1940 report on "Industrial Mathematics," we can discern Fry playing two roles. There is the practical, business-associated scientist Fry, advocating for improving technology in the age of modernity. There is also Fry the idealist, seeking to transform the underlying educational systems of applied mathematics. His article reflected concern for efficiency and modernity. Writing to his friends, Fry would switch, without missing a beat, from the rarified-theoretical to the practical-technological. In one letter he wrote, "The further I have gone with this job, the more conscious I have become of the fact that it would have been completely amateurish if I had not had such friendly cooperation from such a large number of people."[54] There was a growing consensus to be discerned over the growing campaign for applied mathematics. Applied mathematical training proposals were right up his alley—they offered ways to transform his goals into reality.

Brown Comes to the Fore

When Thornton Fry's December 1940 report was circulated, it was not only the National Research Council's members who, having commissioned the report, read Fry's "Industrial Mathematics." Far from it. On the basis of Fry's points—which spoke specifically to issues of economy, business, and education—the plight of applied mathematics in Richardson's words,

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[53] Ibid, 33.
[54] Thornton Fry to Theodore von Kármán, 8 May 1940, Theodore von Kármán Collection, 57, Caltech Archives, Pasadena, California

"alarmed" senators and "roused" generals.[55] Within a few months of the report's publication, taking advantage of the moment, Brown University administrators also shifted into high gear to launch the first applied mathematics program in America. Dean Richardson and President Wriston, enthusiastic readers of Fry's report, led the charge. As early as 8 April 1941, a mere four months after Fry's report was published, Richardson declared, "We have almost come to the point where we are committed to going ahead with this program."[56]

On April 26, 1941, Richardson circulated a memorandum to the heads of other universities' departments of mathematics. In the memorandum he explained how Brown was vitally concerned over the defense program of the nation, and a program in applied mathematics naturally was the possible area to turn to in the emergency.[57] Richardson argued the case for creating a formal program of applied mathematics.

That Wriston and Richardson conceived of centering applied mathematics instruction at Brown was surprising. Brown professors and researchers, compared to well-established research institutions like Johns Hopkins University or the Massachusetts Institute of Technology, exerted little influence in leading scientific development. Brown's separate Graduate School had been established in 1927, and in 1930 had granted only 11 doctoral degrees, 8 of which were conferred on humanities students.[58] Students graduating from Brown did not come out with a scientific outlook scaled to producing pivotal technology.

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[55] R.G.D. Richardson to Richard Courant, 8 April 1941, Courant Papers, 19, Bobst Library, New York University.

[56] Ibid.

[57] R.G.D. Richardson, "Memorandum Concerning the Establishment of Courses in Applied Mechanics at Brown University," 26 April 1941, Courant Papers, Bobst Library, New York University.

[58] "Seventy-Three Given Degrees in Graduate School on Sunday," *Brown Daily Herald*, 16 June 1930, 1.

Brown also suffered from the Great Depression. In a June 1941 economic report to Brown's Corporation, a bicameral body including a Board of Fellows and a Board of Trustees, President Wriston frankly discussed the financial difficulties it faced: "This year [1941], it is anticipated that our actual deficit will be approximately 60,000 and next year, because of anticipated loss of revenue from loss of students, 114,000."[59] These were concerns that very much filled the administration's discussions.

In this crisis and charged atmosphere, the Corporation and the President oscillated between preserving Brown by making it an exclusively undergraduate institution and expanding the university. Attempting to remedy Brown's dire situation, one board member proposed to "drop the Graduate School as a measure of economy."[60] The Corporation prioritized safeguarding Brown's undergraduate education over everything else. But Wriston, presiding over the meeting, ruled out that option citing the university's commitment to providing high quality education in the Graduate School. He also pointed out that professors in the Graduate School were all tenured. Soon the subject turned to the Engineering Division. Board members "proposed that we drop the Engineering Division, the only argument being that a saving would result." Wriston, frustrated by the lack of support for scholarly research, again overruled the suggestion. In his reasoning, he duly noted, "Engineering is one of the departments with the lowest cost per student."[61] Engineering was all too important to be dropped. It was from this department that leading scientists could emerge and could develop cutting edge technology.

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[59] "President's Report to the Corporation," 17 June 1941, President's Papers, 1:8, Brown University Archives, John Hay Library, Providence, Rhode Island.
[60] Ibid.
[61] Ibid.

Wriston and Richardson were committed to preserving the Graduate School and the Engineering Division. The widening gyre of technological, practical mathematics spiraled outwards from national concerns Fry had raised. They saw an opportunity to help Brown come out of its dire economic situation by promoting applied mathematics. They wanted Brown to be at the fore of universities producing seminal research in the sciences. That continuing engagement with producing mathematical theory and applying to society no doubt facilitated Brown's move for applied mathematics.

Richardson played a pivotal role through his influence as a dean, but even more powerfully as a trained mathematician himself. As he had so many times before, Richardson crossed back and forth between his administrative duties and his promotional activities for mathematical research. He had served as Secretary for the American Mathematical Society, a national association for professional mathematicians headquartered in Providence, Rhode Island.[62] He embodied the successful organizer of science, garnering an early reputation in mathematics that made him a spokesman for improving mathematics education in America. He helped form a committee seeking to enlist individuals for specific research projects in connection with defense and the applied field.[63] Such efforts showcased the Dean's aspiration to create a unified applied mathematical body in academia that could aid the needs of industry and expand the institution he was based.

Richardson saw that the arrival of refugee mathematicians from Europe presented an opportunity to improve Brown's status and support industry and engineering. Indeed, European

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[62] Raymond Clare Archibald, "R.G.D. Richardson, 1878-1949," *Bulletin of the American Mathematical Society* 56:3 (1950): 256.
[63] R.G.D. Richardson to Theodore von Kármán, 30 November 1940, Theodore von Kármán Collection, 37:20, Caltech Archives, Pasadena, California.

immigrants served to promote scientific and mathematical activity all over America upon their arrival. These arriving intellectuals were "the men and women who came to America fully made, with their PhD's or diplomas from art academies or music conservatories in their pocket, and who continue to engage in intellectual pursuits in this country."[64] Having already established an international reputation within the intellectual community, European mathematicians and physicists should have been able to exert their influence in American academia.

But American universities were not as welcoming to the incoming refugees as sometimes believed. With the initial arrival of immigrant-mathematicians, a few American authorities voiced concern about coping with the rush of immigrants. Mathematician Oswald Veblen wrote to Richardson on 29 July 1933: "Of course, the Institute [for Advanced Study at Princeton] is already pretty heavily involved with foreigners and [founder Abraham] Flexner is anxious to keep it primarily American."[65] Immigrating foreigners had to reckon with xenophobic sentiment expressed by such academics as Veblen. Though Veblen's views were extreme, many American academics feared the loss of teaching jobs at universities. It was therefore all the more important for administrators to stress the absolute priority of research as opposed to teaching jobs when arguing in favor of immigrants.

So R.G.D. Richardson created appointments at Brown for various immigrants who had developed a strong reputation within the mathematical world. Examples included Otto Neugebauer—a historian of ancient mathematics that later founded the *Mathematical Reviews* publication at Brown. If the immigrants had a pivotal role in bringing applied mathematics to

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[64] Laura Fermi, *Illustrious Immigrants: The Intellectual Migration from Europe 1930-41* (Chicago, IL: University of Chicago Press, 1968), 183.
[65] Oswald Veblen to R.G.D. Richardson, 29 July 1933, Brown University Archives, Richardson Papers, John Hay Library, Providence, Rhode Island

America, then so too did Richardson in providing an entryway for them into the American education system, allowing them to integrate applied mathematics in a way that had never before been accomplished. Gathering other eminent applied mathematicians, Richardson believed that he had enough resources to officially declare the inception of a new program in applied mathematics to be based at Brown. He successfully made his pitch to President Henry Merritt Wriston and the Corporation of Brown University. The academic community had accepted the need for formal instruction in applied mathematics, and would immediately take action in a formal program with a 12-week summer session called the "Summer Session in Mechanics."

All through Richardson and Wriston's efforts lay an American pragmatic progressivism, a sense that Brown University could expand by developing and nurturing an applied mathematics program. Their faith inspired optimism in the larger community, one that prompted generous financial support. Ever since the period of war preparedness that had begun in 1939 in the U.S., war-related mathematical subjects like mathematics and engineering, and even history and epistemology, came to the attention of the Rockefeller philanthropists. This occurrence had partly to do with the fact that state support for science and engineering was growing and the private foundations had to look for a role of their own. By supporting these subjects, the American academic community embraced more European ideals and international mathematical communication, under the special conditions of emergency and war, obtained a new meaning, stressing the benefits that American science could gain from the influx of refugees.

America's entrance into the war in December 1941 changed the conditions for Rockefeller support to mathematics and to refugees considerably. In particular, the great influx of federal money, especially from defense funds, for mathematics and the sciences forced the

Rockefeller Foundation to redefine its goals.[66] There was an increased demand for mathematicians in the U.S. for the war effort, particularly in the basic mathematical training of soldiers. The Foundation had to look for new tasks, and became even more interested in the broader social environment of mathematics and the cultural values it involved.

Supporting Richardson's applied mathematics program was in the interest of philanthropic institutions like the Rockefeller Foundation. The name Rockefeller—a name associated with oil, industry, and capitalism—found social legitimacy through its support of the sciences. It was thus in the Rockefeller Foundation's interest to support a program of applied mathematics at the time, as the program being initiated by Brown would directly aid the defense work.

As a result, applied mathematics received much needed monetary support for its autonomous development, which it could raise neither from the state nor from industrial enterprises. Richardson told von Kármán that he had succeeded in soliciting funds from the Rockefeller Foundation and the Carnegie Corporation, another philanthropic organization. From the Carnegie Corporation Richardson received an initial $2000 toward establishing an Evaluating Committee for Brown's first summer session in applied mechanics. The program also received $7,000 from the Carnegie Foundation for the 1941-42 academic year, and an extra $12,500; the sum of these funds covered most costs of the first two years of the program.[67] The overwhelming support from the organizations revealed that industries and other agencies interested in utilizing applied mathematics recognized the importance of Richardson's efforts for integrating applied

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[66] Siegmund-Schultze, *Mathematicians Fleeing from Nazi Germany*, 189.
[67] R.G.D. Richardson to Theodore von Kármán, 21 June 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.

mathematics into university education. There was clearly overwhelming financial support for Brown's first summer session.

The Rockefeller Foundation and the Carnegie Corporation were at the head of philanthropies that heavily supported scientists' research projects. During the late 1930s and the early years of the war, the philanthropists' scope for projects they funded broadened to include applied mathematics. Mathematics could no longer expect preferential treatment, unless it proved of particular relevance to industry and the sciences.[68] Thus while "pure mathematics"—those mathematicians interested in studying math solely for its own sake—had been at the top of the agenda of the institute, more applied fields came into the domain of the Rockefeller activities during the 1930s. This shift partly accounted for the changing impact of mathematics in those years.

The scientific and mathematical landscape had changed considerably from the early 1900s to the late 1930s. A hodgepodge of mathematical professionals had existed, none of which seemed adequately trained—or interested—in assisting the increasingly technological world of aviation, weaponry, communications and industry. Attempts by industries themselves to remedy this disparity were futile. In these avid discussions over systematizing applied math training, the concern with practicality crossed arenas in areas that appeared disparate. Science, industry, mathematics, and military affairs all collided, drawing on leading figures from the American technical, intellectual, and scientific establishments. At Bell Laboratories, Fry's hope for a

[68] Siegmund-Schultze, *Mathematicians Fleeing from Nazi Germany*, 193.

formal training institute ran smack into the everyday realities of electricians, businessmen, and engineers. Richardson took responsibility for providing formal training in mathematics.

These transformations were not accidental. The developments followed logically and inevitably from the technological progress America was making, a process that Thornton Fry clearly outlined in his report to the federal government. Out of this report, the initiative of Richardson and Wriston, and the newfound support from philanthropic organizations, had changed almost overnight. Now Brown had to show it could do the job.

CHAPTER 2
Meeting the Challenge, 1941-1942

Brown University, University Hall, 17 June 1941. Teachers, foreign students, graduate students, and workers from industry queued outside the Office of the Dean of the Graduate School. They eagerly waited to register for the first Summer Session in Applied Mechanics.[69] Finally, after months of planning and years of discussion, Brown inaugurated its summer experiment: the Program of Advanced Instruction and Research in Mechanics. The intense 12-week session, running from June 23 through September 13, would be filled with courses involving partial differential equations and studies in elasticity and fluid dynamics.[70]

Here in the Summer Session of Applied Mechanics, mathematics, engineering, and physics converged.[71] When Dean Richardson sent out his invitations for the First Summer Session, he invited "industries," "advanced graduate students," and "those of the engineering and physics background" to participate.[72] Responses expressed eagerness. With only 55 available slots, over 150 people requested a spot in the Summer Session. Participants wanted to discuss problems; they yearned to learn in lectures and contribute to seminars. Their enthusiasm assured

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[69] I will interchange the name Summer Session in Applied Mechanics with Brown's applied mathematics program, the First Summer Session, and the Program of Advanced Instruction and Research in Mechanics.
[70] R.G.D. Richardson, "Information Concerning the Summer Session in Mechanics," 6 June 1941, Theodore von Kármán Collection, 70:12, Caltech Archives, Caltech, Pasadena, California.
[71] For a general introduction to the relationship of mathematics with engineering and physics, see Dahan Dalmedico, "L'essor des mathématiques appliqués aux États-Unis: L'impact de la Seconde Guerre Mondiale", *Revue d'histoire des mathématiques* 2: 149-213.
[72] R.G.D. Richardson, letter to the Heads of Departments of Mathematics, 26 April 1941, Courant Papers, 19, Bobst Library, New York University.

Richardson and his co-organizers that their venture would be a success.[73] But the continuation of Brown's program rested on the approval of the Evaluation Committee, which was comprised of prominent university researchers and industrial entrepreneurs. Following the First Summer Session, would they feel the same way Richardson had?

This chapter explores Brown's campaign to establish a program in applied mathematics in the summer of 1941 to the end of 1942. I investigate not only how Brown convinced the Evaluation Committee of the necessity and practicality of an applied mathematics program, but also how Brown differentiated itself from other departments, whether engineering or mathematics departments. Understanding the development of the Summer of Advanced Mechanics requires a reassessment of Brown and its organizers. I argue that the program, rather than merely borrowing bits and pieces from mathematics, physics, or engineering, situated itself in the midst of a powerful series of moves that, at a few critical moments, resulted in the formulation of its own standard ways of acting within applied mathematics.

Life at the Summer School in Advanced Mechanics

Before turning to the Evaluation Committee, it is worth exploring extensively the First Summer Session, for it reveals a great deal about what the initial applied math curriculum was, how it was administered, and where it stood in the turbulent flux of war, science, technology, and university education. Naturally R.G.D. Richardson and President Henry Wriston concerned themselves with making Brown become "a center of industries demanding mechanical

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[73] R.G.D. Richardson, "Information Concerning the Summer Session", 6 June 1941, Theodore von Kármán Collection, 70, Caltech Archives, Pasadena, California.

engineering development."[74] Yet that does not seem to have served as a driving force behind Brown's curriculum. Throughout the summer of 1941 and into 1942, Brown's developing applied math program remained, as Richardson first put it in 1941, "vitally concerned over the defense program of the nation." And it "naturally turns to that field [mechanics] as a possible area in which to serve in the emergency [of war]."[75] Participants grappled not only with advanced mechanics, but also with the dangerous world of ballistics and aviation. The objective was to closely integrate mathematical and physical reasoning, and in the process enable students to obtain a qualitative understanding of their environment and mathematically represent it in models.

The goals of mathematicians in training, however, differed. In the mid-nineteenth century and into the twentieth century, the trend of their discipline was toward an ever-more-rigorous formulation—precise definitions and proofs designed to obliterate the smallest shred of doubt. Professors and graduate students found themselves scrutinizing the calculus of variations and elliptic function theory, or dealing with the theory of hypercomplex number systems.[76] The nature of the mathematical nomenclature deterred others' interest and curiosity in the material, and rendered the possible applications of the math difficult to discern. Even the names describing concepts were convoluted. Hypercomplex number systems were just another name for "algebras."[77] Mechanics, on the other hand, did not concern itself with these topics. Such a passion for airtight logical proofs was impractical and did not drive the curriculum at Brown.

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[74] R.G.D. Richardson to the Heads of Departments of Mathematics, 26 April 1941, Courant Papers, 19, Bobst Library, New York University.
[75] Ibid.
[76] Parshall and Rowe, *Emergence of the American Mathematical Research Community*, 274.
[77] Ibid.

Aspiring applied mathematicians were after more convenient methods to solve equations with a different regimen of their own.

The First Summer Session's schedule was rigid. Monday morning, students arose to attend their first lecture in Wilson Hall, a three-storey Romanesque sandstone building. At 8:30 a.m., they filed into room 26 and listened to lectures on elasticity from University of Wisconsin Professor I.S. Sokolnikoff. "The lectures could hardly be termed elementary," recalled assistant professor Albert Heins. He further reflected on the topics covered in those dense lectures:

> "In the elasticity course we covered the usual graduate course (analysis of stress and strain, stress-strain relations; extension, torsion and flexure of homogenous beams; plane problems of elasticity and the theory of thin plates) and we had time to discuss such pertinent topics as the theory of non-isotropic plates, which at present play a fundamental role in the construction of aircraft."[78]

The lectures were extensive, rigorous and went beyond what was expected. Course material also significantly diverged from the mathematics and engineering curricula already in existence; mathematical techniques were more advanced than those learned in engineering and topics more practical than those studied in math. There was no time for a quick coffee break. The next class promptly began at 9:45 with discussions of partial differential equations, followed by studies in fluid dynamics. With a two-hour break for lunch, courses resumed in the afternoon with seminars on the same topics covered in the morning. Sunday was a day of rest.[79]

Once the daily schedule had ended, participants proceeded to study concepts and practice problems. For a more reserved environment, they retreated to the mathematical library housed in the Metcalf Research Laboratory. There, furious scribbling on paper made the only audible

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[78] Albert E. Heins to G.S. Meikle, 1 October 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.

[79] "Schedule of Classes in Summer School in Applied Mechanics," 23 June 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.

sound.[80] For discussions, others crammed into Wilson Hall 25, a room reserved for conference and study. Experimental procedures and equations filled blackboards. Students—all of varying backgrounds in vocation and studies—conversed.[81] They were in an unprecedented situation. The constant focus on mechanics and applications in defense riveted their attention.

Defense applications pervaded lectures and discussions. The Seminar on Fluid Dynamics "was intended to introduce the students to various subjects of recent research and to show them possibilities for their own research."[82] The seminar inspired a sense of mission in the students: to increase their knowledge and to improve existing mathematical models. Students covered "potential flow, drag and lift of wings," and the "general theory of aerodynamics instability."[83] The relevance to defense was clear. Constant modifications on aircraft models could make them more efficient and decrease risk. The aircraft industry would be concerned with dynamics, since the dynamic stability of nose wheels had the potential to become a serious problem. So too did the lift distribution of a plane's wing.

Despite a focus on defense applications, the relation between pure mathematics and engaged technology was not frozen once and for all. Professors supplemented their lectures with advanced formulas and equations. Professor Stefan Bergmann, an expert in applied mechanics from the Massachusetts Institute of Technology, sought to uphold this relation in Advanced Topics in Partial Differential Equations. He wrote of his approach to teaching:

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[80] "Program of Advanced Instruction and Research in Mechanics," *Bulletin of Brown University* XL: 8 (November 1943): 10.
[81] Ibid.
[82] Richard von Mises and Kurt O. Friedrichs, "Report on the Seminar in Fluid Dynamics," Summer Session 1941, Theodore von Kármán Collection, 70, Caltech Archives, Pasadena, California.
[83] Ibid.

> My activities apart from my regular lectures included giving the students an opportunity to understand the more recent concepts in applied mathematics as well as stimulating research in various problems, especially in elasticity and aerodynamics. I strove to present a technique that would bridge the gap between pure and applied mathematics. With this in mind the methods of numerical calculations was stressed. In informal talks I discussed calculating machines and various other devices, and compared these various machines for the speed with which they can carry out operations.[84]

Bergmann's teaching methods pay special attention to every single application. Yet applications remained important to him. What he wanted was to make sure that a young scientist emerged from the First Summer Session with a deep respect for mathematical techniques in their applications—a relation severely lacking in mathematics and engineering at the time.

Bergmann was not alone in his endeavor. Professor Willy Feller and a professor of mathematics at Brown, J.D. Tamarkin, also lectured on partial differential equations. Their approach was to focus on both the qualitative and quantitative features of differential equations.[85] Qualitatively, both professors considered the graphical, geometrical approach to partial differential equations, while quantitatively they also considered the gritty numerical work. A differential equation tells how a system of things—points, planes or naval ships—changes from one moment to an infinitesimally later moment. Partial differential equations, on the other hand, involve more than one system; they include multiple variables. By itself this is not much use in making applications or predictions: knowing where a fighter plane will be an instant from now will not help a pilot, nor would knowing the propagation of heat a second later help the applied mechanic. For a useful longer-range prediction, the pilot or the navigator had to add up

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[84] Stefann Bergmann, "Director of Research in Small Groups," 27 August 1941, Theodore von Kármán Collection, 70, Caltech Archives, Pasadena, California.
[85] "Schedule of Classes in Summer School in Applied Mechanics," 23 June 1941, Theodore von Karman Collection, 70, Caltech Archives, Pasadena, California. For a general overview of the mathematical topics focused on throughout time, see Davis and Hersh (1981).

many infinitesimal changes to calculate, for example, where a plane would be in a few hours, or to see where heat would propagate farther along in time. This was integration. Generally Brown's curriculum found a new entry into advanced mechanics by instilling this practice—this sort of integration and placement of the final result into simple, recognizable form—into its students.

The program aimed to attack differential equations in their own way. Instead of following a strictly algebraic form of mathematics—filled with symbols and numbers—or the geometrically visual traditions of engineering—comprised of drawings and graphs—the courses sought to integrate both methods into their own. Professor Bergmann wrote an account of his discussions with individual students that reflected this notion. With Dr. Owens, Bergmann discussed "some geometric properties of the characteristic cone for the equation of ultra hyperbolic partial differential equations," while with Mr. Jonah he worked on "Some properties of functions satisfying partial differential equations of the type $\Delta u + c(z)u = 0$."[86] In applied math, despite how intimidating the topic discussed may have been, participants and the program's organizers were merely after a general pattern of flow to extract the features of the system as a whole. Because the program's focus, advanced mechanics, was too complex for the undergraduate mathematician or engineer in training, applied math appeared as the means to accomplish this task.[87] Indeed, the organizers of the Summer of Advanced Mechanics sought a model—one with a visual supported by math—that would capture the character of the equation and the physical system it represented. If any course encompassed this ideology, a special lecture

[86] Stefann Bergmann, "Director of Research in Small Groups," 27 August 1941, Theodore von Kármán Collection, 70, Caltech Archives, Pasadena, California.
[87] Of the 55 participants in the program, 22 people had a Ph.D., 30 had a master's degree, and only 5 had already completed their bachelor's degree. "Statistics of Students in Summer Session in Mechanics," 9 June 1941, Theodore von Kármán Collection, 70:12, Pasadena, California.

given by Dr. Poritsky did: “Graphical and Numerical Methods of Solving Partial Differential Equations.”[88] Such studies were abstract and mathematical, but at the same time they were also real and concrete.

Even while exploring the theoretical nature of differential equations, students of the First Summer Session wrestled with them in the real world. Graduate students and industrialists learned about the “Application of the theory of univalent functions to the study of [airplane] wing profiles.”[89] Here we must note that mathematical ideas were not necessarily introduced in the context of a particular application, such as to a specific aircraft model. While such an approach is advantageous because of immediate relevance of the mathematics, the development of practical problems in the world is fragmentary. The problems of current interests continually change. The organizers of the Brown applied program and its participants were aware of that. What did not change so quickly was the approach used to derive the relevant mathematical models and the methods used to analyze them. Thus classes were taught in a way to establish mathematical ideas’ underlying model development independent of a specific application. This did not mean applications were not considered. They were, but on the broader level of applications, like aviation itself. In addition, connections to the real world, particularly with respect to defense, were a staple of the program.

This training brought many opportunities for participants after the First Summer Session. Program participants found employment with Bell Telephone Laboratories and the General

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[88] “Advanced Instruction and Research in Mechanics,” October 1941, Courant Papers, 22, Bobst Library, New York University.
[89] Richard von Mises and Kurt O. Friedrichs, “Report on the Seminar in Fluid Dynamics,” Summer Session 1941, Theodore von Kármán Collection 70, Caltech Archives, Pasadena, California.

Electric Company.[90] After their completion of the applied math courses students joined the highest levels of the Unite State's government's administrative structure, overseeing defense and military. Of the options offered to him following the summer, Albert Heins wrote:

> In August, Dean Richardson informed me that I had been recommended for a position at the David Taylor Model Basin,[91] Bureau of Ships, Navy Department, Washington, D.C. After discussing this matter with him, we decided that I could accomplish more at Purdue University, for at an engineering school there are untold opportunities for the Instructor of Mathematics to convince the engineering student that mathematics beyond the sophomore level can be extremely valuable in engineering practices. Members of the Brown University Summer School Visiting Committee were of the same opinion[92]

Two striking features of Brown's applied math program and its organization emerge from this account. First, potential employers were eager to hire those with advanced training in mathematics to support defense, even one coming out of an infant establishment. Second, Heins'—and Brown's—decision to teach applied mathematics indicated success of the program's effort to generate support for university-sponsored applied math training. The laborious efforts of Richardson and his colleagues seemed successful.

So while mathematicians spent their time writing abstract mathematical proofs, and while engineers struggled to fix a buckle load problem of a specific bridge, the applied math students learned both the rigorous abstractions of pure math and their use in the real world. This learning served to differentiate them from mathematicians and engineers trained in universities, and

[90] "Report on Advanced Training in Applied Mathematics, With Special Reference to the School of Mechanics at Brown University," November 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.
[91] The David Taylor Model Basin is one of the largest research facilities for ship design in the world.
[92] Albert Heins to G.S. Meikle, 1 October 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.

experts trained in industry. Already students emerged from their summer training with mechanics imprinted on their outlook.

Evaluating Applied Math

On August 29, shortly before the First Summer Session came to a close, a review board convened, half a mile down the hill from Brown's campus.[93] They were the Evaluation Committee, a group of scholars and administrators appointed by Wriston and Richardson, who would review the success of Richardson's endeavor. Collectively, the group had the vested right to critique the organization of the Summer of Advanced Instruction in Mechanics. Their word was enough to discontinue Brown's investment if it were deemed dysfunctional.

Brown's planners, however, did not leave the evaluation to chance; Richardson and Wriston influenced the selection of the committee members. After avid discussions with Richardson over whom to invite, Brown President Henry Wriston personally sent invitations to each member requesting they participate in the review. "You have already given this problem consideration and your experience will point the direction in which you will wish to recommend action,"[94] wrote Wriston to the Committee candidates. His letter suggested that the invited members held attitudes naturally inclined towards the cause for applied mathematics. Furthermore, it assumed that his request would be complied.

[93] R.G.D. Richardson, to Theodore von Kármán, 22 August 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.
[94] Henry Wriston to von Kármán, 22 August 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.

And it was. All invitees accepted Wriston's call.[95] The Committee included Marston Morse, of the Institute for Advanced Study and President of the American Mathematical Society; Mervin J. Kelly, Research Director of the Bell Telephone Laboratories; George B. Pegram, Dean of the Graduate School at Columbia University; Theodore von Kármán, Director of the Aeronautics Laboratory at the California Institute of Technology; and Warren Weaver, Director for Natural Sciences at the Rockefeller Foundation.[96] When Wriston and Richardson sent out their invitations, they called on an illustrious assortment of scientists, administrators, and entrepreneurs. The Committee stood as a powerful, highly respected voice for the cause of applied mathematics. Their conclusions would form the basis for continuing Brown's program.

As Wriston and Richardson hoped and expected, the Committee remained sympathetic to Brown's ideas. Warren Weaver had taken a degree in civil engineering and had experience with engineering research.[97] He understood the merits of actively integrating mathematical rigor into the sciences. Serving now as a Rockefeller functionary, he had the ability to provide financial aid for Brown's cause. Mervin Kelly also aligned himself with the views of Brown. As his colleague Thornton Fry had outlined in 1940, Kelly and the rest of industry craved for mathematically trained technicians.[98] Both Marston Morse and George Pegram understood the merits of developing a mathematical research community focused on applications. Their roles as administrators for renowned research institutions indicated as much. Perhaps the most influential

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[95] R.G.D. Richardson to Theodore von Kármán. 22 August 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.
[96] "Program of Advanced Instruction," *Bulletin of Brown*, 4.
[97] Reid, *Courant*, 193.
[98] Cf. 38.

member of the committee, Hungarian émigré and aerospace engineer and physicist Theodore von Kármán, was also the most supportive of Brown's ambitions.

Von Kármán was the applied math advocate of all advocates, an administrator and a researcher who sought to bring mathematical sophistication to practical problems. Internationally, he was already well respected when he arrived in the United States in the 1930s. Previously he had taught at the prestigious University of Göttingen and served as the Director of the Aeronautical Institute at Aachen.[99] Arriving in America to take a position at Caltech, he embarked on a campaign to make applied mathematics respectable to students, faculty and the aeronautics industry. Such efforts paid off, as his influence figured prominently in the rise of Caltech's highly regarded aeronautics school.[100] These achievements gave him an authority and influence over mathematicians, engineers, physicists, and industry. When Richardson initially conceived of an applied mathematics institute at Brown, he envisioned von Kármán as the program's "kingpin."[101] Even before Brown's First Summer Session began, Richardson, Wriston, and other organizer's of Brown's applied mathematics program counted on von Kármán's approval. His membership on the Evaluation Committee reveals that they were confident they would get it.

Of all of the Evaluation Committee members, von Kármán stood as the model applied mathematician Brown wanted to produce. It was von Kármán who had his feet planted in both

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[99] Theodore von Kármán, *The Wind and Beyond: Theodore von Kármán, Pioneer in Aviation and Pathfinder in Space* (Boston, MA: Little Brown and Company, 1967), 57.
[100] John L. Greenberg and Judith R. Goodstein, "Theodore von Kármán and Applied Mathematics in America," *Science* 222: 4630 (1983): 1301. Von Kármán's school led to the founding of the Jet Propulsion Laboratory, now a federally funded research and development center under contract with NASA.
[101] R.G.D. Richardson to Richard Courant, 8 April 1941, Courant Papers, 19, Bobst Library, New York University.

the practical and theoretical aspects of applied mathematics, especially in aerodynamics. He had worked on the buckling of columns and on the stability of vortex patterns that affect flight. One of his bigger feats had been the completion of a ten-foot wind tunnel he had designed in the mid-1930s.[102] So useful and impressive was this accomplishment that West Coast companies tested their aircraft on this model.[103] His university-produced research, then, stood as an example to follow, an illustration of how industry and the mathematical research community could be mutually linked.

Von Kármán's wind tunnel was a manifestation of what applied mathematics could achieve. On the one hand, it was the product of an engineer and a physicist creating a physical model used to measure how the force of wind slows a plane or a vehicle. On the other, it was the result of a mathematician struggling to reconcile mathematical variables that afflict the pilot flying through windy conditions: the uncertain path of airflow, the angle of the plane's mounted wing, and the plane's changing speeds.

For von Kármán, the true innovation of this research model lay in the reversal of a previous research method: instead of air standing still and the aircraft moving at various speeds through it, the same effect could be obtained if the aircraft stood still and the air moved past it.[104] Multiple benefits arose from this approach. The stationary researcher could study the aircraft in action and could measure the aerodynamic forces being imposed on the aircraft. Furthermore, it

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[102] A wind tunnel is a research tool used in aerodynamics research. It is used to study the effects of air moving past physical, solid objects. This makes it particularly useful for studying vehicles like aircraft in free flight, though it can also be used to study the structures of large buildings.
[103] Goodstein, Judith R. and John L. Greenberg, "Theodore von Kármán and the Arrival of Applied Mathematics in the United States, 1930-1940" (Pasadena, CA: 1983), 5.
[104] von Kármán, *Wind and Beyond*, 75.

was more cost effective—energy was saved and the demand of testing vehicles minimized.[105] This was the type of solution industry wanted. Such an achievement occurred thanks to von Kármán's technical expertise. The organizers of Brown's applied mathematics program expected von Kármán could emphasize to the Evaluation Committee that Brown was up to his standards.

Despite the committee's preconceived views, its members insisted that nothing be left untouched in its review. Though the members were proponents for an applied mathematics curriculum in higher education, the questions of how to implement such a program and whether Brown was the best place to accomplish this remained. The committee considered whether Brown "should plan to do this type of work in the summer of 1942," or whether there was a "need for haste in getting plans made."[106] To formulate their opinions, the members visited some of the classes offered on Friday, August 29. At 3 p.m., in the privacy of President Wriston's office in University Hall, they reconvened. At tea time, they conversed with program participants, inquiring about the students' experiences and future plans.[107] Thorough and analytical, the Evaluation Committee reviewed all aspects of the program, from teaching methods to research produced to jobs offered to participants.

After the Evaluation Committee returned home, they frequently corresponded with one another and wrote their reviews. On 8 September 1941, merely a week after the group met, Warren Weaver submitted his draft report, admitting that he had not taken "any particular care

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[105] Ibid.
[106] R.G.D. Richardson Theodore to von Kármán, 22 August 1941, Theodore von Kármán Collection, 70, Caltech Archives, Pasadena, California.
[107] R.G.D. Richardson to Theodore von Kármán, 29 August 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.

about form of expression."[108] Weaver insisted that letters within the committee lack technical jargon or vague wording. His concern was to openly discuss the forces working against applied math and Brown's ability to combat those forces, not to waste time with formalities.

The committee quickly came to consensus. As was to be expected from a group who emphasized with Brown's cause for applied mathematics, the committee did not splinter into many opinions, nor did hostile factions arise. A unified consensus reverberated through the Evaluation Committee. Pegram's draft review reflected the sentiments of the group. He frankly acknowledged the need "to open the field of applied mathematics for persons who are trained primarily in mathematics."[109] And in his initial review, he concluded, "Brown would seem to be in a good position to do this.[110] Pegram's conclusion exuded general satisfaction over the First Summer Session's curriculum and its organizers. There needed to be a new discipline, distinct from the traditions of pure mathematics and the experimental nature of engineering.

The committee did call for some specific curricular adjustments. They had little patience for a curriculum that strictly adhered to a "lecture system" or was riddled with excess "mimeographed notes."[111] They wanted professors to pause during lectures and have students take the reins of the course. Their vision included formulating innovative mathematical teaching methods: "What do you think we ought to do at this juncture, and why do you think we ought to

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[108] Warren Weaver to Marston Morse, 8 September 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.
[109] G.B. Pegram, "Memorandum," 7 October 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.
[110] Ibid.
[111] Warren Weaver to Marston Morse, 8 September 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.

do it?"[112] To the Evaluation Committee, especially to Warren Weaver, physical visualizations were vital to the education of an applied mechanic; it was helpful for students looking to enter academia and university research, but it was also especially helpful to train students interested in pursuing a career in industry.

Perhaps surprisingly, the Committee was concerned by what it saw as the First Summer Session's excessive concentration on national defense and applied mechanics. In the eyes of the Evaluation Committee, the program should not be viewed simply as a short-term project that would not continue in the long run. Weaver opined: "As regards the shortest term scheme, I will only say that it does not interest or excite me very much, being by nature a temporary and unsatisfactory expedient."[113] He expressed dismay over how the curriculum seemed to have scrapped long-term plans to remedy the training problem. Furthermore, the members viewed the First Summer Session as too narrowly focused. Kelly asserted that the Brown program should not restrict itself to the scope of "applied mechanics."[114] If Brown's applied math program continued to instruct students in this manner, then the subject could only be viewed as a subsidiary of mechanical engineering. An emphasis on defense would only serve to short-circuit Brown's plans. Over and over again, the Evaluation Committee proclaimed that long-term considerations must prevail over short-term ones in order for an applied mathematics department to be created.

Industrialists and mathematicians echoed the same sentiments in fall 1941 when the Evaluation Committee solicited reviews to the First Summer Session's attendees. Applied math

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[112] Ibid.
[113] Ibid.
[114] M.J. Kelly to Marston Morse, 15 September 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.

advocates popped up everywhere. One outsider, an industrial executive named Frederic Willard, claimed to have always felt the inadequacies of advanced training in applied mechanics.[115] But if Willard was an outsider to organizing an applied mathematics curriculum, looking in, then I.S. Sokolnikoff was the consummate insider, an applied mathematics professor at the University of Wisconsin and promoter, looking out. Sokolnikoff had frequently lobbied for the organization of an applied mathematical community in universities, remaining "skeptical of the effectiveness of any program that holds out a promise to only industrial concerns."[116] The Wisconsin engineer took to formulating a mathematical discipline with an eye scaled to long-term success. He wanted a university-sponsored applied mathematics discipline to be respected and to produce original research. To Sokolnikoff, adhering to the interests of only the government or to industry would undermine the credibility of applied mathematics.

Even though the committee members agreed on the need for applied mathematics, it was not necessarily inevitable that they would pick Brown as the place to inaugurate it. Indeed, universal acceptance towards situating applied mathematics at Brown proved elusive. Not everyone was sanguine about Brown's program. Karl Compton, President of the Massachusetts Institute of Technology, decided that Brown was not capable of cultivating an applied mathematics department. "The primary reason," Compton reasoned, "is that the accessory departments and activities which would have to contribute to any largely successful program are

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[115] F.W. Willard to Marston Morse, 15 September 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.
[116] I.S. Sokolnikoff to R.G.D. Richardson, 27 September 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.

too meager at that institution."[117] Compton's opinion was not disinterested, of course. He pointed out that Brown was not on the same level as other research institutions such as his own MIT, Harvard, or Princeton. He condescendingly suggested that Brown was capable of organizing only an "annual get-together."[118] Unsurprisingly, Compton deemed MIT able to run its own applied mathematics program. MIT, like the rest of American universities concerned with applied mathematics, was transfixed by the coming triumph of applied math as its legitimization drew near.

The Committee members continued to deliberate over whether Brown was the right place to nurture applied mathematics, revealing that the real evaluation was not necessarily about applied mathematics but about Brown itself. In a memorandum that addressed the concerns of Compton and other skeptics in October 1941, Pegram commented: "Brown University seems to me to be in an advantageous position to conduct instruction and research with a view to attracting person interested [in applied mathematics."[119] The First Summer Session convinced Pegram—and other members—of the effectiveness of Brown's applied mathematics curriculum. Richardson had managed to gather the appropriate resources: qualified instructors, students, and an abundance of high-quality textbooks.

Another concern engaged the Evaluation Committee members: the lack of federal government representation on the Committee. Although the government had previously responded to Brown's lobbying for creating an applied mechanics program with interest, it went no further than that. Questions first raised by Richardson about how to obtain the attention of

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[117] Karl Compton to Marston Morse, 23 September 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.
[118] Ibid.
[119] G.B. Pegram, "Memorandum," 7 October 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.

influential officials like United States Vice President Henry A. Wallace dominated the committee's concerns. Asked how he thought they could get his attention, a frustrated Weaver exclaimed, "I will be damned if I know."[120] Foreshadowing of generations of applied mathematical researchers to come, the Committee recognized the importance of federal support.

In November 1941, the Committee submitted its official report, "A Report on Advanced Training in Applied Mathematics, with Special Reference to the School of Mechanics at Brown University." The verdict was in—unanimous—and emphatic: "In our judgment, it was a distinguished success—for […] we view [the program] to be much more important and promising, much better suited to your [Brown's] special assets, and much more worthy of your support."[121] This was a remarkable moment. Applied math, one of the most obsure and belittled disciplines of the math and sciences, had become, by the Committee's verdict, valued. Here was a discipline manifestly at Brown and yet not at Brown, absolutely practical and yet completely abstract. Applied math was a developing discipline, a cause like any other that would bring disparate specializations together. Expressing that unity in plain language was a substantial achievement.

Developing a Program

As the conclusions of the Evaluation Committee suggested, Brown could be confident that the program would continue, although Brown needed to reorient its curriculum so that it was not specifically dependent upon specific defense purposes. Less than two months after the

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[120] Warren Weaver to Marston Morse, 8 September 1941, Theodore von Kármán Collection, 70:11, Pasadena, California.

[121] Evaluation Committee, "Report on Advanced Training in Applied Mathematics, With Special Reference to the School of Mechanics at Brown University," November 1941, Theodore von Kármán Collection, 70:11, Pasadena, California.

Evaluation Committee's report was published, however, Pearl Harbor was attacked and America officially entered World War II. Consequently, the orientation of the Program was necessarily shifted back to shorter range goals in order to aid the war effort. War fever struck the University, and the pressure was high to support the war with intensive study of applied mechanics. But underpinning this mobilization of the program's work for war were longstanding mathematical ideas. Underneath the frenzied wartime activity, the plans for the long term development remained intact.

The First Summer Session had provided advanced courses only for graduate students; now even undergraduates began their training in the advanced applied mechanics sessions. On Thursday, 2 October 1941, the weather on Brown campus was cool and windy. Freshmen and upperclassmen aspiring to demonstrate their singing talents gathered in Faunce House to audition for the Glee Club. A few doors down in the "Private Dining Room," the Interfraternity Governing Board convened to discuss the rushing rules for the 1941-42 season.[122] Desiring to join the prestigious social societies, undergraduate students seemed oblivious to the efforts of Wriston and Richardson. Yet on that same day, 25 undergraduates were accepted for training in advanced mechanics. Their instruction would focus on "specialized problems in mathematics which bear upon aviation and airplane construction and other weapons and instruments of war."[123] In a sense the University was including the undergraduates in the war effort, and at the same time were integrating a new discipline into university education. That undergraduates were

[122] "Glee Club Will Try Out Vocal Aspirants Today, Tomorrow," "IGB Meets to Make Rushing Plans Today," *Brown Daily Herald*, 2 October 1941, 1.
[123] "U.S.'s First Applied Mechanics Program to Begin Here Today," *Brown Daily Herald*, 2 October 1941.

allowed to participate pointed to Brown's intentions to incorporate applied mathematics into the University.

Following the First Summer Session, Brown's progressive and technical goals were also realized with the hiring of new faculty to spearhead the applied mechanics program. In the First Summer Session, faculty appointments were necessarily those from a wide range of universities and specialties. Now Richardson and Wriston needed to secure the right faculty who shared both their vision and standards for the new program. In particular, the success of Wriston and Richardson's venture hinged on hiring a professor who could serve as the applied mechanics program's authority, guide, and counsel in making further decisions and appointments. Richardson sought experts who could pass judgment on technical matters relating to their fields of specialization. They selected 38-year-old German émigré William Prager.[124] In choosing "Willy" Prager as his mathematical adviser, Richardson took a chance on an experienced, yet fresh and untried talent.

Prager was one of a growing number of European immigrants arriving in the United States from wartime Europe. In the 1930s, he was a privatdozent at Göttingen University before finding a position at the University of Istanbul in Turkey. Brown was at the fore of American institutions housing refugees, including historian of mathematics Otto Neugebauer and mathematician Hilda Beringer.[125] Richardson assured Wriston on 24 April 1941: "It is not necessary to speak of Prager's eminence as a mathematical engineer. The list of papers and books speaks for itself. He probably is one of the leading aeronautic experts in the world

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[124] "Brown University News Bureau," 24 November 1941, Brown University Archives, William Prager (Bio) File, John Hay Library, Providence, Rhode Island.
[125] Siegmund-Schultze, *Mathematicians Fleeing from Nazi Germany*, 65.

today."[126] Before the First Summer Session even started, Richardson was already vying for Prager's services.

Though Prager was relatively young to be heading an infant program, he proved capable of coordinating an applied mechanics curriculum. When he arrived on Brown's campus in the late autumn of 1941, applied mechanics students immersed themselves in research related to defense. Within a few months of his arrival, energized by the positive report of the Evaluation Committee, the Advanced Instruction in Mechanics at Brown prospered even more under his tenure. Enrollment for the Second Summer Session in 1942 nearly doubled from the First Summer Session with 110 attendees.[127] The increased participation of students reflected a growing enthusiasm for applied mathematics in a wartime environment.

Prager provided much needed expertise in plasticity and elasticity, subjects of applied mechanics that had not been as well represented in the First Summer Session. His teaching duties were restricted to lecturing on these topics.[128] Elasticity involves the study of solid materials that can undergo reversible deformation. That is, material that twists, curves and bends but then returns to its original state. Plasticity is the study of deformation that is irreversible and permanent—like the cracks in cement that emerge from frigid temperatures. Understanding these processes was useful for meeting the demands of war. After all, the problem of fractured steel was raised following multiple occurrences of the breaking-in-two and total loss of some wartime

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[126] R.G.D. Richardson to Henry Wriston, 24 April 1941, Brown University Archives, Wriston Papers. 4: OF-1C-11, John Hay Library, Providence, Rhode Island.
[127] "110 Take Advanced Mechanics Course," *Brown Daily Herald*, 24 June 1942.
[128] Prager's specialty lay in these two sub-studies of applied mathematics.

all-welded tankers and dry cargo ships.[129] Such naval ships carried a load that, after exceeding the threshold of a ship's yield, caused ships to receive permanent damage to their shapes. This was a form of irreparable buckling; underlying its deformation were applied mathematical theories of plasticity. Because the Navy wanted to reduce safety risks and solve this problem, extensive analysis of stress concentration in the steel structures of naval ships occupied the attention of applied mathematicians.[130]

This issue provides another example of a situation in which only applied mathematicians like Prager could successfully address the problem. An engineer's concern would have been the design of the ship as a whole. But as the example of naval ships revealed, the focus of research had shifted from the structure's design to the intricacies of the material used for the construction. Theories of elasticity and plasticity explained the behavior of these solid masses, which were mathematically complex. Techniques used to find ways of manipulating the behavior of the material encompassed Fourier methods, variational calculus, integral transforms, complex variables, finite difference, finite elements, and so forth.[131] Solutions, then, involved creating workable mathematical theory that modeled the mechanical behavior of ships' structural materials. The engineers did not accomplish this, but the applied mathematician did.

With his specialty lying in the studies of plasticity and elasticity, Prager produced a more distinctive instructional style than the First Summer Session. His mathematics reconciled the conflicting demands of real world problems and advanced mathematics. "I aimed not only at making my students familiar with the principal results which so far have been obtained in this

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[129] Gijsbertus de With, *Structure, Deformation, and Integrity of Materials* (Weinhelm, Germany: Wiley-VCH, 2006), 785.
[130] Ibid, 787.
[131] William Prager, *Theory of Plasticity* (Providence, RI, 1942), 11.

field [of plasticity]," declared Prager, "but also at indicating to them the direction in which further research seems to me most likely to be fruitful."[132] Here Prager proclaimed the mathematical philosophy he wanted to instill in his students. Drawing strongly on mechanics, he wanted the students of Brown's program to practice a socially engaged mathematics, to learn to see the great mathematical structures that embrace and explain real world objects and behaviors.

In the fall of 1942, the Program of Advanced Instruction and Research in Mechanics expanded to include more applied mathematics topics. Prager paid special attention to lecturing on the "Theory of Turbulence."[133] These topics complemented events in the war abroad. In November 1942 the United States Navy ships began intercepting Japanese fleets near the Solomon Islands; in the same month Hitler issued an order demanding all captured commandos to be executed. The study of turbulence in the atmosphere and the ocean constitutes a grand challenge for math. Any attempt to understand the interaction of the atmosphere and ocean through fluid mechanical processes involves accounting for nonlinear physical processes that intervene in air and ocean currents, ranging from millimeters to thousands of kilometers.[134] Yet Prager and his students sought to model these natural phenomena that seemed impossible to map. Even a crude model would be helpful to a ship's navigator mapping a course at sea or the pilot or parachutist calculating the safest place to land. The interests of applied mathematics remained tied to the war.

All through Brown's applied mathematics lay this productive theme: find the most convenient representation through mathematics and apply it to the difficult, practical problem.

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[132] Ibid, ii.
[133] "Advanced Instruction and Research in Mechanics," Academic Year 1942-1943, Science Library, Brown University, Providence, Rhode Island.
[134] Ibid.

Necessarily, the war reoriented the program's instructional curriculum towards defense: ballistics, aviation, and the formulation of sturdy ships. Yet while making those decisions, Prager made sure that the program never lost sight of the larger theoretical issues—those mathematical models and equations, like partial differential equations or the mathematical foundations of plasticity and elasticity, that could be reapplied to a multitude of concrete problems. By relying on the fullness of the numerical-visual approach rather than the icy edge of algebra, or the diagram-ridden look of geometry, Brown's applied mechanicians developed new mathematical ambitions under Prager's direction. Not for them just a mechanical engineering analogy, nor would impractical interests sully their research. Instead, in the increasingly war-torn world of the early 1940s, math reformers campaigned for applied mathematics.

These observations from The First Summer Session—and a characteristic that carried over to the following sessions in applied mechanics—revealed that Brown was prepared to allow this educational program to evolve. Propelling this discipline was an emerging pedagogy to be found in the instructional style of Brown's faculty. Already the Program of Advanced Instruction and Research in Mechanics seemed to be merging into the university system.

Mechanics, instruction, evaluation, and war—each of these ways of parsing Brown's world tells us something about the ways in which the initial applied mathematics program came to be. It contributed to military defense as the United States entered World War II, and at the same time led to solving industry's problems first recognized by Thornton Fry. But Brown was not satisfied to leave the program where it stood in 1942.

Chapter 3
Expanding Horizons, 1942-1943

With the success of Brown's Advanced Instruction and Research in Mechanics, the program's position among American universities was unmatched in 1942. Standing at the crossroads of mathematics, physics, and engineering, Brown's applied mechanics curriculum reconciled these disparate yet inextricably linked disciplines and fields. Students already began to garner an early reputation for developing advanced mathematical techniques that underlie the nitty-gritty of engineering and physics. Still, one major worry remained. When the Evaluation Committee first published its report, the committee expressed support for Brown's endeavor in all ways but one: sponsoring a formal academic journal in applied math. "We are of the opinion that no new avenues of publication for applied mathematics are essential at the present time," intoned the Committee.[135] Prager was dissatisfied with the Evaluation Committee's unwillingness to support an applied mathematics journal. And he was not alone in his discontent.

But the *Quarterly of Applied Mathematics*? We might imagine such a journal was of little interest to the industrialists, government officials, and researchers investing in the applied mathematics program when set against the backdrop of World War II.[136] Just ten days before Prager's post to Theodore von Kármán, 9 March 1942, the American Secretary of War, Henry Stimson, had just reorganized the General Headquarters, United States Army into three major

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[135] Evaluation Committee, "Report on Advanced Training in Applied Mathematics, With Special Reference to the School of Mechanics at Brown University," November 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.

[136] Many authors mention the creation of these journals in passing, with little analysis into its implications. Authors include Rees (1980), Siegmund-Schultze (1997), Parshall and Rowe (1994).

commands: Army Ground Forces, Army Air Forces, and Services of Supply and Defense commands subordinated to the War Department.[137] The applied math program's labor most likely would have concentrated on cultivating advanced technologies for the war effort and instructing applied mathematicians, and also with aiding these new divisions. A journal might just be a distraction. Yet producing a journal remained a priority for Prager from 1942 onwards. His insistence shows that he intended Brown's applied mathematics program to be not just an aid for the war effort but also to be integrated into its university structure.

In 1942, Prager, Richardson and Wriston went against the recommendations of the Evaluation Committee. They announced the establishment of the *Quarterly of Applied Mathematics*, a journal devoted to publishing seminal research in applied mathematics. In his letter to von Kármán dated 19 March 1942, Prager affirmed that, "the need of such a journal [of applied mathematics] is felt very keenly by all persons working in this field."[138] Prager's motives and goals were clear. An increased sensitivity to applied mathematics required a more efficient way to coordinate Brown's actions and further develop applied mathematics' credibility. A publication outlet was a critical ingredient in this process.

One powerful push towards guaranteeing applied mathematics' position in higher education came in 1943 with the establishment of an official applied mathematical publication outlet: *The Quarterly of Applied Mathematics*.[139] In this chapter I argue that establishing this journal marked the realization of Prager's goal for systematizing applied mathematics training and research—university sponsorship of scholarly publications. This concept fit with research

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[137] Mina Rees, "The Mathematical Sciences and World War II," *The American Mathematical Monthly* 87:8 (October 1980): 608.
[138] William Prager, letter von Kármán, 19 March 1942, Theodore von Kármán Collection, 80:38, Caltech Archives, Pasadena, California.
[139] Henceforth I will refer to the *Quarterly of Applied Mathematics* as the *Quarterly*.

goals for the applied mathematics participants at Brown. If research and publication were to be institutionally mandated activities, then the institution needed to provide suitable outlets for this work. Moreover, by establishing a research-level journal, Brown revealed that it was placing new emphasis on research and exerting its influence in setting and monitoring American standards of publication in applied mathematics.

A Growing Applied Mathematics Community

Prager's bold decision to carry on organizing a research outlet in 1942 was not the only factor making the *Quarterly*'s first issue possible in 1943. Since the summer of 1941, Brown had nurtured a growing applied mathematical community: professors, researchers and students. Any applied mathematics journal depended upon this interacting group of scholars for both readers and contributors. This community extended beyond Brown, to New York University.

New York City, Washington Square, New York University, 18 July 1941. In the middle of Brown's First Summer Session, respected applied mathematician Richard Courant penned a memorandum for immediate release. Etched across the document: "Concerning an Emergency Institute for Advanced Training in Basic and Applied Sciences."[140] Just as Richardson had done in his own memorandum a few months prior, Courant now pressed for systematizing training and research in applied mathematics. Only Courant wanted to organize his own initiative based at NYU.

Courant and the other organizers of NYU's "Emergency Institute" did not mean to undermine the status of Brown's program, nor did they seek to surpass Brown's success.

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[140] Richard Courant. "Memorandum Concerning an Emergency Institute for Advanced Training in Basic and Applied Sciences," 18 July 1941, Courant Papers, Bobst Library, New York University.

Courant, like Richardson, Wriston, Prager and other applied math enthusiasts, was transfixed by the significance of applied mathematics and its potential service to industrial needs. The imminence of war motivated NYU's initiative more directly. Both summarizing and lobbying, Courant opened his memorandum by referring directly to the urgent need to produce applied mathematicians for defense:

> The American mobilization of scientific research for defense purposes has taken up a considerable part of the human resources previously available for teaching on a higher level. Perhaps no serious harm would be done if it were a question of an effort of limited duration. However, not only must we face the possibility of a prolonged war, but regardless of its duration and outcome, we shall have to gear ourselves for an intense and persistent effort in the future task of reconstruction. It is imperative to secure a steady supply of young men of the highest ability in pure and applied sciences and to counteract the threat of discontinuity in scientific training.[141]

If Richardson spoke for mathematical enthusiasm in his earlier memorandum, here Courant spoke for mathematical and scientific preservation. Courant directly referred to the potential danger war posed for the future of science and mathematics. Bit by bit, using the wartime environment to make his case, he wanted to ensure practical mathematical investigations' longevity.

Courant's earlier experiences fueled his insistence on creating an applied mathematics institute of this nature. Like Prager, he was a German émigré; he had arrived in 1934, much earlier than Prager had. A Jewish mathematician, Courant had experienced firsthand how political forces could break up a mathematical community at a top-tier institution like Germany's Göttingen University. There, he had held a prestigious position as Director of the recently formed Mathematics Institute, an applied mathematics institute.[142] But in the spring of 1933,

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[141] Ibid.
[142] Siegmund-Schultze, *Mathematicians Fleeing from Nazi Germany*,169.

rumors had arrived at Göttingen of a speech by Berlin mathematics professor Ludwig Bieberbach, who had contended that a "German essence" existed in mathematical creation, and condemned Jewish mathematical practitioners for having soiled the discipline.[143]

Bieberbach's speech foreshadowed the demise of the applied mathematical community at Göttingen—and many other German institutions—where Courant and Prager had held appointments. Throughout the early summer of 1934, the situation at the Mathematics Institute was chaotic. Jewish professors were removed from the faculty. A Nazi party member succeeded Courant as Director, and all applied mathematical activity at the institute ceased.[144] Applied mathematicians, even if not fired, dispersed, fleeing to countries not wreaked by havoc. This mistreatment of his colleagues infuriated Courant, who often reflected and lamented on this time as the period of "destruction at Göttingen."[145] This personal experience provided strong personal impetus to recreate a new community of applied mathematician experts in America.

Without a doubt, then, Brown's applied math program stood as a powerful if highly contested symbol of a new discipline in America, a realization of Courant's desire to consolidate and rebuild a community of applied mathematicians. Yet that was not enough for Courant and the other applied mathematics enthusiasts. Brown participants expressed support for expanding upon their enterprise. Evaluation Committee member Mervin Kelly fervently made his case for expanding available applied mathematics programs back when the Committee convened in 1941. He contended that other universities were suitable to formulate an applied mathematics program, though he also conceded, "The facts are that this has not been done and is not apt to occur unless

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[143] Reid, *Courant*, 159.
[144] Ibid, 161.
[145] Richard Courant to Theodore von Kármán, 29 October 1934, Theodore von Kármán Collection, 6, Caltech Archives, Pasadena, California.

there is some general development to stimulate it. Brown should accomplish this."[146] Precisely when Brown was getting started, Kelly wanted other applied mathematics programs to emerge.

At NYU, however, formulating an "emergency institute" was no easy task. By late autumn 1941, NYU had only secured three faculty members for its applied mathematics initiative: Kurt O. Friedrichs, James J. Stoker, and Richard Courant himself.[147] All were well-qualified instructors for practical, advanced mathematical topics. Richardson and Wriston seemed to have acquired the majority of available applied mathematicians. Even Friedrichs and Stoker had already served as instructors for Brown's First Summer Session. Thus in his initial efforts to coordinate a program, Courant had developed a rather modest operation at NYU.

Courant was also frustrated by the lack of enthusiasm, if not cooperation, on the part of the fellow scientists on whom he had particularly counted for support. In particular, he was disappointed with von Kármán. While von Kármán had enthusiastically supported Richardson and Wriston's applied mathematics program, he also rejected Courant's institute idea as unacceptable. After all, in the eyes of von Kármán, "Courant was not really an applied mathematician."[148] In contrast to von Kármán and Prager, Courant did not have an engineering background but was a pure mathematician by training. Von Kármán was skeptical of Courant's ability to efficiently apply mathematics to physical problems.

Von Kármán was also disturbed by Courant's description of the NYU initiative as an "emergency institute." The problem of applied mathematics could not be solved "through the

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[146] Mervin J. Kelly to Marston Morse, 15 September 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.
[147] S.Y. Cheng and Tao Tang, eds., *Recent Advances in Scientific Computing and Partial Differential Equations* (Providence, RI: American Mathematical Society, 2003), viii.
[148] Kurt O. Friedrichs, quoted in Constance Reid, *Courant* (New York, NY: Springer-Verlag, 1976), 226.

ordinary process of supply and demand," von Kármán dourly noted in his review of a program proposal similar to Courant's.[149] Any applied mathematics or mechanics institute could not just churn out a new cohort of practitioners on demand.

Nonetheless, by 1942, Courant's initiative propelled forward and surpassed expectations. Responding to requests from the military, Courant and Friedrichs became substantial contributors to the theory of explosions in the air and underwater.[150] At the request of the government's Bureau of Aeronautics, Courant assisted in the design of nozzles for jet motors.[151] For Courant, conducting these government-sponsored projects justified the "emergency institute" at NYU. Indeed, through the mathematical investigations of NYU's faculty, Courant's initiative was supported by and provided much support for American defense.

It would be natural to assume that NYU's "emergency institute" served as a rival initiative to Brown's.[152] Instead, Brown and NYU sought to build up and strengthen an applied mathematics community. And it was the strength of this community that led to the formation of an applied mathematics journal.

Applied mathematicians at NYU and Brown constantly corresponded with each other about systematizing applied mathematics. When Richardson began drafting his memorandum announcing Brown's First Summer Session, he consulted with Courant: "we should cooperate as much as possible. When our own ideas are a little clearer, we shall want to talk with you."[153]

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[149] Theodore von Kármán, quoted in Judith R. Goodstein and John L. Greenberg, "Theodore von Kármán and Applied Mathematics in America," *Science* 222 (1983): 1303.
[150] Rees, "The Mathematical Sciences and World War II," 611.
[151] Ibid.
[152] Many historians and scholars make this point. See Siegmund-Schultze (2009) and Lax (1989).
[153] Richardson, letter to Courant, 18 March 1941, Courant Papers, 6, Bobst Library, New York University.

Courant later replied with a flattering offer: "the suggestion that some of us might come to Brown this summer on certain days for single or connected sequences of lectures, seems perfectly feasible and delightful."[154] Courant and Richardson both understood that there was a scarcity of applied scientists adequate to instruct students. They extended a helping hand to each other.

No matter how cooperative they were, however, a peer-reviewed publication would be needed to involve other applied mathematicians and facilitate their activities. On a chilly 1942 morning in Washington Square, New York City, Courant found himself struggling with the study of variational methods. But reanalyzing his work simply was not enough. "I have a very bad conscience," Courant wrote to Prager, "remembering that I wanted to send you a copy of my address on variational methods. I am enclosing my last remaining copy of the proof with the request that you review it without any inhibitions."[155] It was not necessarily that the technicality of the math made Courant seek assistance over his own work. His proof was mathematically complete and logical. But Courant had no journal to defer to and reference others' work. If he wanted to know about other scholars' similar interests, he could only do so through personal communication. Yet personal communications could only work for so long for a growing field. To develop a national community, a publication outlet was needed even more. More and more the idea emerged that a journal allows the field to establish and to grow so that a researcher in California would not have to ask around to find out about other people's work.

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[154] Richard Courant to R.G.D. Richardson, 17 April 1941, Courant Papers, 19, Bobst Library, New York University.

[155] Richard Courant to WIlliam Prager, 13 November 1942, Courant Papers, 18, Bobst Library, New York University.

Variational methods are useful for resolving practical problems such as how much money should be allocated to various functions in government spending: pensions, health care, education, welfare, or defense.[156] During World War II, variational methods were convenient methods for optimizing spending on defense. The underlying mathematical complexity overwhelmed Courant. And so he asked for Prager's advice not only because of Prager's expertise in the field, but also because no amount of labor, effort, or expense on Courant's part could be exerted to extend his awareness of other researchers' methods. Only communication with his peers, like Prager, could break the impasse. Courant and Richardson and Prager's programs exhibited a relationship of collaboration and mutual aid.

That is not to say that the relationship between the applied mathematicians at Brown and NYU was always a cooperative, supportive one. At times the two universities vied with one another to hire the same applied mathematicians. The biggest threat to NYU's applied mathematics program came when Richardson offered to Friedrichs a position at Brown. Writing to NYU Chancellor Henry Chase on 2 March 1942, Courant lamented, "It would indeed be a very severe blow for our team work in applied mathematics [at NYU] and for our plans to lose Professor Friedrichs, who represents quite a unique combination of all the qualities we need."[157] It was with great pleasure that Courant also announced Friedrichs' rejection of the "tempting offer" out of "loyalty […] to our group."[158]

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[156] Jagdish Rustagi. *Variational Methods in Statistics* (New York, NY: Academic Press, 1976), 2.
[157] Richard Courant to Henry Chase, 2 March 2 1942, Courant Papers, 19, Bobst Library, New York University.
[158] Ibid.

Courant also made a grab for the talent he wanted. He convinced and arranged a job for applied physicist Eleazer Bromberg with a single question: "Why not here [at NYU]?"[159] Richardson and Courant surely competed for the same resources for their respective initiatives. But their actions reflected more than that. In consensus, everyone agreed that because applied mathematics was still new in America, any applied mathematics program had to establish its credibility beyond question. On the West Coast von Kármán constantly lobbied for that same cause at Caltech. Applied scientists and mathematicians were dispersed everywhere in America. The ingredients were now in place to make an applied mathematics journal possible.

Publications First—Organizing a Journal

The Evaluation Committee had believed it would be difficult to stimulate broader interest in applied mathematics: "The Committee does not believe that a sufficiently prompt and effective improvement [to industry from applied mathematics] will result from the ordinary evolution of educational methods. Something striking and forceful is required."[160] The committee did not elaborate further on what they believed that could be. But it can be inferred that they wanted to join mathematics and science with the wider practical domain of ballistics, aviation, and telegraphic communication. Such innovative mathematical methods could only result from extensive research and investigations.

These investigations would have to appear in print. But where would all these papers—written by faculty and students—describing these new methods have been published? In the

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[159] Richard Courant, quoted in Constance Reid, (New York, NY: Springer-Verlag, 1976), 235.
[160] Evaluation Committee, "Report on Advanced Training in Applied Mathematics, With Special Reference to the School of Mechanics at Brown University," November 1941, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California, 6.

journals of The *Transactions of the American Mathematical Society*, the *Annals of Mathematics*, or *The American Journal of Mathematics*? In the periodicals of the *Mathematical Reviews*? In the European-based annals of the *Mathematische Annalen* or *Mathematische Zeitschrift*?[161] Since the Evaluation Committee already deemed creating an applied mathematics journal unnecessary, it is clear that they believed applied mathematical papers could be published in these other places. Yet for Richardson and Prager, such an assessment was unrealistic. Both wanted a new publication that would serve not just applied mathematicians from the Brown circle, but also national and international science in the broadest sense.

At first, applied mathematicians resisted Prager and Richardson's ideas, seeing in it needless mathematical excess. After all, organizing a journal required publishers, editors, writers, production, marketing, and much more. Among the dissenters was Warren Weaver, Director of the Division of the Natural Sciences at the Rockefeller Foundation, who as early as February 1939, had been "opposed to such a journal " and had preemptively dismissed its utility.[162] Like the Evaluation Committee, Weaver believed that the efforts of mathematicians and scientists should be allocated elsewhere.

But as administrators and researchers like Richardson and Prager ventured deeper into placing a firm foundation under applied mathematics, the notion of publications proved even more essential. Applied mathematics papers were inappropriate for the mathematics and engineering journals that already existed in the Untied States. The content of the applied mathematics papers in plasticity and elasticity often were rejected by journals like the

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[161] These were the top-tier journals of the day, as cited by Reinhard Siegmund-Schultze in "Emancipation of American Publications," *Historia Mathematica* 24 (1997): 154.
[162] R.G.D. Richardson to Theodore von Kármán, 14 July 1942, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.

Transactions of the American Mathematical Society. They were deemed to contain unsuitable content.[163] On the one hand, applied mathematical papers were not rigorous or analytical enough for the contents of pure mathematics journals. And such papers were too complex mathematically to be comprehended by engineers.

In pursuing a journal, Prager drew on the past to make his point. Before the 1940s, academic German publishers, especially the renowned Springer publishing house, dominated the distribution of mathematical publications. It was understandable that American publishing firms would be adverse to publishing "advanced monographs" and papers and even books. For American publishers, mathematical papers had seemed risky "due to a feeling of uncertainty as to prospective sales."[164] It would be difficult for any new American journal in applied mathematics to succeed, given that Springer dominated the international market. Indeed, in the mid-1930s mechanical engineer and mathematician William Durand experienced many difficulties acquiring an American publisher for his six-volume *Aerodynamic Theory*, despite the availability of Guggenheim money to fund it.[165] American publishers wanted profits, which were difficult to acquire due to intense international competition.

Now more than ever, Prager reasoned, Brown's timing was right to lead applied mathematical publishing with a peer-reviewed journal of its own. In 1938, just as anti-Semitic pogroms in Nazi Germany broke up a thriving mathematical community there, so too did it mark a turning point for German publishing dominance. German editors and mathematicians like Otto

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[163] Siegmund-Schultze, *Mathematicians Fleeing from Nazi Germany*, 118.
[164] R.G.D. Richardson to Theodore von Kármán, 14 July 1942, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.
[165] Richard P. Hallion, *Legacy of Flight: The Guggenheim Contribution to American Aviation* (Seattle, WA: University of Washington Press, 1977), 214.

Neugebauer, unwilling to tolerate anti-Semitic interference in their work, resigned.[166] Springer's activities became increasingly immobilized by the war. Fully aware of the situation, Prager took up the cause of publishing articles in a July 1942 letter addressed to Dean Richardson, President Wriston, and other Brown administrators. This time, he reordered his reasoning in words that instantly seized the imagination of the administrators: "Imagine a new journal for the university that would include the control, the selection of editors, and the financial backing."[167] Here Prager appealed to the university's potential of becoming a leading research institution, not necessarily to the prospects of mathematical development in partial differential equations or other applied math topics. That argument he reserved for mathematicians and scientists.

Prager singled out Brown as the institution to support the applied mathematics journal he envisioned. The university had already revealed its ability to enrich the quality and quantity of mathematical activity in America. In 1940 Professors Willy Feller and German émigré Otto Neugebauer, who would later go on to become the founder of Brown's History of Mathematics Department, founded *The Mathematical Reviews*. Assuming editorial responsibility, the journal served to alter American and world reliance on Germany's *Zentralblatt für Mathematik* to *The Mathematical Reviews* as the world's leading review journal for mathematics.[168] Clearly other faculty at Brown had shown that producing a journal was perfectly feasible. Now was the chance for applied mathematics.

Shortly after Prager sent his letter urging Richardson and Wriston to take action, Richardson released his August 1942 "Memorandum on the Proposal for a New Journal." Now

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[166] Siegmund-Schultze, "Emancipation of Mathematical Research Publishing," 155.
[167] William Prager to R.G.D. Richardson and Henry Wriston, 14 July 1942, Theodore von Kármán Collection, 70:11, Caltech Archives, Pasadena, California.
[168] Rees, "Mathematical Sciences and World War II," 614.

the Brown's administrative leaders officially backed Prager's proposal and guaranteed financial support. As early as January 1943, they wanted the *Quarterly of Applied Mathematics and Mechanics*—Prager's working title—to be published with Prager himself acting as "Managing Editor." Supporting Prager in his duties would be a "board of five (or six) editors appointed by Brown University to be designated EDITORIAL BOARD and a group of eight or ten other leaders in the field to which the journal is to be devoted will be invited to cooperate, to be known as COOPERATORS."[169] That the Editorial Board was appointed by Brown officials, and not by leading applied mathematicians in America, already reflected the University faculty's and officials' commitment to producing a journal in their own way.

Yet for Richardson and Prager, the chain of responsibility for the journal did not end with applied mathematicians. The American Mathematical Society, the American Society of Mechanical Engineers, the Institute of Electrical Engineers, and the Radio Engineers were also "invited to delegate one representative to the group."[170] Applied mathematics includes a whole wide range of scientific and mathematical topics to be discussed; they—physicists, engineers, even chemists—should, then, also be included and allowed to provide their own input. Familiar faces convened together to form the first Editorial Board: Theodore von Kármán, Thornton C. Fry of Bell Labs, Professors I.S. Sokolnikoff and J.L. Synge, and Hugh L. Dryden, an aeronautical scientist working for the National Bureau of Standards.[171] Prager hoped that the inclusion of other scientists would aid applied mathematics' reputation within the scholarly community.

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[169] R.G.D. Richardson. "Memorandum on the Proposal for a New Journal." August 1942, Theodore von Kármán Collection, 80:38, Caltech Archives, Pasadena, California.
[170] Ibid.
[171] Ibid.

Prager's publication initiative in this World War II world era occurred at a crucial moment in the systematization of applied mathematics at Brown. For despite Wriston and Richardson's resounding support for Prager's project and the unhampered enthusiasm of other American applied mathematical advocates, entrepreneur Thornton Fry was not at all satisfied with the working title of the journal. He said so, very publicly, in an October 1942 letter posted to Prager and the rest of the Editorial Board, just as the U.S. Navy Task Force began deploying its first aircraft carriers, troop ships, and other technologically advanced vessels to North Africa. Evoking his 1940 article, Fry suggested renaming the journal to *Industrial Mathematics*. First he reasoned, "the words mean exactly what I hope the journal will aim to carry."[172] He envisioned the journal staffing the best technical people, laden with monetary support from businesses.

Second, Fry's suggested title would both promote and safeguard applied mathematics' status in American academia. The journal would not give way to "degenerating into a graveyard of the worthless articles on pure mathematics which other journals do not want."[173] As far as Fry was concerned, the current title of Prager's journal was inappropriate for the exigencies of modern technology. No shoddy second-hand articles by pure mathematicians barely discussing pressing applied mechanical problems—mechanical, hydraulic, or electrical systems—would do. Industry was the key to the future, a future that would only come about properly if applied mathematicians broke with its past, a miserable era characterized by marginalized activities. In place of the old, the new world of applied mathematics would be based on a methodical approach that considered the priorities of commercial enterprises and services.

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[172] Thornton Fry to William Prager, 27 October 1942, Theodore von Kármán Collection, 80, Caltech Archives, Pasadena, California.
[173] Ibid.

"How could it be otherwise?" reasoned Fry.[174] In terms reminiscent of applied mathematics struggles in the United States some years earlier, Fry reminded the Editorial Board that current technologies needed to be backed up by mathematical reasoning and experiments. Airplanes were seeking higher altitudes and faster speeds. Those piloting the planes—especially fighter planes in World War II—and directing their movements, not to mention the passengers entrusting their lives to the more speedy commercial aircraft, had to have the correct and most efficient physical structure. Every mathematical variable, from the strength of the metal alloy employed and to the angle of the wings, counted.[175] The prevalent but obsolete mechanical systems of flight were bound to be inferior. Only the developing applied mathematical theories that would be found in Prager's envisioned journal had the opportunity to overturn the old. Fry's unwavering support for this vision of the journal issued from many sources, from the practicalities of producing ever more efficient technologies and his entrepreneurial ambitions to a sense of where applied mathematics would stand in relation to its sister disciplines of engineering and pure math. Producing a journal was all at once academic, profitable, and pragmatic.

Yet, in both recognizing this need and putting forth this solution, Fry was very understanding when his suggested title, *Industrial Mathematics*, was turned down. While Sokolnikoff "heavily endorsed his point of view with regard to the content of the new journal," he also dismissed the title. The rest of the Editorial Board concurred with Sokolnikoff's reasoning that Fry's suggested title "might prove a handicap because of the past shoddy meaning

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[174] Ibid.
[175] Ibid.

to which it refers."[176] "Shoddy" in the sense that the term had been so often thrown around, used by government officials and scientists without much regard for an agreed upon meaning. The Board then settled on its new title, the *Quarterly of Applied Mathematics*, vowing to select articles with great care.

The myriad letters illustrating Prager and the Editorial Board's relentless optimism and self-confidence also reveal a biting disregard for complacent scientific authority. In particular, disregard for Richard von Mises, a German solid mechanician who had effectively succeeded building up applied mathematics in Germany in the 1930s. He had done so before emigrating to America in 1939 by establishing an applied mathematics journal of his own. But in doing so, he was perceived to be "utterly unable to cooperate with" and to have a "dictatorial attitude" of how a mathematics journal should be organized.[177] If the Editorial Board would not budge an inch in managing the journal, they had no more intention of altering their way of organizing applied mathematics to suit the disapproving glances of mathematical authorities like von Mises. It was not surprising that von Mises, who rescinded his participation in the editing activities of the *Quarterly*, was severely offended.

From organizing the *Quarterly* early on, Prager had formed strategic bonds with other applied mathematicians and industrial men. All held deep respect for other authorities like von Mises who had helped to build up the reputation of applied mathematics. Prager filially acknowledged "von Mises' many contributions and efforts to the [applied] sciences through

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[176] I.S. Sokolnikoff to Thornton Fry and William Prager, 30 October 1942, Theodore von Kármán Collection, 80, Caltech Archives, Pasadena, California.

[177] William Prager to Richard von Mises, 15 October 1942, Theodore von Kármán Collection, 80, Caltech Archives, Pasadena, California.

sheer will."[178] But when it came to organizing an applied mathematics journal at Brown, the Editorial Board was absolutely undeterred by the head-shaking of such towering figures.

The Impact of Marketing the *Quarterly*

In April 1943, merely a year after initial ideas for a journal were formulated, newly printed issues of the *Quarterly* came off the press and were immediately distributed across the United States. But a journal of applied mathematics was never just about promoting rigorous mathematical concepts for potential use. Now the *Quarterly* was a tangible manifestation of the intellectual and research enterprise at Brown. Prager believed that this journal would play a large role in legitimizing the Program of Advanced Instruction and Research in Mechanics at Brown. Now he needed to ensure this aim would happen. But publishing a journal was one thing; marketing it was another.

At first glance, it might seem impossible that such a new journal would exert any sort of influence on systematizing applied mathematics. But Prager's marketing efforts served to make more individuals aware of the activities of this applied mathematical community—in particular industry, management companies and the military. Consequently a widening clientele of manufacturers and businesses emerged, persuaded by the notion that that Brown's program of applied mathematics was worth investing in.

New and uncertain. Yet when the first few issues of the *Quarterly* finally were distributed in April 1943, it was of political, mathematical and economic significance. The United States government had just reversed its previous, hostile attitudes towards scientific publishing. In

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[178] William Prager, letter to Theodore von Kármán, 27 October 1942, Theodore von Kármán Collection, 80, Caltech Archives, Pasadena, California.

Washington D.C., March 1943, President Franklin Delano Roosevelt reactivated the Alien Property Custodian office within the Department of Justice. The office had originally been created during World War I in connection with the Trading with the Enemy Act of 1917. The renewed Alien Property Custodian now had the power in World War II to seize and license for American publication all enemy-produced items that were normally copyrighted.[179] This meant German books, journals, and much more would be made more accessible to Americans, while German mathematicians became increasingly isolated from foreign research. Encouraged by well-earned governmental support, the *Quarterly* could facilitate research and development with access to the work of foreigners abroad.

Having foreign research made available through governmental support, Prager pounded out the *Quarterly*'s message wherever he could. Of the initial 5,000 printed issues of the *Quarterly*, Prager sent 350 to "University Libraries," 820 to "Directors of Research in Industry," 225 to "present and past students," and 260 to "foreigners."[180] The journal had a wide spread and returns were good: subscriptions continued to rise so that by May 1943, 4,268 issues had been sent out and only 176 remained.[181] This new marketing and dissemination strategy led to readership being expanded not just to the applied mathematical community but also to those with the potential to support applied mathematic: in particular, the industrialists. The only hostility

[179] Ibid.
[180] "Report on Subscriptions as of June 14, 1943." 14 June 194, Theodore von Kármán Collection, 80:39, Caltech Archives, Pasadena, California.
[181] Ibid.

towards the journal came from "the M.I.T. group," who Prager noted, had "always looked down upon Brown's project as an entirely unwarranted competition."[182]

When the readers initially opened the *Quarterly* to read its contents, they found a short, simple and elegant expository essay on "Tooling Up Mathematics for Engineering." Readers did not step straight into the technical details of Hugh Dryden's "Review of the Statistical Theory of Turbulence" or Prager's paper on "Plane Rigid Frames." Instead, they became immersed in a dialogue between the mathematician and the engineer and their responsibilities. Utilizing a language style that transcended the scientific and economic world, von Kármán provided a simple definition for the applied mathematician's role: "tool designers" who provide the means "to get the solution of engineering problems into production."[183] Von Kármán was in a position to effectively advocate the enrichment of mathematical education and the incorporation of mathematical notions into scientific courses.

In this light, von Kármán's article reads as something quite different from a purely metaphorical tract. First, the definition he provided of the applied mechanic was not some abstract figure; it was a most useful expert to be utilized. Second, the article served as an advertisement call to appeal to potential users. In 1943, more than ever, it was Brown's applied mathematics program that was responsible for the proliferating an ideal and respectable image of applied mathematics.

Read by engineers, mathematicians, government officials, and entrepreneurs, the *Quarterly* received rave reviews. "After carefully reading Kármán's clever dialogue several

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[182] William Prager to Theodore von Kármán, 22 February 1943, Theodore von Kármán Collection, 80:11, Caltech Archives, Pasadena, California.
[183] Theodore von Karman. "Tooling Up Engineering for Mathematics." *Quarterly of Applied Mathematics*, Providence, RI, p. 6.

times, […] and thumbing through the other papers, last night" wrote Chief of Aerodynamics Research at Curtiss-Wright Corporation, Edmund B. Moore, "I wish to convey through you to the Editors congratulations and appreciation of their efforts in establishing this long-needed publication of such high standards and obvious usefulness now and in the happier days to come."[184] Researchers and industrialists had come to view the success of systematizing applied mathematics at Brown as a value not captured by the purely abstract or solely pragmatic, but integrating both.

Helping to foster such enthusiasm were the contents of the technical papers published. Nitty-gritty equations and mathematical reasoning filled the *Quarterly's* first issue in papers like "A Direct Image Error Theory." Such analysis included mathematical techniques, like matrices and calculus, which were incomprehensible to the untrained expert.[185] Yet actual prose also spelled out the simple material utility of these complex mathematical topics. For geometrical optics, an "updated image theory" simplified previous theories by "not restricting ourselves to specific planes and directions."[186] The author simply chose the most convenient mathematical mechanism, reducing excess numbers, that could be used to ease production of products governed by geometrical optics, such as light sources, detectors, and projection screens.

Thanks to the immediate success of the *Quarterly*, technical companies began to offer support. On 29 June 1943, an anonymous "leading engineer of the research division of one big aeronautical corporation" writing to Richardson offered to "contribute toward the expenses of the

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[184] Edmund B. Moore to William Prager, 25 May 1943, Theodore von Kármán Collection, 80, Caltech Archives, Pasadena, California.
[185] Max Herzberger, "A Direct Image Error Theory," *Quarterly of Applied Mathematics* 1:1 (April 1943): 73.
[186] Ibid, 74.

Quarterly."[187] Clients. The very thought made Richardson excited and cautious. On the one hand, the financial assistance offered a solution to continuing production of the Brown journal, which was only guaranteed one year's funding by the University. On the other hand, Richardson feared that the "contribution of expenses" to the journal would not make the journal—and Brown's applied mathematics program by extension—a "house organ of this particular firm."[188] Richardson did not want industrial supporters to subordinate science to their whim. The idea of introducing industrial-university relations was attractive, but not if it would eclipse the authority or credibility of university researchers.

The solution established a permanent link between industries and Brown University. The anonymous backer suggested, "an approach be made to some 20 or 30 firms whose research laboratories would be interested in the type of material published."[189] Naturally it would be of fundamental importance that such contributors should keep hands off the policy of the journal. This was a very agreeable solution. Whereas the relationship to private firms and universities had been unheard of decades ago, now they were partners.

Prager's involvement in the *Quarterly* continued to intensify in 1943. Within a few months of the journal's first publication of articles, it moved to sell subscriptions outside of the United States. Now readers from Peru, France, England, even Australia, wanted to read the Brown-produced applied mathematics journal.[190] In the midst of that growth, sponsorship expanded. By the third issue of the *Quarterly*, published in October 1943, Brown University was

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[187] R.G.D. Richardson to the Editors of the *Quarterly of Applied Mathematics*, 29 June 1943, Theodore von Kármán Collection, 80:11, Caltech Archives, Pasadena, California.
[188] Ibid.
[189] Ibid.
[190] "Report on Subscriptions as of June 14, 1943." 14 June 194, Theodore von Kármán Collection, 80:39, Caltech Archives, Pasadena, California.

no longer the sole financial backer. Bell Telephone, Bristol Company, General Electric, and United Aircraft Corporations provided considerable support as well.[191] Prager and other applied mathematicians could be rest assured that the journal was there to stay. Now students and professors had an official outlet to publish their research for potential employers and patrons to see. The journal dealt with the rational, logical, and deductive reasoning of applied mathematicians.

By Brown's lights, especially in the eyes of Richardson and Prager, Brown University became an influential research institution through the *Quarterly of Applied Mathematics*. Every American concerned with applied mathematics—every university administrator, every government official, and every business executive—was attracted to its potential. Clearly, the importance of the *Quarterly* was not confined to the far reaches of an isolated applied mathematical community. Advantages were ubiquitous, coordinated by a practical, technical language appealing to the scholarly community and the business-oriented. Government officials, too, looked on with interest over how they could utilize the research.

All through Brown's work lay an educational reformation, a sense that applied mathematics could be further entrenched into academia through engaged reason and practical output. Publications and journals served as avenues to accomplish this. In particular, the *Quarterly of Applied Mathematics* stood as a manifestation of those goals. It also stood as the only applied mathematical journal in the Untied States, one that was linked to outside agencies like aircraft companies, electrical energy-producing industries, and telecommunication

[191] Prager, William et al., eds., *Quarterly of Applied Mathematics* 1:3 (October 1943): 1.

conglomerates. At every stage of the story, the journal was powerfully bound to the campaign for systematizing applied mathematical training at Brown University. Brown had already begun to move beyond its liberal arts status and turned into a growing research institution.

Through the efforts of an applied mathematics community and the support of industries and government, publication outlets were the glory of Prager and Richardson's Program of Advanced Instruction and Research in Mechanics. The distributed *Quarterly of Applied Mathematics* would not be enough to ensure the importance of applied mathematics in university education. It was an established department that Richardson and Prager wanted. Challenges hovered like storm clouds over the discipline. In 1945, Brown's Advanced Instruction and Research in Mechanics remained separate from the undergraduate and graduate school, albeit still affiliated with them. Now Prager and Richardson wanted full recognition. We shall see that the program received validation and a new status, emerging with an identity that altered the status of Brown University.

Chapter 4
Applied Mathematics Established, 1944-1946

In December 1945, less than five years after Dean Richardson and President Wriston initiated their plans for Brown's applied mechanics program, William Prager wrote to Theodore von Kármán. His letter struck a different tone from previous correspondences to the renowned applied mechanic: "It may interest you to know that Brown expects to set up our Program of Advanced Instruction and Research in Mechanics as an Institute of Applied Mathematics by the fall of 1946."[192] Unlike when Richardson and Wriston had requested von Kármán's services in the Evaluation Committee in 1941, and unlike when Prager had invited von Kármán to participate on the *Quarterly of Applied Mathematics*' editorial board in 1942, now Prager was not asking for von Kármán's administrative or scientific expertise. Instead, Prager was proudly reporting his next step for Brown's applied mathematics project.

With the end of the war in August 1945, Richardson and Prager were able to secure the Program of Advanced Instruction and Research in Mechanics' place at Brown University with the official establishment of the Graduate Division of Applied Mathematics by September 1946. The department arose from a significant enterprise producing original mathematical methods for industry and the economy and now had a vast intellectual spread. Improvements, expansions, and new networks sprouted from Brown in the form of research, publication journals, and graduating students conferred with doctorates. But what activities did these applied mathematicians do in the war that allowed for the creation of a department? What became of

[192] William Prager to Theodore von Kármán, 11 December 1945, von Kármán Collection, 81, Caltech Archives, Pasadena, California.

their research after the war? And how was the administrative structure of Brown University altered?

In my final chapter, I argue that—in the interconnected fields of engineering, physics, and mathematics—Brown's Division of Applied Mathematics systematized a discipline that swiftly displaced the traditional scientific tenets of the time. As intellectual researchers, they revealed that their work did not just depend on the wartime environment. Rather, Brown's applied mathematics program adopted and adapted the methods of "Wissenschaft,"[193] the research ethic that had become firmly entrenched in German higher education in the nineteenth century. This encouraged increasing emphasis on research as an officially sanctioned and supported endeavor in the university setting and, by intimate association, to the emergence of an applied mathematical community. Furthermore, the interests of the program resulted in the sustained support and federal funding for research and development.

World War II Activities

The Second World War gave rise to a strong relationship between Brown's applied mathematics program and the federal government. Beforehand, such a connection was rather weak. When Richardson initially led the applied mathematics initiative at Brown, he and Wriston appealed to philanthropic institutions for monetary support. In particular, they requested financial aid from the Rockefeller Foundation and the Carnegie Corporation.[194] The support of these philanthropies typified a common practice before the war: if university researchers wanted

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[193] Generally the nineteenth-century "Wisseschaft" research ethic refers to the commitment to scholarly research at the graduate level with the availability of state-financed research. A common methodology in research and professionalization resulted from this as well. For a more detailed introduction, see Calinger (1996) and McClelland (1980).

[194] Reinhard Siegmund-Schultze, Rockefeller and the Internationalization of Mathematics *Between the Two World Wars* (Boston, Germany: Birkhauser Verlag, 2001), 54.

extra funds, they appealed not to the government but to philanthropic organizations. World War II marked the reversal of that policy, where Brown's applied mathematicians did not have to depend on the university or the generosity of philanthropic institutions. Researchers could now request extra grants and funds from both industry and the government.

From New York City the Secretary of the Carnegie Corporation, Robert Lester, relayed good news to President Wriston on 21 May 1943. "I am glad to be able to tell you that, at a meeting of the trustees of the [Carnegie] Corporation held May 20, the following resolution was adopted," wrote Lester. "From the balance available for appropriation, the sum of twenty-five thousand dollars ($25,000) […] is appropriated to Brown University, as an emergency grant toward and support of the work in applied mathematics and mechanics."[195] In Richardson and Prager's initial efforts to accrue the necessary resources for systematizing applied mathematics at Brown, both had found substantial amounts of financial support from the Carnegie Corporation. No other agency aside from philanthropic institutions and Brown provided extra funds.

But times changed. Later that year, the government inaugurated the Office of Scientific Research and Development, a federal agency that included an applied mathematics group of its own.[196] The Applied Mathematics Panel, as it was called, helped with the increasingly complex mathematical problems that were assuming importance and with those other problems that were relatively mathematically simple but needed mathematicians to formulate them adequately. This included exploring the technology of submarines, radar, electronic countermeasures, explosives,

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[195] Robert Lester to Henry Wriston, 21 May 1943, Wriston Papers, Brown University Archives, OF-1C-11: 3, John Hay Library, Providence, Rhode Island.

[196] The Office of Scientific Research and Development had several parts: one devoted to medical research; one devoted to fuse research; and the third and largest; the National Defense Research Committee, which comprise groups of scientists and engineers concerned with technology.

and rocketry.[197] Applied mathematicians needed to be able to consider the mechanical structure of physical objects, such as the shape of an aircraft or naval ship, in conjunction with the more theoretical, like telecommunications.

The Panel, situated in New York, came to be a vital link between universities and the military during the war. It included the same mathematicians who had taken an active role in promoting applied mathematics initiatives at Brown and New York University: Richard Courant, Thornton Fry, Marston Morse, and Rockefeller functionary Warren Weaver, who served as the Chairman.[198] Together, they set up contracts with universities that expressed increasing interests in applied mathematics research: Harvard, Princeton, Columbia, NYU, and Brown. No doubt appreciative of Brown's efforts in particular, the Panel employed quite a few Brown applied mathematicians as technical aides, such as I.S. Sokolnikoff and William Prager.[199]

Additionally, Brown's Program of Advanced Instruction and Research in Mechanics came to be "[u]nder the auspices of the Engineering, Science, and Management War Training Program of the U.S. Office of Education," an agency that provided generous financial support to Prager and Richardson's initiative.[200] Here lay a new sponsor for university researchers. Richardson, Prager, and Wriston did not have to worry about obtaining extra funds from philanthropic institutions to support the Program of Advanced Instruction and Research in Mechanics. They could appeal to government agencies: both the Office of Scientific Research

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[197] Tinne Hoff Kjeldsen, "New Mathematical Disciplines and Research in the Wake of World War II," in *Mathematics and War*, ed. Jens Hoyrup (Basel, Switzerland: Birkhäuser Verlag, 2003), 131.
[198] Ibid.
[199] Richard Courant to William Prager, 16 July 1943, Courant Papers, 19, Bobst Library, New York University.
[200] William Prager to Theodore von Kármán, 11 December 1945, von Kármán Collection, 81, Caltech Archives, Pasadena, California.

and Development and the Office of Education wanted an immediate link between theory and reality. Not only was applied mathematics important to academia, but also it was equally crucial to the military.

By the winter of 1933-1944, as the United States prepared for the invasion of France by delivering airborne operatives and weapons, the Program of Advanced Instruction and Research in Mechanics had expanded to include a wide variety of scientific and mathematical professionals interested in defense research. Participants arrived from all over: from the West Coast, the Midwest, the South, the East Coast, and even from abroad. By that winter, over 525 professors, graduate students, undergraduates, government researchers, and industry-employed workers had enrolled in the program.[201] No doubt Richardson and Prager could read the situation as well as anyone else: the government wanted any mathematically trained individual to support the war effort.

At Brown, studies focused on problems in classical dynamics and the mechanics of deformable media. Courses from the first few years of the program expanded to include the "Hydrodynamical Theory of Propellers" and the "Mathematics of Ultra-High Frequencies in Radio."[202] Whereas previous classes in the program, such as "Partial Differential Equations," seemed to consider general applied mathematical methods, these new additions specifically addressed defense-related problems. Hydrodynamic flow is caused by the flow of water around a submarine's hull due to a propeller blade. Students studied the angular effects of adjusting the angle of a propeller's blade, all in the search for making submarines produce less disruptive water movement below the surface. They also explored the highly analytic nature of radio waves

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[201] "Program of Advanced Instruction and Research in Mechanics," *Bulletin of Brown University* (November 1943): 27.
[202] Ibid.

and frequencies.[203] Although mathematically rigorous, waves were of immediate use to producing radio devices, operating at very high frequencies. The more waves used, the more the frequencies became crowded and caused interference. Such devices were fragile to the point that they could be disrupted by storms and vehicle ignitions.[204] Manipulating the underlying theory of radio waves, applied mathematicians sought to correct interference. Brown researchers crossed back and forth between abstract considerations of the status of shock and radio waves and the practical exigencies of putting radio technology to immediate use.

Prager, too, frequently corresponded with government officials and other active applied mathematicians concerning defense research. With Courant, he began studying the "Interaction of Shock Waves" in the beginning of 1944. Shock waves were a problem the military grappled with throughout World War II. When the velocity of an aircraft approached fast speeds, a pile of waves began to form and create a "barrier." This made sustained flight at fast speeds difficult and risky. Motivated to resolve this issue, Prager immediately plunged himself into practical, war-related matters of shock waves. He asked: how could our "newfound understanding of shock waves" be "applied to aeronautics and improving the safety of planes?" How could "new kinds of metal material be effectively employed to sustain fast speeds in flight?"[205] Prager, and other applied mathematicians at Brown, were as willing to attack the basic equations of shock wave theory as they were to reflect on its uses for defense. These projects provided Brown's applied mathematics program much support from government contracts.

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[203] Ibid.
[204] Rees, "Mathematical Sciences in World War II," 54.
[205] William Prager to Richard Courant, 16 February 1944, Courant Papers, 19, Bobst Library, New York University.

On Brown's campus, there was thus no time for tinkering with numbers, no time for exploring, for its own sake, the myriad ways one could account for various natural phenomena, whether explosions, shock waves, or physical deformation. As Prager's work in shock waves illustrates, Prager introduced "waves" without concern for its "true nature," as a "pure" mathematician would have. After introducing "the theory of waves," Prager—as well as other faculty in Brown's applied mathematics program like Sokolnikoff and Reissner—attempted to mathematically deduce the connection among quantities and numbers. They hoped to formulate a mechanical picture out of this approach. That is, a mechanical image of planes being slowed down by turbulence, or "pressure waves underwater with propellers."[206] No abstruse theoretical postulates here, just a matter-of-fact assessment that equations let the work proceed.

This methodological approach to studying applied mathematics in the wartime environment gave rise to many career opportunities for emerging applied mathematicians from the Program of Advanced Instruction and Research in Mechanics. By late 1944 and into 1945, program participants found many positions with the U.S. Army, the National Defense Research Committee, the U.S. Navy, and other "Miscellaneous Government Agencies."[207] All throughout the 1940s the wartime environment influenced the physical and mathematical topics researched, not necessarily the specific research interests of scholars. That a large number of students completing Brown's applied mathematics initiative could fill many positions in the military points to the success of the initiative.

Yet the need to formulate military strategies for defense and offense also influenced the rise of a new field in applied mathematics: operations research. Operations research is the

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[206] "Program of Advanced Instruction and Research in Mechanics," *Bulletin of Brown University* (November 1943): 32.
[207] Ibid, 29.

analytical method of problem solving and decision-making used for management.[208] Radar research during the war reflected the rise of this new field. Applied mathematicians were able to reveal that radar was technically an efficient tool in air defense, particularly for detecting submarines underwater or incoming aircraft. However, while "the technical feasibility of the radar system" was well established, "the operational achievements fell far short of requirements."[209] Now the military did not want to just invent new kind of weapons and equipment, but to analyze what went on in the fighting field. Using mathematical advanced mathematical methods, political strategists wanted to suggest ways to *optimize* existing military equipment's use. They also wanted to *optimize* the number of troops deployed to certain areas. No longer were the equations of applied mathematics being applied to technology, but they were also being applied to social phenomena.

In response to ever more "urgent requests from the armed forces," Richardson and applied mathematicians at Brown began eying other modern technology aside from aircraft and submarines: computers. The "Applied Mathematics Group [at Brown] is looking for two or three competent and experienced computers," wrote Richardson to various researchers at New York University, Caltech, and Princeton on 12 July 1945.[210] At the end of the war, students and researchers at Brown grappled with computers so that American forces fighting in the Pacific could calculate distances to destinations and approximate numbers with ease.

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[208] Operations research is too broad a field to be sufficiently explored in this thesis. For a great introduction into the overall activities of operations research during World War II, see Rosenhead (1989).
[209] Harold Lardner, "The Origins of Operational Research," in *Operations Research '78*, ed. K.B. Haley (Amsterdam: North-Hollan Publishing Company, 1979), 8.
[210] R.G.D. Richardson to Heads of Mathematics Departments, 12 July 1945, Courant Papers, 19, Bobst Library, New York University.

Just as the demands of industry and technology had shaped applied mathematics' rise at Brown, so too had the concerns of American defense during World War II. Professors and students at Brown's Program of Advanced Instruction and Research in Mechanics insisted on including rigor in praxis, which only applied mathematicians were adequately equipped to fulfill. Such an emphasis on foundations, encouraging defense work, was vital. But it would be a mistake to assume that the demands for more advanced technology and efficiency in World War II were sufficient to legitimize Brown's applied mathematics program for the postwar world. More would be needed for that.

The Legitimization of Applied Mathematics

By mid-1945, Richardson and Prager had spent the past four to six years facing the problem of systematizing applied mathematics from two very different perspectives. As the Dean of the Graduate School since January 1923, Richardson had helped lead the institution in its quest to expand Brown University's research capabilities. As the applied mathematics researcher and program director, Prager sought to instill a distinct applied mathematical outlook that differed from engineering, physics, and pure mathematics. A combination of their efforts, along with the opportunities provided by demands for industry and defense research, converged to create the first applied mathematics initiative in America.

But as the war ended, Richardson and Prager's efforts now seemed threatened. The Applied Mathematics Panel and the Office of Science and Research Development dissolved as Emperor Hirohito announced Japan's surrender in August 1945. What, then, would happen to applied mathematics? Would it return to the fringes of mathematical inquiry, being marginalized once again by pure mathematics?

Throughout the war, President Roosevelt had recognized the contribution of mathematicians to the war: operations research, ballistic problems, numerical analysis, aeronautics and mechanics.[211] He looked for a way to accommodate mathematics and maintain the friendly relationship between university research and government during peacetime. Writing in 17 November 1944 to Vannevar Bush, then Director of the Office of Scientific Research and Development, Roosevelt pondered "how similar benefits [from mathematics and the sciences] might be obtained in peace-time."[212] Bush's reply came in July 1945, a few months after Roosevelt's death. In his report to the President, *Science, The Endless Frontier*, Bush wrote that basic research was: "the pacemaker of technological progress" and "New products and new processes do not appear full-grown. They are founded on new principles and new conceptions which in turn are painstakingly developed by research in the purest realms of science!"[213] He recommended the creation of what would eventually become in 1950 the National Science Foundation. It served to maintain the beneficial link between universities and government that had been created during World War II.

Long before plans were finalized on establishing the National Science Foundation, politicians—like President Roosevelt—thought and planned new institutions that would be built upon the model of science the war had created. Policy makers recognized that the mathematical work produced by Brown's applied mathematicians engendered real benefits for military

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[211] G. Baley Price, "The Mathematical Scene, 1940-1965," in *A Century of Mathematics in America*, ed. Peter Duren (Providence, RI: American Mathematical Society, 1988), 382.
[212] Franklin Delano Roosevelt to Vannevar Bush, in Milton Lomask, *A Minor Miracle: An Informal History of the National Science Foundation*, NSF 76-18 (Washington, D.C.: National Science Foundation, 1975), 18.
[213] Vannevar Bush, *Science, The Endless Frontier*, 124.

confrontations, particularly in operations research and mechanics.[214] That the federal government supported the National Science Foundation's creation later signified acknowledgement for applied mathematics'—and the sciences in general—potential in other areas, particularly management of the economy. No longer were systems of government, communications, technology, and mathematics free to grow and expand in relative isolation. Politicians wanted to facilitate the development of advanced computers, forms of transportation, and more. The National Science Foundation, a federal agency and a promoter of the math and sciences, would ease relations between universities and politics.

During the entire span of time from the Foundation's planning in 1945 to its inception in 1950, however, Richardson and Prager continued to look for a way to accommodate the applied mathematics initiative at Brown without endorsing government ambitions fully. While Richardson welcomed the prospect of government support, there were other sides to the relationship he wanted to omit. Richardson hoped that industries and government agencies would not come forward, hire applied mathematicians, and dictate research. As Prager reflected at a 1953 conference about Richardson's efforts: "The difficult task of steering the program through the war years fell to R.G.D. Richardson. To his foresight, initiative, and perseverance to not subordinate mathematics to the wills of others."[215] Richardson did not want to shackle applied mathematicians' work to the contracts and patronage of industries and government bureaucrats. That implied merely reshaping and adapting already existing ideas, merely twisting the

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[214] Milton Lomask, *A Minor Miracle*, 27.

[215] William Prager, "The Graduate Division of Applied Mathematics at Brown University," in *Proceedings of a Conference on Training in Applied Mathematics* (New York, NY: Columbia University Press, 1953), 34.

mathematical functions and numbers. No, he wanted to expand upon mathematical ideas and create new ones.

With this realization, Richardson threw himself back into the task he had begun in 1940, namely, the development of an applied mathematics program within the University. Only this time, he aimed to make the Program of Advanced Instruction and Research in Mechanics into a university-recognized department, a department with the power to confer doctoral and masters' degrees in applied mathematics. Prager joined the cause. Both lobbied for the creation of an applied mathematics department, determined to put an influential stamp of university education on the new world order of applied mathematics.

By November 1945, faculty members voted on adopting "a new step for applied mathematics". With few objections from faculty members who voted, "the Division of Applied Mathematics in connection with the Graduate School" was established. William Prager was appointed to serve as the Division's first Chairman.[216] The Division's staff included five full professors, four associate professors, three assistant professors; space was reserved to allow for four more visiting professors as well.[217]

Here was an admirable vision now fully realized: the Division of Applied Mathematics, equipped with its well-trained professorial staff and mathematical texts, would stretch its influence to wherever also embraced applied mathematics. Conferring doctoral and master's degrees, the discipline would multiply itself until technicians, industrial entrepreneurs, and other technocrats, had the intense mathematical background needed.

[216] Ibid, 37.
[217] Ibid.

Indeed, the establishment of the Division of Applied Mathematics represented a critical moment in systematizing applied mathematics. As Richardson wrote to Prager on 18 November, 1946, the Division of Applied Mathematics' secure placement at Brown represented both good news and reflected other issues: "I am not informed that the Ph.D. degree is being given in Applied Mathematics in any of the other U.S. member institutions. Since this rating is always comparative, I see nothing that might be done; we could be rated at the same time as the best and the poorest in the field."[218] Under these circumstances, it became ever clearer that Brown was far from likely to mimic other research institutions. The faculty and administrators involved with the Division were the ones setting the curriculum. They set the standard and presented a model to be built on or followed.

Scientists, businessmen, and bureaucrats lauded Richardson and Prager's efforts and the official establishment of the Division. The Division continued to receive considerable amounts of funding from philanthropic organizations like the Rockefeller Foundation and the Carnegie Corporation, but also from federal agencies and industries. The Office of Naval Research, the Bureau of Ships, and other "miscellaneous governmental groups that cannot be named" provided contracts to support applied mathematics research for the department. But the contracts did not dictate the type of research Prager and his colleagues should pursue. Instead, the agreements stipulated that the researchers should "review of any mathematical theory for mechanics

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[218] R.G.D. Richardson to William Prager, November 18, 1946, Wriston Files, Brown University Archives, John Hay Library, Providence, Rhode Island.

wherever deemed desirable."[219] Despite Richardson's previous fears over how university research could be hindered by governmental interaction, it did not occur.

The continued support of federal agencies, like the National Science Foundation in the 1950s, characterized a new tenet of scientific research that had not existed before the 1940s: that is, state-financed research investing in applied mathematics and basic science. The government and industries recognized that the advances in mathematics had the potential to be converted into technological innovations by the process of technology transfer. And so the establishment of the Division of Applied Mathematics in connection to the Graduate School at Brown was welcomed.

As far as Richardson and Prager were concerned, a wartime environment was insufficient to justify the establishment of a separate department of applied mathematics. Richardson insisted that people needed exactitude and rigor in praxis, which only applied mathematicians were adequately equipped to fulfill. Such an emphasis on foundations, encouraging original research was vital. No bureaucrat- or industry-driven employment system would do. Education was the key to the future, as was individual research project interests—only now the university had the extra benefit of help from the government and industry.

Running the Brown University Division of Applied Mathematics

In the postwar years, industrial demand for applied mathematicians rose ever more sharply. Industrial laboratories, from Bell Labs to aircraft companies, could not get enough of applied mathematicians. Nor could government agencies, which continued to provide grants and contracts to Prager and his colleagues. Federal expenditures for research and development were

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[219] William Prager to Theodore von Kármán, 18 October 1947, von Kármán Collection, 70:10, Caltech Archives, Pasadena, California.

so great that they passed the $1-billion mark by 1950.[220] Thus applied mathematics continued to prosper. Recruiters combed the campuses for graduating students from the Division. The activities and research pursued by the department in the postwar years revealed that Brown's Division of Applied Mathematics did not have to depend on a wartime environment for work.

Brown professors of applied mathematics pushed the new discipline hard. As student enrollment increased, the department offered more than 16 courses yearly. Professors William Prager, Chia-Chiao Lin, Rohn Truell, and Herbert Greenberg rotated teaching duties.[221] If a graduate student arrived wishing to receive a doctoral degree, he supplemented his coursework with his own research and "a series of seminars" in "pure mathematics, physics, and engineering."[222] Graduate students were expected to become masters of mathematics grounded in the physical, real world. In doing so, they learned about structures, dynamics, vibrations, fluids, optics, and much more.

Still, although applied mathematics had received its legitimization in the establishment of a Department at Brown, immediate acceptance within the University proved more elusive. Applied mathematics faculty members and students constantly found themselves bickering with other departments, vying for space to research and study. Students had to share desks with the graduate students of the Mathematics Department, who, at times, was not very accommodating. At the end of the 1940s, the applied mathematics department was housed in "Brunonia Hall," a former dormitory. Faculty members and students despised placement there. One student lamented to Prager, "as we [students] study our notes and our books, each pen stroke and page

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[220] Lomask, *A Minor Miracle*, 7.
[221] William Prager to R.G.D. Richardson, 3 October 1946, Brown University Archives, Division of Applied Mathematics, John Hay Library, Providence, Rhode Island.
[222] Ibid.

rustle becomes more unbearable everyday."[223] Within Brown's campus, applied mathematics students and professors struggled to garner the space they wanted.

At first, the space crunch caused by overcrowding seemed negligible to administrators. Yet space sensitivity had sufficiently mounted by 1950 that even this problem—minute and trifling as it may have been a few years before—affected applied mathematicians' research, such as the slowed production of the *Quarterly*. In search of other buildings to "house the new department," Prager set out 17 July 1950, and "with Professor Levy, examined with great interest the house at 182 George Street which, needless to say, has large quantities of room suitable for our purposes."[224] The building was, Prager argued, a special-asset, not only for the research space it could provide the Division of Applied Mathematics, but also for the comfortable learning environment it could give graduate students. Prager's placement ambitions for the Division carried weight. Largely at his behest, in May 1953, the Division was able to move itself away and settle into 182 George Street, which to this day is where the Division of Applied Mathematics remains housed.

A striking feature about Brown's systematization of applied mathematics emerges from this little vignette. Despite years of attempting to settle into university education as a distinct discipline, the Division of Applied Mathematics could still be conflated with the math department. This idea, subtle as it was, revealed itself in the administration's delayed undertaking to remedy the overcrowding issue within mathematics and the sciences.

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[223] Quoted in William Prager to R.G.D. Richardson, 11 October 1947, Brown University Archives, Division of Applied Mathematics, John Hay Library, Providence, Rhode Island.
[224] William Prager to Henry Wriston, 17 July 1950, Brown University Archives, Division of Applied Mathematics, John Hay Library, Providence, Rhode Island.

Administrators did not initially believe that the applied mathematics department needed facilities of its own.

But the research produced by faculty members of the department reveals otherwise. Professors—like Prager, Truell, and Levy—continued to produce popular and technical publications for the *Quarterly of Applied Mathematics*. So well regarded had the journal become after the war that von Kármán wrote to Prager from Italy on 29 October 1947 about expanding the journal's distribution. "Traveling through France and Italy," von Kármán wrote, "I noticed that many people heard of the *Quarterly of Applied Mathematics* and would like to read the articles published. The journal really has excellent reputation. I thought it would be a good idea to send more journals their way."[225] Now the influence of Prager and Richardson's original applied mathematics initiative had spread to Europe. Readership continued to increase even after the war had ended. Increased readership required more space to be able to produce more issues of the *Quartelry* at Brown.

Out of all the applied mathematicians at Brown, Prager's post-war work revealed that research in applied mathematics did not necessarily depend on the interests of the government or industry. Strolling to work everyday, Prager gained "inspiration from his surroundings." Walking along the sidewalks of George Street and Hope Street, he observed the cars that drove by and sometimes "clumped together into traffic jam during rush hour."[226] From these daily observations, Prager targeted traffic flow and sought to mathematically model it. He wanted to monitor traffic congestion and to advise motorists of possible alternative routes.

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[225] Theodore von Kármán to William Prager, 29 October 1947, von Kármán Collection, 81: 2, Caltech Archives, Pasadena, California.

[226] William Prager to Theodore von Kármán, 16 November 1948, von Kármán Collection, 70: 12, Caltech Archives, Pasadena, California.

In his instruction and research in applied mathematics, Prager continued to lecture on transportation theory. In the 1950s, he gave a series of lectures on the “fluid theory” of highway traffic. He explained that traffic flow could be modeled like a wave. Once traffic volume exceeds a critical threshold, small perturbations in the flow “amplify” and “traffic waves develop.”[227] These waves travel backwards along the road, forcing drivers to brake and accelerate constantly. Prager’s lectures and papers incorporated rigorous equations and complex mathematical theories to make his point. But always, without the crutch of equations, he would return to a more lax speak, “providing useful analogies.”[228] Driven by his own curiosity, Prager followed the same approach to applied mathematics as he had sought to instill in students during the World War II era. He emphasized mathematical principles and eschewed succumbing to the demands of others. Applied mathematics was an investigative science. The simplicity and scope of deducing mathematics that modeled the real world remained, for Prager, an ideal of mathematics for Brown’s Division of Applied Mathematics, one that he and the rest of the faculty taught.

The Second World War had lasting influences on the institutionalization of applied mathematics: the continued relationship to government contracts and industrial consultations. But in the immediate postwar era—and beyond—applied mathematics’ use and Brown’s Division of Applied Mathematics’ influence increased. For while the establishment of the Division built on years of intense efforts to remedy the lacking mathematical skill of industry, Richardson and Prager had managed to keep the University from being merely a passive follower; instead, the Division of Applied Mathematics was an influential force in science and research.

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[227] G.F. Newell, “Memoirs on Highway Traffic Flow Theory in the 1950s,” *Operations Research* 50: 1 (January 2002): 173.
[228] Ibid.

In June of 1950, the contrast between the Division of Applied Mathematics in the Graduate School and the department's predecessor, the Program of Advanced Instruction and Research in Mechanics in 1940, could not have been greater. The Brown of 1940 still remained a traditional college, only having just inaugurated its graduate program a few years ago. Their research output was minimal, and the focus was on providing a liberal arts education rather than on actively promoting research. Brown—six, ten, and many—years later, was by contrast a well-known research university, at the fore of directing the field of applied mathematics and committed to supporting research. They helped push forward a new value in researching not just the "pure" aspects of the sciences and mathematics, but also the "applied."

Mid-twentieth-century Brown University, and the rest of America for that matter, was crisscrossed with intersecting disciplines and industrial interests: techno-practical engineering, abstract mathematics, communication networks, and industrial defense that all converged into the Division of Applied Mathematics at Brown University. In this context, the department introduced by Richardson, Prager, and Wriston, was a leading academic influence. If anyone of that time could explain the significance of the program and its mathematical output, it was Prager. In 1978 he mused: "While the Applied Mathematics Group at Brown University worked on numerous problems suggested by the military services, I believe that its essential service to American Mathematics was to help in making Applied Mathematics respectable in the U.S."[229] Prager, Richardson, Wriston, and other applied mathematics enthusiasts had constructed the discipline of applied mathematics out of a material, technological world.

[229] William Prager, in Rees, "The Mathematical Sciences and World War II," 612.

CONCLUSION

By September 1950, applied mathematics was no longer a shunned, obscure discipline. No longer could Brown's Division of Applied Mathematics' faculty be breezily dismissed by pure mathematicians and solely be perceived as a less rigorous discipline. Instead, applied mathematics became highly valued. Prager plowed through problems of classical mechanics and partial differential equations, at times considering issues of a more concrete nature. Other researchers entered the debate over the possibility of sending a man into space. The National Science Foundation continued to provide grants for professors' projects.

Brown's Division of Applied Mathematics' faculty was actively engaged in the circles of physicists, mathematicians, industry, and government, and the correspondences reflected it. 6 January 1950, Hungarian mathematician John von Neumann, who had been a principal member in the Manhattan Project, personally wrote to William Prager, requesting that he "deliver a special address" for the "Conference on Applied Mathematics and Mathematical Physics at the 1950 International Congress of Mathematics."[230] From every corner, esteemed mathematicians sought out the services of Brown's distinguished applied mathematicians.

Prager accepted von Neumann's request swiftly. Flattered, he wrote, "Thank you very much for your kind letter, especially when so many able men surround you. I gladly accept this invitation and very tall assignment."[231] As reflected in Prager's humble reply, applied

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[230] John von Neumann to William Prager, 6 January 1950, Courant Papers, 13, Bobst Library, New York University.
[231] William Prager to John von Neumann, 20 January 1950, Courant Papers, 13, Bobst Library, New York University.

mathematicians did not isolate themselves to an ivory tower. Various occupations required the uses of applied mathematics—analytical, technical, and practical. Mathematics was now well suited to the services of other disciplines and occupations demanding it, whether aviation, economic theory, money allocation, or management. Scholars abandoned their previous bias against applied mathematics, delving into a new world of mathematics rarely explored before. The advent of computers and other forms of telecommunication became an indispensable real-world playground for the enormous breakthrough of applied mathematics in America.

Applied mathematics was by no means derivative, nor can it be dismissed from the place and time of its development. As Richardson and Prager established an applied mathematics department, Brown prospered as a growing research university intimately connected to industry and the government. Funding was no longer to be separate from the university, but tied to federal funding, government grants, and generous contracts from industries. Creating this standardized, procedural relationship was a monumental project that utilized the wartime environment: applied mathematics and its institutionalization at Brown. Professors like Prager aimed for an engaged mathematics that could speak to, on the one hand, students attempting to mathematically model their surroundings, and on the other, scientists, entrepreneurs and bureaucrats struggling to improve America's economy and technology.

Acknowledging the influence of their environment, Richardson and Prager mused over the future and their experiences during World War II. One of their more fitting characterizations of applied mathematics' place in society was a comment Prager remembered Richardson once making towards the end of the war: "The last war [World War I] was a chemists' war. The next war, if we have one, will be a mathematicians' war."[232] Those specific instances—of war, education, and technology—in history bathed the world in an expanding sphere of applied mathematics that paved the way for telecommunications and the computer age.

A Mathematized World

Looking back on American applied mathematics in December 1989, mathematician Peter Lax, one of the next generation of applied mathematicians who came after Prager, Courant, and von Kármán, praised the "remarkable group of [applied mathematical] immigrants" who used their mathematical ideas and skills to bring "a greater affinity for applications of mathematics to physics and engineering [in America]."[233] "This group brought to these [American] shores outlooks and styles that were radically different," Lax judged, "from the purity then prevailing."[234] For Lax, it was the mathematical innovation and ideas of European immigrants that had led academics like Brown's Richardson and Wriston to seek to develop applied mathematics. By Lax's lights, these applied mathematicians—von Kármán, Courant, and Prager—were intellectual geniuses.

Lax's diagnosis, however, is far too narrow. I would argue that mathematical ideas were not the main forces that led to Brown University's Division of Applied Mathematics. Certainly such ideas influenced the research of the department and the topics taught in the curriculum. But if anything, outside the library, mathematical books, and offices of professors lay industrial and technological problems to be tackled. Airliners wanted safer and more efficient planes, state

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[232] William Prager, Interview by Jay Barry, 6 November 1968, Brown University Archives, William Prager File, John Hay Library, Providence, Rhode Island.
[233] Peter Lax, "The Flowering of Applied Mathematics in America," *SIAM Review* 31:4 (December 1989): 538.
[234] Ibid.

authorities wanted to reduce traffic jams, and economists wanted to figure out the most rational way to allocate money to the military, education, and housing. The respect for Brown's department came from the outside authorities seeking to employ these learning applied mathematicians. Leaders of Brown University, primarily Wriston and Richardson, aimed directly towards improving the image of their university as well. It was about coordinating the various languages of math and business and praxis.

Far more important is to situate Brown's applied mathematics department at a turning point in the history of the twentieth century, when disciplines merged and communicated with each other and those outside their professions. Systematization of applied mathematics was the priority of the day, for both mathematician and administrator. An inadequate curriculum for the discipline revealed itself in the industrial problems and economic problems of the government. In the first few sessions of the program, Prager and Richardson supervised instruction, seeking to make it ever more distinct from related fields like engineering. Teams of itinerant observers worked together incessantly to formulate a community and research journal accessible to anyone. Researchers delved into war-related issues and into the most mundane activities.

Creating this systematized, procedural instruction of applied mathematics was a monumental project that utilized the practicalities of engineering and the abstract thought of mathematics. As a result, applied mathematics never inhabited a place isolated from industrial policy, scientific lobbying, or political advocacy. It would ease matters if we could attribute the mid-twentieth-century push towards applied mathematics to a single drive-wheel: if we could say that it all came down ultimately to the genius of mathematical theories themselves. But that reasoning to justify the establishment of Brown's department was not that simple.

For the department, the modern technology of aeronautics and the economy was not external to mathematical investigations and developments—not a context that from the rigidity of numbers shaped, influenced, or distorted thought. Students, and the department, were a product of a world where the material and the abstract shaped one another at every moment. What emerged in the 1940s was not merely a reordering intellectual dominance. Instead, the establishment of Brown University's Division of Applied Mathematics represented a shift in the priorities of university education: instructing students while having an increased role in producing seminal technology. Circles of such a wide-spanning technologies pulled each other along. Technologies required people to use it, mobilizing people required theory, and theory required equations.

Looking Forward, Looking Back

Times changed. Prager resigned as Chairman of the Department in 1954 to focus on his own research and teaching duties. That same year, an undergraduate curriculum leading to the Bachelor of Science degree in applied mathematics was instituted. Throughout the latter half of the twentieth century, applied mathematics grew. Between the years 1940 and 1974, Prager advised a combination of 178 student dissertations, master's theses, and undergraduate honors theses.[235] More advanced mathematical topics paved the way to expand the use of applied mathematics use. What had once been taught in applied mathematics in the 1940s, primarily the classical mechanics topics of thermodynamics and aeronautics, expanded to include probability and statistics. After so many years of campaigning for applied mathematics, Prager, Richardson,

[235] "Theses Prager Advised," Brown University Archives, William Prager File, John Hay Library, Providence, Rhode Island.

and many other advocates witnessed higher education's embrace of the discipline. Brown University set the standard of how applied mathematics would be taught.

When Prager arrived to take up his position at Brown University in 1941, he entered an institution in which the success of inaugurating an applied mathematics curriculum was already symbolically tied to visions of expanding a university. Here systematizing a discipline was a practical problem demanding funding, career options and workable problems. In a time of war, the faculty of the Program of Advanced Instruction and Research in Mechanics seized upon the opportunities provided by industry and government. At the same time, they strove to make their discipline distinct from neighboring subjects such as physics and engineering.

My aim in this thesis has been to reconsider the "internalist" narratives that so often structure the history of mathematics and the history of institutions. In analyzing the development of Brown's Division of Applied Mathematics within an extra-mathematical context, while still maintaining an "internalist" narrative, not only do we see the influence of ideas, programs, and scientific instruments, but also the sway of applied mathematicians' and administrators' interactions with groups—especially government and industry—outside the intellectual sphere. Prager, even Richardson with his mathematical background, would be portrayed by "internalist" historians who have briefly considered the growth of American applied mathematics as the mathematical innovator and pioneer who developed applied mathematics in a sustained drive for practicality and scholarly respect. There is much validity to reading this sort of history,—for reading history with "internalist" lens exposes those moments when Brown researchers built upon each other's theories. However, my intention here is not to think of history as solely just about mathematical ideas, but also to situate it within the greater cultural world of university education and technology. This history has served to expand our understanding of Brown University as a whole.

As important as the wartime environment was to stimulating applied mathematical activity situated at Brown from 1941 to 1946, it was more crucial to create a foundational system that would continue beyond the war. For Prager it was the formation of an applied mathematical community consolidated together in a separate department with publication outlets of its own. Additionally, this new class of applied mathematicians, produced from Brown's curriculum, could look to industry and government for consultation jobs and contracts. Tacit echoes of the department's legacy at Brown can be seen today. Recently Brown University established a $15.5 million National Science Foundation-funded Mathematics Institute. In a new age requiring higher computation abilities and ever more rigorous background in mathematics, we find a new age for applied mathematics. This opportunity would probably not have been possible for Brown University if not for its early, pioneering commitment to applied mathematics.

BIBLIOGRAPHY

Primary Sources

Archival Sources

Brown University Archives, John Hay Library, Providence, Rhode Island:
Division of Applied Mathematics
President's Papers—Henry Wriston
Richardson Papers
William Prager File
Caltech (California Institute of Technology) Archives, Pasadena, California:
Theodore von Kármán Collection
Bobst Library, New York University, New York City:
Courant Papers

Books, Mathematical Publications, and Reports

Archibald, Raymond Clare. "R.G.D. Richardson, 1878-1949." *Bulletin of the American Mathematical Society* 56:3 (1950); 256-265.

Bush, Vannevar. "Science: The Endless Frontier." Washington: United States Government Printing Office, 1945.

Fry, Thornton. *Elementary Differential Equations*. New York, NY: D. Van Nostrand Company, 1929.

Fry, Thornton. "Industrial Mathematics." *The American Mathematical Monthly* 58:6 (June 1941): 1-38.

Hardy, Godfrey H. *A Mathematician's Apology*. Cambridge, MA: Cambridge University Press, 1992.

Herzberger, Max. "A Direct Image Error Theory." *Quarterly of Applied Mathematics*, 1:1 (1943): 69-77.

National Research Council. *Research: A National Resource*. Washington, D.C.: Government Printing Office, 1941.

Prager, William. "The Graduate Division of Applied Mathematics at Brown University." In *Proceedings of a Conference on Training in Applied Mathematics*. New York, NY: Columbia University Press, 1953.

Prager, William. *Quarterly of Applied Mathematics* 1:3 (October 1943).

Prager, William. *Quarterly of Applied Mathematics* 30:1 (1972): 1-5.

Prager, William. *Theory of Plasticity*. Providence, RI: 1942.

"Program of Advanced Instruction and Research in Mechanics." *Bulletin of Brown University* XL: 8 (November 1943).

Richardson, R.G.D. "Advanced instruction and research in mathematics." *American Journal of Physics* 11 (1943): 67-73.

Newspaper Articles

"110 Take Advanced Mechanics Course." *Brown Daily Herald*, 24 June 1942.

"Glee Club will Try Out Vocal Aspirants Today, Tomorrow." *Brown Daily Herald*, 2 October 1941.

"IGB Meets to Make Plans Today." *Brown Daily Herald*, 2 October 1941.

"Seventy-Three Given Degrees in Graduate School on Sunday," *Brown Daily Herald*, 16 June 1930.

"U.S.'s First Applied Mechanics Program to Begin Here Today." *Brown Daily Herald*, 2 October 1941.

Secondary Sources

Bayart, Denis and Pierre Crépel. "Statistical Control of Manufacture." In *History and Philosophy of the Mathematical Sciences Volume 2*, edited by I. Grattan-Guiness. Baltimore, MD: Johns Hopkins University Press, 1994.

Calinger, Ronald, ed. *Vita Mathematica: Historical Research and Integration with Teaching*. Washington D.C.: Mathematical Association of America, 1996.

Cheng, S.Y. and Tao Tang, eds. *Recent Advances in Scientific Computing and Partial Differential Equations*. Providence, RI: American Mathematical Society, 2003.

Cole, Jonathan R. *The Great American University: Its Rise to Preeminence, Its Indispensable National Role, Why it Must be Protected*. New York, NY: PublicAffairs, 2009.

Dahan Dalmedico, Amy. "L'essor des mathématiques appliquées aux États-Unis: l'impact de la Seconde Guerre mondiale." *Revue d'histoire des mathématiques* 2 (1996): 149-213.

Davis, Philip J. and Reuben Hersh. *The Mathematical Experience*. Boston, MA: Birkhäuser Boston, 1981.

Fagen, M.D., ed. *A History of Engineering and Science in the Bell System: Volume 1 The Early Years (1875-1925)*. New York, NY: The [Bell Telephone] Laboratories, 1975.

Fermi, Laura. *Illustrious Immigrants: The Intellectual Migration from Europe 1930-41*. Chicago, IL: University of Chicago Press, 1968.

Goodstein, Judith R. and John L. Greenberg. "Theodore von Kármán and Applied Mathematics in America." *Science* 222: 4630 (1983): 1300-1304.

Goodstein, Judith R. and John L. Greenberg. "Theodore von Kármán and the Arrival of Applied Mathematics in the United States, 1930-1940." Pasadena, CA: 1983.

Hallion, Richard P. *Legacy of Flight: The Guggenheim Contribution to American Aviation*. Seattle, WA: University of Washington Press, 1977.

Hanle, Paul. *Bringing Aerodynamics to America*. Boston, MA: MIT Press, 1982.

Hunter, P.W. "An Unofficial Community: American Mathematical Statisticians Before 1935." *Annals of Science* 56 (1999): 47-68.

Kármán, Theodore von. *The Wind and Beyond: Theodore von Kármán, Pioneer in Aviation and Pathfinder in Space*. Boston, MA: Little Brown and Company, 1967.

Kjeldsen, Tinne Hoff. “New Mathematical Disciplines and Research in the Wake of World War II.” In *Mathematics and War*, edited by Bernhelm Boos-Bavnbek and Jens Hoyrup, 126-152. Basel, Switzerland: Birkhäuser Verlag, 2003.

Kline, Morris. *Mathematics: The Lost of Certainty*. New York, NY: Oxford University Press, 1980.

Lardner, Harold. “The Origin of Operational Research.” In *Operations Research ’78*. Proceedings of the Eighth IFORS International Conference on Operational Research, edited by K.B. Haley. Amsterdam: North-Holland Publishing Company, 1979.

Lax, Peter D. “The Flowering of Applied Mathematics in America.” *Siam Review* 31: 4 (December 1989): 533-541.

Layton, Edward T. *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession*. Baltimore, MD: Johns Hopkins University Press, 1986.

Lomask, Milton. *A Minor Miracle: An Informal History of the National Science Foundation*. Washington, D.C.: National Science Foundation, 1975.

McClelland, Charles E. *State, Society, and University in Germany 1700-1914*. Cambridge, England: Cambridge University Press, 1980.

Newell, G.F. “Memoirs on Highway Traffic Flow Theory in the 1950s.” *Operations Research* 50:1 (January 2002): 173-178.

Parshall, Karen H. and David E. Rowe. *The Emergence of the American Mathematical Research Community, 1876-1900: J.J. Sylvester, Felix Klein, and E.H. Moore*. Providence, RI: American Mathematical Society, 1994.

Price, G. Baley. In *A Century of Mathematics in America*. Edited by Peter Duren. Providence, RI: American Mathematical Society, 1988.

Rees, Mina. “The Mathematical Sciences and World War II.” *The American Mathematical Monthly* 87:8 (October 1980): 607-621.

Reid, Constance. *Courant in Göttingen and New York: The Story of an Improbable Mathematician*. New York, NY: Springer-Verlag, 1976.

Reingold, Nathan. “Refugee Mathematicians in the United States of America.” *Annal of Science* 38 (1981): 313-338.

Rosenhead, Jonathan. “Operational Research on the Crossroads: Cecil Gordon and the Development of Post-war OR.” *Journal of the Operational Research Society* 40 (1989): 3-28.

Rustagi, Jagdish S. *Variational Methods in Statistics*. New York, NY: Academic Press, 1976.

Siegmund-Schultze, Reinhard. “The Emancipation of Mathematical Research Publishing in the United States from German Dominance (1878-1945).” *Historia Mathematica* 24 (1997): 135-166.

Siegmund-Schultze, Reinhard. *Mathematicians Fleeing from Nazi Germany: Individual Fates and Global Impact*. Princeton, NJ: Princeton University Press, 2009.

Siegmund-Schultze, Reinhard. “Military Work in Mathematics 1914-1945: an Attempt at an International Perspective.” In *Mathematics and War*, edited by Bernhelm Boos-Bavnbek and Jens Hoyrup, 23-82. Basel, Switzerland: Birkhäuser Verlag, 2003.

Siegmund-Schultze, Reinhard. *Rockefeller and the Internationalization of Mathematics Between the Two World Wars*. Boston, Germany: Birkhäuser Verlag, 2001.

Stolz, Michael. “The History of Applied Mathematics and the History of Society.” *Synthese* 133 (2002): 43-57.

Walsh, J.L., “History of the Riemann Mapping Theorem.” *The American Mathematical Monthly* 80:3 (March 1973): 270-276.

Walter, Scott. “Minkowski, Mathematicians, and the Mathematical Theory of Relativity.” In *The Expanding Worlds of General Relativity*. Vol. 7 of the *Einstein Series*, edited by Hubert Goemner, 45-86. Boston, MA: Birkhäuser, 1999, p. 47.

With, Gijsbertus de. *Structure, Deformation and Integrity of Materials*. Weinhelm, Germany: Wiley-VCH, 2006.