HISTORY OF HEAT TRANSFER

ESSAYS IN HONOR OF THE 50th ANNIVERSARY OF THE ASME HEAT TRANSFER DIVISION

edited by

EDWIN T. LAYTON, JR.

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PREFACE

"Energy is pure delight"

William Blake

The history of heat transfer should be a major chapter in the history of the latter-day development of energy; but so far that chapter has hardly been written. Since the late 18th century, our world has been reshaped by enormous increases of energy production. This happened once before, when Western civilization was put in motion by the serious energy production that began in the Middle Ages.

Yet the history of technology, and with it the history of power production, was seriously neglected until rather recently. "History is past politics." said the historian, Walter Bagehot; and with few exceptions that is how history was written before this century. The late historian of Medieval technology, Lynn White (1978)[1], was among the first to clearly identify the Medieval power revolution; and he archly remarked that before 1931 Medieval technology had no history. He meant that the history of Medieval technology (like that of heat transfer today) had been largely unrecorded until then. In particular, the enormous advances of Western power technology between the 10th and 13th centuries remained almost invisible until 1931.

The year 1931 was, for White, the annus mirabilis of the study of Medieval technology. It yielded three new books by Medieval historians who had looked beyond the accounts written by the scribes of kings and gone to anthropological records. In 1931 it first began to come clear that anonymous craftsmen had wrought stunning changes in the quality of Medieval life -- changes that kings had taken for granted -- changes that their chroniclers had not deemed worth mentioning.

It was White, more than anyone, who discovered the magnitude of the power revolution that so profoundly changed the lot of humankind in the Middle Ages. The invention of the horse collar and the windmill, along with

[1]White, L., Jr., 1978, Medieval Religion and Technology, University of California Press, Berkeley, Preface

the wholescale exploitation of the water wheel, expanded human power output a hundredfold. In 1086 AD, the conquering Normans took stock of English water wheels in the Domesday book. They counted 5624 of them where there had been virtually none, a few centuries earlier.

Of course, power production continued to increase down through the centuries; but in the 18th century it began its second really radical expansion. Practical steam engines came into being at the end of the 17th century and were transformed into something approaching modern form by James Watt during the end of the 18th century. Watt's partner, Matthew Boulton, reflected 18th century thinking when -- only half in jest -- he told Samuel Johnson's biographer, James Boswell, "I sell here, Sir, what all the world desires to have, power."

Table 1 indicates roughly what these two energy revolutions achieved. These numbers are subject to large variations, of course. But they make it clear that, if the Medieval period saw hundred-fold increases in power, the last 200 years have seen something like a million fold increase.

Table 1 Some Typical Values of Available Power

Power source	Date introduced	Typical power output
Man	----------	0.05 HP
Farm horse	9th C	0.3 HP
Water wheel	10th C	3 HP
Windmill	11th C	5 HP
Steam engine	early 18th C	12 HP
Steam power	20th C	up to 3,500,000 HP

The increase of power production during the past 200 years has been accompanied by unceasing problems involving heat flow. Watt's first patent (of the external condenser) provided means for eliminating a wasteful transient heat transfer process. From that patent to the invention of superconductors, heat flow has been a critically important issue in our power-based world. Some have argued that today's world is information-based; but that world also presents a stunning array of electronic cooling problems.

Yet the history of this aspect of our world has hardly been told. Historians of science lose interest after the grand contributions of Fourier, Maxwell, and Planck. Historians of technology have been content to look at the grand power-producing machines, without looking at this part of the intellectual hisotry associated with modern power technology.

Heat transfer, of course, has owned its place within the American Society of Mechanical Engineering since the 1930's. Now, as we observe the 50th anniversary of its recognition within ASME, we have the opportunity to challenge historians to start looking seriously at the history of the problem of manipulating energy, as well as at the mere history of the effects of energy. And we hope that some of these historians will prove to be engineers within the Heat Transfer Division.

We begin our look at the history of heat transfer with an account of the ASME Heat Transfer Division. We learn that a small band of hard-working, energetic, and supremely optimistic Chemical and Mechanical engineers picked the subject up in the 1930's. In a spirit of "pure delight" they plumbed it capabilities and worked magic with their new-found techniques.

Part II of this collection is made up of articles describing the scientific origins of our subject -- the discoveries of the way energy-in-transition behaves. Part III is a collection of memoirs and biographies of some of the great 20th century contributors to the field. (In addition to the memoirs listed in the Contents, Prof. S. Ostrach is to present an account of his early work on free convection, at the meeting.) These are followed in Part IV with several accounts of the assimilation of the subject into engineering practice. We conclude with a broad bibliographic review of source literature for subsequent scholars.

The result has been enormously stimulating for us. It has let us see this field in a large historical context for the first time. The excitement of those who have contributed both articles and background material has been contagious. The authors of this volume have illuminated us, and taught us so much that we did not know when we began.

We have come away greatly encouraged about the vitality of the field. We hope that reliving the animus of our early contributors, might help reclaim that zeal for today's workers.

White began his collection of essays by saying that, as a result of historical exposure,

> "The Middle Ages are not what they used to be.
> Indeed, they have changed almost beyond recognition..."

If this modest step toward creating a history of heat transfer succeeds, subsequent historians will expand upon and complete the themes that the authors have stated here. If it succeeds, perhaps 21st century historians will likewise be able to say,

> "Heat transfer is not what it used to be."

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Historical Source Material

A HISTORY OF THE HEAT TRANSFER DIVISION

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"What good is a new born baby?"
Benjamin Franklin

The ASME Heat Transfer Division originated in the formation of an ASME Heat Transfer Professional Group in 1938. This Group became a regular Division of ASME three years later. We trace the history of the Division and its antecedents in an attempt to see our work whole. In doing so we have been greatly helped by two unpublished works: H.B. Nottage's (1968) 30-year review, and S.P. Kezios' (1980) 42-year review, of the Division's history. We have also received wonderful cooperation from many heat transfer people who have been a part of our history. Their help is not all acknowledged or reported explicitly; but it is a real presence in this account.

I PRECURSORS

The new subject of heat transfer was established as an important scientific branch of heat engineering just after the turn of the twentieth century. The foundations of heat transfer were laid by some of the ablest scientists and engineers in Britain and France during the latter 18th century and throughout the 19th century.

But in the earlier 18th century, the observations of Joseph Black, Benjamin Thompson, Benjamin Franklin, and others had formed our insights into heat flow behavior. The Scottish chemist, Joseph Black (1803) gave us latent and specific heats, but he also provided accurate descriptions of many heat transfer phenomena. Benjamin Thompson (see, e.g., Brown (1979)) was the renegade American who became Count Rumford, and who is best known for the cannon-boring experiments which helped to establish the mechanical theory of heat. But in several other experiments, he made important qualitative observations of natural convection.

Benjamin Franklin provided us with a remarkably early observation of the relative solar reflectivity of cloths. Sometime in the 1730's, either Franklin or his associate, Joseph Breintnal, laid cloth patches of various colors out on the snow and observed the depth to which each sank as the sun shown upon them (see, e.g., Cohen (1943).) They concluded that the lighter the color was, the better the cloth reflected the sun's rays.

Commenting on these experiments, Franklin says, "What signifies Philosophy that does not apply to some Use? May we not learn from hence that black Clothes are not so fit to wear in a hot Sunny climate or Season, as white ones." This is the same Franklin who had something quite different to say as he watched a balloon ascent in France a half century later. Asked what good these ascents were, he replied, "What good is a new born baby?" Franklin, it would seem, came at last to understand the essential tension that we feel in our subject today -- the tension between the pursuit of purpose and the pursuit of pure understanding.

These 18th century phenomenologist gave us the insights so necessary to a new subject. But in the final analysis, one cannot avoid crediting Joseph Fourier with originating the modern <u>science</u> of heat transfer. His mathematical method for analyzing heat conduction provided us with our first predictive heat transfer theory. Forty years later the Englishman, James Clerk Maxwell completed Fourier's theory by supplying the theoretical basis for predicting the transport coefficients neded in the theory.

We find the same flow of ideas from France to England in the development of fluid mechanics. The French engineering theorists C.L.M.H. Navier and S.D. Poisson erected the basic analytical apparatus used by the Englishman, G.G. Stokes, to develop equations for viscous fluid flow in their modern form. This, in turn, paved the way for analyses of convection starting in the late 19th century.

It was in the late 1800's that Germany began to assume a position of leadership in science and engineering. German leadership owed a great deal to the German system of Technische Hochschulen. A particularly important heat transfer center was the laboratory of "technical physics" (What we would call "Applied physics") set up by Oskar Knoblauch near the beginning of this century at Munich. Knoblauch numbered Wilhelm Nusselt, Ernst Schmidt, and Max Jakob among his students.

The University at Göttingen became another major center of engineering and physical theory. The famous mathematician, Felix Klein, seeing too great a gulf between the applied and pure sciences, was influential in creating a series of technical institutes at Göttingen. In 1904 he accepted August Föppl's recommendation that his student, Ludwig Prandtl, be given charge of the Institute for Technical Physics there (see, e.g., Lienhard (1975).) Later that very year Klein was delighted when his new professor presented a remarkable paper at the Third International Congress of Mathematicians at Heidelberg. The title of the paper was "Uber Flüssigkeits-Bewegung bei sehr kleiner Reibung." ("On Fluid Motion with Very Little Friction.") In it, Prandtl showed that viscous drag was usually isolated in a thin layer next to a body moving through a fluid. The thinness of this region in which the liquid velocity changed from that of the body to that of the exterior flow, simplified the mathematics and made it posible to predict the flow. Thus Klien's efforts paid off as Prandtl gave us the boundary layer concept. Göttingen had immediately produced the major fluid mechanical revolution of this century and its prophet as well.

These institutes made a fertile ground for the new discipline of heat transfer, as for well fluid mechanics, since they wed engineering to the applied sciences. For some 25 years, the German academic establishment laid the foundations of heat transfer with great energy and spirit. This steady advance of German science and engineering was halted by Hitler and his National Socialists, who brought Germany, along with its scientists and engineers to the brink of total ruin by the end of WW-II.

However, during the 1920's and 30's, the German advances were accompanied by the exportation of subject of heat transfer. In the 1930's and 1940's this exportation was broadened to include some of the key German heat transfer people as well. The 1920's and 30's saw a rapidly rising interest in "technical heat transfer" within several of the more enlightened universities and industries in the United States. These trends made it clear to many American mechanical engineers, well before 1938, that their organization must do something to focus interest on this important new subject.

But the United States was ill-equipped to make heat transfer into a serious scientific inquiry in the early 20th century. While Germany led the integration of scientific research into engineering, we danced to very different drum in 1900. Our ideal was the practical inventor/engineer -- the Edison role-model.

Changes were nevertheless afoot. Even in the late 19th century, Johns Hopkins, Cornell, and Stanford were developing research orientations in the German mold. Robert Thurston, a founder of ASME and its first president, was also a pioneer in creating laboratories associated with mechanical engineering departments -- first at Steven's Institute and then at Cornell.

These were followed by another uniquely American institution, the land grant university. Under the Morrill act, each state was granted land to set up a university whose "leading object" was to educate the citizenry in "agriculture and the mechanical arts." These universities were natural heirs to the technische hochschule concept; and by the early 20th century vigorous traditions of engineering research emerged in several land grant colleges. This work was supplemented by the growth of engineering at traditional universities and the new institutes of technology. By 1950, M.I.T., for example, had become a research giant that had clearly surpassed its old-world prototypes.

II. HEAT TRANSFER IN THE EARLY DAYS OF ASME

The American Society of Mechanical Engineers was founded in 1880, 58 years before the Heat Transfer Division was begun. Only eight heat transfer papers were published during the first thirty-three years of the society's existence. Table 1 lists them all, since they display the character of the subject during this time. The titles suggest their lack of sophistication, and the papers themselves are pretty rudimentary. Few, for example, even use the concept of thermal conductivity.

The subject of thermal power, of course, was a major concern during the first third-century of the ASME, and while much is said about heat flow in other Transactions papers, it is only treated as a thermodynamic difference term. Very little was known about the mechanisms of heat flow, and the subject remained an unknown territory, even for investigators of machinery that depended upon heat transfer processes. It was an obscure research area within the pragmatic field of mechanical enginering.

The ASME was nevertheless quick to see that research would be needed to fulfill its objectives. As early as 1909 it established a Standing Committee on Research. Of course one might question how strong ASME's initial committment was. According to Nottage the Society logged the lordly expenditure of $0.58 for the business of that committee in 1909. It is worth noting that this was only two years after the establishment of the first ASME technical division in 1907 -- the Gas Power Division. The Gas Power Division was followed by many other divisions, all of which had titles that identified them with the major technologies and industries of the day: steam power, petroleum, railroads, machine shops, and so on to the smallest, the "Printing Industries Division."

Table 1 A complete List of the Heat Transfer Papers Published During the First 32 Years of the Transactions of the ASME

Emery, C.E. ,1881, "Experiments with Non-Conductors of Heat," Trans. ASME, Vol. 2, pp. 34-40.

Ordway, J.M. ,1884, 1885, "Experiments with Non-Conducting Coverings for Steam Pipes," Trans. ASME, Vol. 5, pp. 73-112, 212-215; Vol. 6, pp. 168-198.

Baldwin, W.J., 1886, "Notes on Comparative Values of Metal Surfaces for Warming Air," Trans. ASME, Vol. 7, pp. 361-374a.

Carpenter, R.C. ,1891, "Heat Transmission Through Cast-Iron Plates Pickled in Nitric Acid," Trans. ASME, Vol. 12, pp. 174-186.

Barrus, G.H. (1902) "Tests of Steam Pipe Coverings," Trans. ASME, Vol. 23, pp. 791-845.

Kent, W.,1903, "Heat Resistance, the Reciprocal Heat Conductivity," Trans. ASME, Vol. 24, pp. 278-285.

Wagner, F.C. ,1905, "The Transfer of Heat at High Temperatures," Trans. ASME, Vol. 26, pp. 594-607.

Orrok, G.A. ,1910, "The Transmission of Heat in Surface Condensation," Trans. AMSE, Vol. 32, pp. 1139-1214.

Our nagging need to know more about heat transfer mechanisms became apparent in the Research Committee from the start. In 1911, W.F. Goss, Chairman of the Research Sub-committee on Steam Devices, issued a report on the "present state of knowledge of the laws governing the transmission of heat through metallic turbes from gases and liquids to gases and liquids" in which he outlined this important research area in heat transfer.

George Orrok's 1910 paper (see Table 1) mirrored Goss's challenge with the first paper that took on any of the appearance of the modern subject. He devoted 75 pages to a thorough analysis of heat exchangers that included the use of an overall heat transfer coefficient and the development of a logarithmic mean temperature difference. He also reflected a clear understanding of the historical antecendents of our subject. His 48 references included the works of Poisson, Péclét, Joule, Kelvin, Reynolds, and Stanton. He did not mention any of the great German investigators since their efforts had not yet borne fruit.

It took 32 years to produce the first eight ASME heat transfer papers; but only after the eighth one -- only after Orrok's paper -- did heat transfer become a regular and rapidly expanding part of the intellectual life of the Transactions of the ASME.

Figure 1 shows the number of heat transfer papers published each year in the Transactions, before the separate Journal of Heat Transfer was begun in 1959[1] Orrok's paper clearly touched a nerve. In its wake, ASME heat transfer work begins in earnest -- Figure 1 makes it clear that, after 1911, "the game is afoot!"

III EVENTS LEADING TO THE FORMATION OF THE HEAT TRANSFER

The astronomer, George Ellery Hale, was an early champion of research in the United States during the early 20th century. He sought to enlarge the National Academy of Sciences by admitting engineers and by making it a champion of research across a broad front of scientific disciplines. He created a major opportunity for influencing American scientific development by founding the National Research Council (NRC) in 1916, just before we entered WW-I. The NRC was made permanent by President Wilson's executive order in 1918, and it was housed with the ASME in the Engineering Societies Building in New York.

Since they were located in the same building, the ASME Council offered the services of its Research Committee to the NRC in 1920. In that offer the ASME identified heat transfer as one of its established research areas. When the NRC established its own Committee on Heat Transmission in 1923-24, Willis Carrier -- the great pioneer of air conditioning and founder of the Carrier Corporation as well as a strong ASME contributor in the field of heat and mass transfer -- was made its chairman.

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[1] It took many judgements to identify the "heat transfer" papers for Fig. 1. We include: physical property papers if they focus on thermal conductivity, diffusivity or emissivity; major discussions if they introduce new results and are published separately from the paper; papers on furnace performance if they introduce new results and are published separately from the paper; papers on furnace performance if they deal with radiation ab sorption; thermal stress papers if they involve solution of the heat diffusion equation; etc. Another person is unlikely to duplicate Fig. 1 precisely.

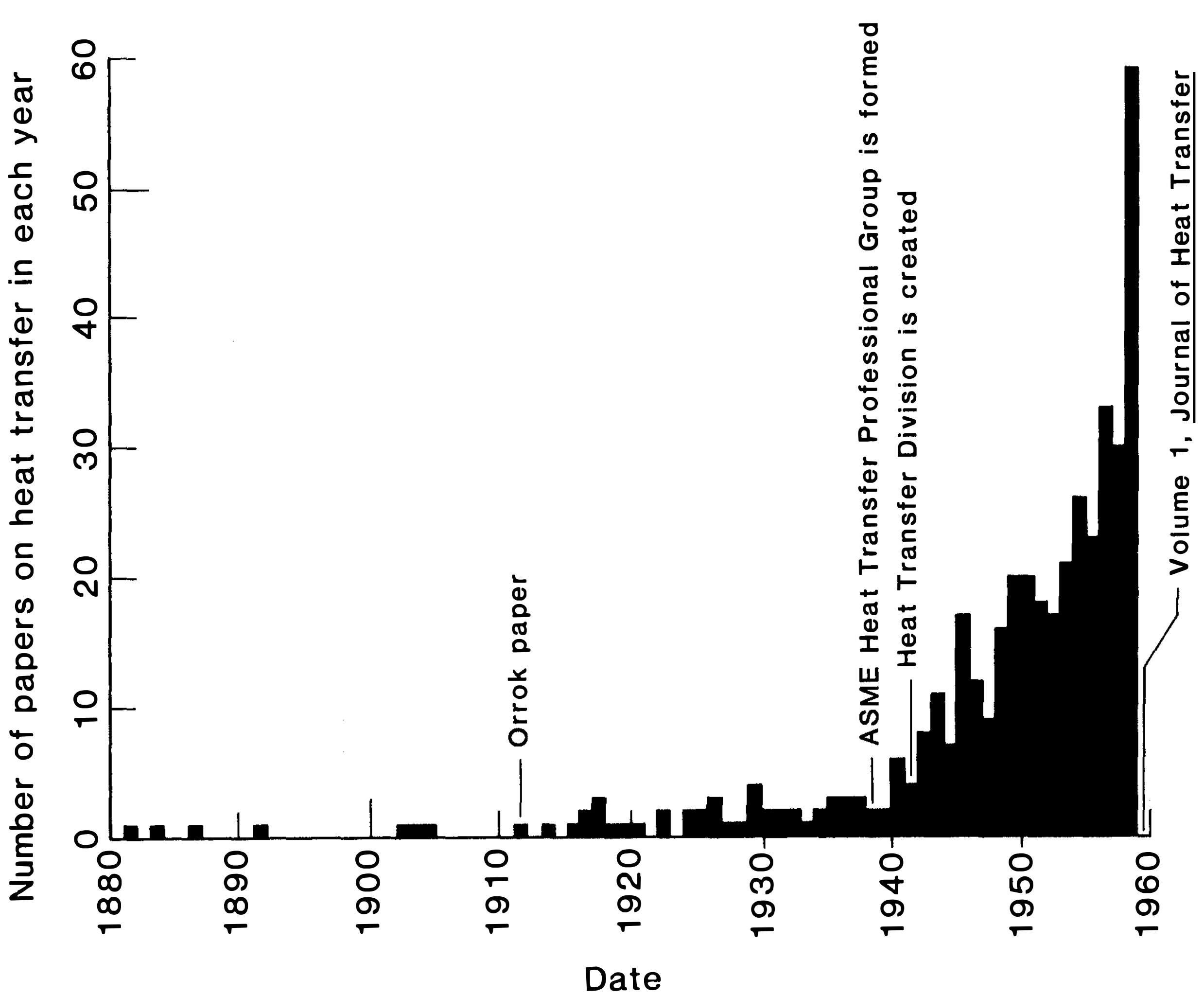

Fig. 1 The numbers of papers on heat transfer published each year in the Transactions of the ASME from the first volume in 1880 until the Journal of Heat Transfer was established as an independent journal in 1959.

In 1927 the NRC provided the Committee on Heat Transmission with a salaried Director, W.V.A. Kemp. Two years later, Kemp (1929) issued a report calling for heat transfer standards, meetings, research funding, and the preparation of two heat transfer texts, one of which was completed. That text was W.H. McAdam's (1933) first American heat transfer textbook. ASME heat transfer sessions were also initiated at regular meetings in 1933.

Many of the influential heat transfer activists at this time were, like McAdams, chemical engineers. Chemical and mechanical engineers were closely linked in those days. The American Institution of Chemical Engineers had not yet begun its spectacular post-war growth as a separate discipline, and the ASME provided the chemical engineers with its best forums for the study of heat transfer. An easy cooperation joined chemical and mechanical engineers; it joined theoretical, experimental, and applied activities; and it joined the universities and industry. These diverse people, all interested in opening up an exciting new field, were united by their common adventure.

Heat transfer in 1933 had an East Coast focus, and the subject was strongly driven by the needs of the East Coast process industries. McAdams brought this spirit to his book. It was a rich lode of data and empirical representations of those data. And yet McAdam's book was only published because the NRC had such confidence in the subject of heat transfer that they promised to cover any losses that McGraw-Hill might suffer. Nottage recalls a McGraw-Hill representative publicly saying of McAdams at the first National Heat Transfer Conference in 1957, "... and McGraw-Hill stands in the reflected glory of this man." McAdams took the podium and grumbled, "Hell, they didn't even want to publish the damn thing."

A second locus, younger and much more academic, was meanwhile taking shape in California. Under the leadership of L.M.K. Boelter (Then at the University of California at Berkeley) young faculty at Berkeley and Stanford (and soon at UCLA as well) read and synthesized the more theoretical German literature. They also read and organized the recent American work, and they transmuted the two influences into an American academic discipline. In 1932 a set of teaching notes by Boelter, V.H. Cherry, and H.A. Johnson (1965) summarized what they'd learned; but the tidal wave of published work created by the effort did not really become evident until a few years later, nor was it immediately reflected in the definition of heat transfer within the ASME.

The first grass-roots working heat transfer committee in ASME was formed in 1934 as a part of a new Process Industries Division of ASME. It borrowed leadership from the NRC heat transfer committee, and it immediately drove to create a wider representation of the heat transfer discipline within ASME. It certainly had cause to do so. Nottage recalls that when, in 1937, a heat transfer session was scheduled in a small room and a power session in a large room, the rooms had to be switched to accomodate the burgeoning interest in heat transfer.

Nottage is careful to identify the part that chemical engineers played in bringing pressure to bear on expanding the involvement of ASME in heat transfer during this period, for ASME was <u>their</u> forum in the subject as well as ours.

Table 2 C. Lucke's Committee Structure for an ASME Heat Transfer Division, as Proposed in 1934.

1	Thermophysical Properties
2	Fundamental Principles and Research
3	Heat Transfer In and Through Insulated-Wall Enclosures
4	Heat Transfer Processes Involving Vapor and Gas Mixtures with Condensation and Evaporation
5	Condensing and Evaporating Equipment
6	Fluid-to-Fluid Unfired Heat Exchanges
7	Combustion Furnace Heat Transfer and Equipment
8	Direct Fired "Low-Temperature" Solid heaters, Melters, and Energy Power Equipment
9	Direct Fired Fluid Heaters and Boilers of all Types
10	Direct Fired "High-Temperature" Solid and Gas Heaters, Kilns, and Material Processing Equipment

IV THE FORMATION OF THE HEAT TRANSFER DIVISION: 1937-1941

The first stage in forming a Heat Transfer Division within ASME took place at the 1937 Winter Annual Meeting. So many registrants indicated their interest in the subject of heat transfer at this meeting that it became clear to ASME it would have to form a Heat Transfer Professional Group within the Process Industries Division. That group was officially formed at the 1938 Summer Meeting.

It may seem odd that we trace our history to the formation of this professional group rather than to the formal establishment of the Heat Transfer Division itself. However, it was clear that this was the first step in splitting the Industrial Process Division into two divisions. Our subject now had an enormous momentum that would clearly not be denied. The formation of a separate division was not only invevitable, but it was actually planned to occur in 1940.

As it happens, the formation of the Division was delayed until 1941. Nottage argues that the delay was the result of neither disinterest nor resistance, but rather of pre-occupation. The subject of heat transfer itself was expanding like a blast front, and matters of organization were simply overwhelmed by the work at hand.

And forming the Professional Group into a division was, by then, almost an afterthought. The shape and form of the Division were solidly set by the time the Professional Group was formed in 1938. Nottage, for example, presents the proposed list of committees suggested for a heat transfer division by Charles Lucke as early as 1934. We reproduce this list in Table 2 since it so dramatically reflects similarities and differences in our thinking about heat transfer over the span of more than half a century.

V. THE AMERICANIZATION OF HEAT TRANSFER, IN THE 1930's AND 1940's

To understand the dynamism of the subject of heat transfer within ASME, we must look at the evolution of the subject immediately before and after the formation of the Division. We have seen that ASME was originally a gathering of engineers with very practical concerns and needs. Turn-of-the-centry German theory must have first seemed, to these people, to emerge from some distant ivory tower. Boelter's systematic effort to introduce this advanced material into the United States had originally caused him troubles. Tribus (1987) reports that Boelter was tagged with the nickname "heini" during WW-I and accused of being a German sympathizer for his trouble.

Yet he did more than anyone to bring us up to a modern understanding of heat transfer before the gathering clouds of Nazism began to deposit high-level German scholars on our shores. The first, of course, were Jewish refugees. Theodore von Kármán, whose wide-ranging work in fluid mechanics included important work in heat convection, came to M.I.T. as a visiting professor in the early 1930's and moved here permanently two years later. He was followed by Max Jakob who visited the United States in 1936, and came here permanently in 1937. Jakob joined the Illinois Institute of Technology, and consulted at the Armour Institute.

Jakob formed the first outpost of the German school of heat transfer here. After thirteen years, his carefully prepared lectures emerged in the form of a highly influential new textbook [Jakob (1949)] which he introduced with the words:

> "[I] allow ample space for the German literature of the 25 years before Hitler. Since obviously, German science has doomed itself for a long time to come, ... the earlier literature will not be accessible."

Jakob underestimated the way American specialists were struggling to learn what the Germans knew. His book gave us an important window into that knowledge. Yet, by then, he was actually the <u>second,</u> not the first, German scientist to open that window to a general American readership.

While Jakob worked in the late 1930's and early 1940's, a new breed of young men were being educated at such places as Berkeley, Stanford, and M.I.T. Many of these were young military officers during WW-II. These people found their way both to the salient heat transfer problems of the day and to the German experts in the United States. People like R.M. Drake, Jr., M. Tribus, A.L. London, and R.A. Seban pursued such problems as anti-icing, internal combustion, and these problems and they entrained the German-American specialists into these problems. As Fig. 1 shows, they were now expanding the heat transfer literature at such a rate as to double it every five years.

Then, as the Allies moved into Germany in 1945, they quickly recruited the best German scientists to work in the own countries. In the United States this program was called "Operation Paperclip." German scientists were brought here for two years and then offered citizenship or a return to Germany. Ernst Schmidt was first recruited under this program, but subsequently went to England instead. Our most notable "Paperclip" acquisition was E.R.G. Eckert who was brought to Wright-Patterson Air Force Base.

Eckert arrived with a copy of his brand new German heat transfer text in hand -- a surviving copy from a first printing that had largely been destroyed by allied bombings. R.M. Drake, Jr., then a young army captain, had been working on translations of two earlier German texts when he met Eckert and learned of his more up-to-date book. He immediately dropped the other two books to help Eckert translate this book into English. He also developed a table of physical properties to accompany it and arranged with McGraw-Hill to publish it. When it came out [Eckert (1946)] it provided us with our <u>first</u> direct window into the German school of heat transfer.

Jakob's book was initially the more influential of the two books because it was based on many years experience teaching in the United States. It was more accessible to our students. However, Eckert's book sparkled with more recent material. It revealed to us for the first time a variety of German wartime advances, particularly in the area of convective heating. And its last edition [Eckert and Drake (1972)] is still serving us.

But there was much more to establishing an American school of heat transfer than just German importation. It may be in vogue today to malign McAdams' first American heat transfer book for its lack of sophistication, but Tribus (1971) wrote:

> "McAdams always sought the 'correlation' and Boelter always sought the 'mechanism.' About a dozen years ago, I had dinner with McAdams, and he said to me, 'If I had to do it over again, I would do what Boelter did."
>
> When I told Boelter this, he replied in his characteristic manner, 'Bill should never feel that way. What he did in producing his book was absolutely essential to the development of heat transfer."
>
> I will give it as my professional judgement as one who has taught, researched, and designed in the field of heat transfer, that the two schools were indeed absolutely essential, each complementing the other".

And that is the strength of the American evolution of the subject in a nutshell. A new subject of heat transfer was born along with the Heat Transfer Division.

Boelter, Jakob, and Eckert brought German analysis to bear on the richly empirical foundation the process engineers had erected in America. Out of this tension emerged a synthesis -- a new subject that was a step stronger than it had been in either of the schools that had given it birth.

VI FROM THE BIRTH OF A DIVISION TO THE BIRTH OF A JOURNAL: 1938-1959

An odd recurring phrase in Nottage's prose is spirit essence. An early section of his paper is titled, "The Motivating Spirit-Essence," and he keeps coming back to that strange expression. It first seems over-dramatic -- excessive. But as his story unfolds, it becomes clear that he uses it to convey an excitement in those early days of the Division that he finds hard to express.

Table 3 lists the chairmen of the Heat Transfer Division, starting from the Heat Transfer Professional Group in 1938. It makes a fascinting gallery of the names that have established our field.. During the first fifteen years the Division (or Group) was chaired five times by Chemical Engineers. Nottage emphasizes that the Division pointedly drew non-ASME people into its committees and other business -- that it had had that kind of evangelical zeal.

The tradition of Heat Transfer Luncheons and later, banquets, began in 1943. They were organized by another heat transfer notable of the period, Florence "Flossy" Buckland. According to Nottage, "heat transfer ebullience...was so contagious that we didn't wish to interrupt our informal sharings." Her purpose was simply to keep lunch from getting in the way of conversation.

It was during this period that members of the Division began to flex their muscle and exert pressure on the society. The first demand was for centralization of publication, and it was backed up with a high standard of paper screening and evaluation. This led to organizing the heat transfer papers together in the Transactions, as well as in the Journal of Applied Mechanics, which by then had become the first separate ASME journal. The idea of creating a separate Journal of Heat Transfer was also clearly on the minds of a lot of people from the start. However, by 1945, the Transactions included a full symposium on heat transfer in fins (causing the spike in Fig. 1 for 1945) and the pressure for a separate journal was temporarily eased.

In fact, by 1944 some Division members wondered aloud whether it might be wise to split a separate "Society of Heat Transfer Engineers" away from ASME.

Table 3 Chairmen of the Heat Transfer Professional Group, and the Heat Transfer Division

1938 J.H. Sengstaken	1955 H.B. Nottage	1972 F. Landis
1939 T.B. Drew	1956 M. Tribus	1973 L.H. Back
1940 E.D. Drew	1957 S. Kopp	1974 R.J. Goldstein
1941 E.D. Grimison	1958 S.P. Kezios	1975 R.W. Graham
1942 T.B. Drew	1959 W.E. Hammond	1976 V.E. Schrock
1943 L.M.K. Boelter	1960 H. A. Johnson	1977 E. Fried
1944 W.S. Patterson	1961 W.M. Rohsenow	1978 F.W. Schmidt
1945 L.M.K. Boelter	1962 K.A. Gardner	1979 R.L. Webb
1946 R.H. Norris	1963 J.F. Wachunas	1980 C-l. Tien
1947 C.F. Kayan	1964 J.A. Clark	1981 A.F. Rathbun
1948 A.P. Colburn	1965 P.T. Vickers	1982 A.E. Bergles
1949 L.B. Schueler	1966 S. Ostrach	1983 R.J. Simoneau
1950 G.A. Hawkins	1967 S. Levy	1984 C.J. Cremers
1951 G.L. Truve	1968 T.F. Irvine, Jr.	1985 R.K. Shah
1952 A.C. Mueller	1969 S.J. Green	1986 J.R. Lloyd
1953 P.R. Trumpler	1970 R.A. Seban	1987 F.A. Kulacki
1954 H.B. Nottage	1971 W.H. Cook	1988 J.M. Chenoweth

Yet the division leadership held the view that it would be more effective for the Division to expand its autonomy without leaving ASME. In fact, Nottage (1945) wrote an anonymous Mechanical Engineering article in which he argued for such a role for the Division within ASME.

The two markers of autonomy for an identifiable professional group are a journal and technical meetings, and by the late 40's the pressure for an independent conference was rising. The first such meeting that actually came about was the first International heat transfer conference[2]. It was called the General Discussion on Heat Transfer, it took place in London in 1951, and it was jointly sponsored by the ASME and the British IME. The tradition of involving other societies in the international meetings was established at that meeting and it has continued ever since. ASME organization of this meeting was largely handled by A.C. Mueller, who became the Chairman of the Division the following year.

As it turns out, the Heat Transfer Division did not take the lead in creating its own conference. Other divisions did that first. Indeed, it is clear that Nottage, who chaired the Division in 1954 and 5, was more concerned with strengthening the

2 This was followed by the second international conference ten years later in Boulder, Colorado, by the third one five years later in Chicago, and by the fourth one four years later in Minsk. Since then, these conferences have followed a strict four-year rotation.

Division than separating it from the mother society. However, two events converged in 1957 to create a separate National Heat Transfer Conference and to give it its present shape and form.

Before 1957 the ASME had, for a long time, sponsored two technical conferences a year -- the Winter and Summer Annual Meetings. But, as other divisions began running their own Summer conferences, ASME decided that it was impractical to continue running two technical meetings a year. It charged the divisions with creating their own technical conferences and (by 1962) changed the Summer meeting into a business meeting. The second major change that occured was the formation of a Heat Transfer Division within AIChE. And who do you suppose was their first Division Chairman? It was none other than Al Mueller who had chaired the ASME Heat Transfer Division in 1952 and who had organized the first International Conference.

The long-standing ASME-AIChE cooperation was continued into this conference; and it has, from the start, been a joint effort between the two societies. Planning for the first meeting had gone on for 2-1/2 years at the hands of Tribus, Kezios, Nottage, and Kopp, among others, as well as George "Dusie" Dusinberre from Pennsylvania State University who served as Conference Chairman. Dusinberre arranged to hâve the meeting held at the Nittany Lion Inn at Penn State. The key organizers from the Chemical Engineering side were Alan Foust and, of course, Al Mueller.

The meeting was, by all reports, a splendid success. It was there that committees were set to plan the future National and International Conferences. It was there that McGraw-Hill celebrated the 25th anniversary of McAdams book as symbolic of the development of the Division itself. The mood of the meeting, according to Notttage, took more the form of a technical retreat than did subsequent meetings which were generally held in cities.

We turn next to the last major step turning the division into a full-fledged technical society within ASME -- the creation of the separate Journal of Heat Transfer. This was finally precipitated in 1958.

VII THE JOURNAL OF HEAT TRANSFER

Kezios reports that the Division appealed to ASME headquarters from as early as 1952 to create its own journal. However the ASME editor, George Stetson, and the Publications Committee, were unsympathetic. It became, in Kezios' words,

> "an annual ritual for the Chairman of the Division to meet with the editor at headquarters and plead the case for a publication identity for the HTD.

.....no one sensed the.....steady increase in the proportion of the total ASME journal-quality papers."

When Kezios made his 1958 pilgrimage to New York, he was armed with statistics showing that heat transfer papers had for five years occupied 25 percent of the Transactions. But two other factors had also come into play by this time.

In 1958 the ASME announced that the Transactions was to be split into four different journals. One was the Journal of Applied Mechanics which had long been bound as an independent journal within the Transactions. Separate journals for power and industry were also created. And all the remaining subjects now appeared within the last ASME generalist's journal, the Journal of Basic Engineering.

Kezios was at first dismayed by the news. It seemed to close the door on the possibility of creating a heat transfer journal. But then he realized that this was opportunity -- if four journals, then why not five! Then Kezios discovered the second factor that finally led to approval of the new journal. In New York (on his own out-of-pocket funds) he found a new ASME editor -- Jack Jacklitsch, who had replaced Stetson. With Jacklitsch's help, Kezios was able to persuade ASME leaders that the society had indeed overlooked the potential of the new Journal that the Division so badly wanted.

Yet one might be well advised to give the conservatism of the earlier editorial management its due. E.M. Sparrow (1987), under whose superb guidance the Journal flourished during the 1970's, says of the 1950's:

> ".....all mechanical engineering research was interwoven in one journal, the Transactions.....we felt ourselves part of the larger fraternity of mechanical engineers and not part of a special subgroup. The age of ultra-specialization not yet set in."

Indeed, a few years later, Lienhard wrote letters to Jacklitsch trying to convince him to preserve the Journal of Basic Engineering. But it was ultimately abolished in favor of several new divisional journals. These were doubtless needed, but we were left with no general subject-matter journal within the society.

We were then entering an era of high specialization, and a Society that had previously sought to retain its concentricity was now hurrying to subdivide itself. The time was right, and the new Journal of Heat Transfer came out in February, 1959.

News of the new journal was met with glee by the Division. Kezios says that when he announced the creation of the new journal at the first heat transfer session of the 1958 Winter Annual Meeting, Tribus leaped up with a triumphal shout. And he describes the mood of the Division dinner as one of "jubilation."

The editors who made the Journal what it is are all listed in Table 4. At first the Journal was edited in ASME headquarters with Kezios acting as a consusltant. Then a new position of Senior Technical Editor was created for it. This position was finally flanked by an increasing number of Associate Editors.

The Transactions included 59 heat transfer papers and technical briefs in 1958 (see Fig. 1.) When the Journal of Heat Transfer came out in 1959 it ran this number up to 80 or so, and it now gives us almost 200 papers per year. But the Journal alone was not adequate to handle the burgeoning output of heat transfer papers, and other journals also came into being about this time. The International Journal of Heat and Mass Transfer actually predated ours. Other nations joined in this information explosion, and now German, Japanese, and Russian journals are available in English along with several other American journals.

VIII FROM ELATION TO MISGIVINGS: 1958-1970

The timing of the high tide of heat transfer matched that of the Sputnik revolution. Our defeat by the Russians in space had humiliated us in 1957, and we reacted by asserting our supremacy in science. German influences had already put us on the road to a far more science-oriented sort of heat transfer, but now the move toward improved science had become a national imperative.

We were armed with a new Journal and with re-enforcements from graduate schools, both old and new. We were also armed with new money from new agencies. Each new technical development led to another. And thus, as the 1960's ground on, if we took smaller steps with each successive paper, we did not always notice.

The idea that the Division should begin awarding excellence in heat transfer emerged in the mid-1950's. Sigmond Kopp and Myron Tribus were eventually instrumental in setting up the concept of the Heat Transfer Memorial Award. The Award was first established as a Divison honor, and then not until 1959. It was not actually given until 1961. The first recipient was Novak Zuber who, three years earlier in the course of doing his Ph.D. degree with Tribus at UCLA, had developed the ingenius hydrodynamic theory of boiling burnout. Tribus and Kopp themselves also won it, but not until 1968.

The Heat Transfer Memorial Award is given for excellence in the "art" or "science" of heat transfer, and/or "general" contributions to the field. It has been awarded to one or two people each year in one or two of these categories (once it

Table 4 The Editorship of the Journal of Heat Transfer

1959 to 1962	J. Jacklitsch with S.P. Kezios as Consulting Editor
	(The position of Senior Technical Editor was established in 1963. Subsequent names are those of Senior.Technical Editors.)
1963 to 1969	S.P. Kezios
	(An editorial board of Associate editors was established in 1968. Between 1971 and 1986 that board has grown from
1970 to 1971	W.H. Geidt (R.A. Seban finished Giedt's second year after he suffered a heart attack.)
1972 to 1980	E.M. Sparrow
1980 to 1984	K.T. Yang
1985 to 1989	G.M. Faeth

was given in all three.) The importance of this honor was recognized by ASME when they incorporated it as a regular Society award in 1974.

The Max Jakob Award, on the other hand, began as a regular Society award in 1961 and it has emerged as the most prestigious heat transfer prize. This is because it is given jointly by both the AIChE and the ASME. It is also given just once a year. The first four awards went, fittingly enough, to Eckert, Boelter,McAdams and Schmidt.

Figure 2, a photo taken at the 1952 Winter Annual ASME Meeting, shows a remarkable superposition of ASME awardees. Myron Tribus who helped instigate the Heat Transfer Memorial Award and later won it himself; Max Jakob for whom the major heat transfer award is named; and Warren Rohsenow who subsequently won both awards, and who chaired the division in 1961, as well.

Another marker of the burgeoning society was the expanding committee structure of the Division. By 1963 there were 13 "K" committees (Division committees are numbered K-3, K-4, etc.) This number shrank to 11 by 1970. It presently stands at 15. The ones that died during the 1960's are revealing. We lost:

K-4, Editorial Advisory Board
K-6, Experimental Techniques
K-11, Direct Fired Equipment
K-15, Teaching Heat Transfer

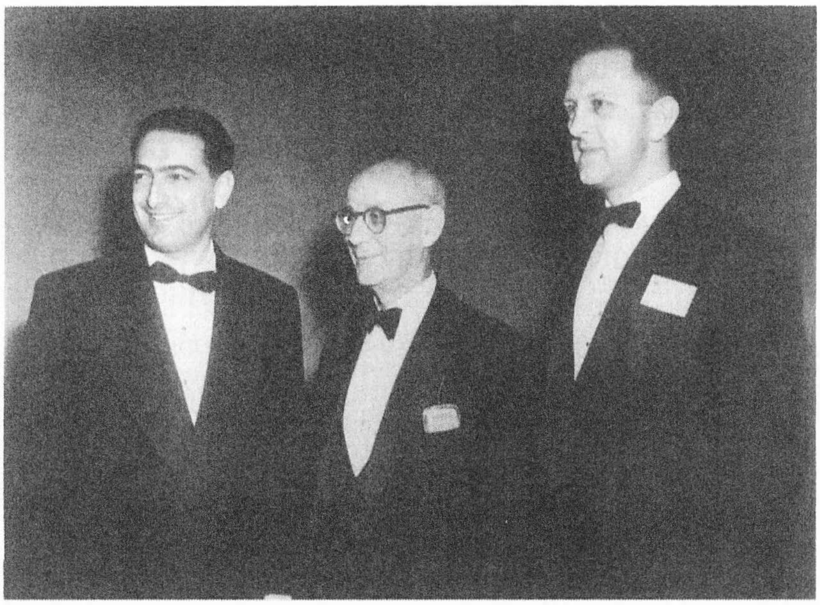

Fig. 2 Three heat transfer notables at the 1952 Winter Annual Meeting: Myron Tribus receiving the Alfred Noble prize; Max Jakob receiving the Worcester Reed Warner Medal; and Warren M. Rohsenow receiving the Junior Award. (Photo courtesy of Elizabeth Jakob.)

We can guess what these drops meant -- more autonomy for the Journal, less general concern for experimental methods as specialist committees were set up, a shift in interest from furnaces to other more specialized reactors. And the death of the committee on teaching suggests another kind of outcome of increased specialization -- the Division members' interest in education had by now shifted to specialist training in graduate school.

Nottage's history -- written in 1968 -- ended with an expression of the frustration that he felt as he watched the Division drift away from a concern for student well-being. In a listing of current problems he included:

> "Aloofness from.....disturbing questions and currents in education, in professional realities, in value problems, in down-to-earth ethics, and in the nature of responsible freedom -- all of which [are significant] in Heat Transfer....."

Nottage's distress was, of course, shared by some others in the Division. The contrast between steady growth of the heat transfer research enterprise on the one hand, and rising signs of social distress, student rebellion, and academic confusion on the other, was painful to anyone able to see it for what it was.

Research funding, spurred by the post-Sputnik drive to increase America's scientific power, grew dramatically in the late 1950's, and 1960's. The engineering societies had, in this rare instance, worked together to benefit engineering research. After WW-II, the four "Founder Societies" formed the Engineers Joint Council

(EJC) to act in common matters. Now they showed adroit management and keen strategic sense in lobbying for the interests of engineering research and education.

In 1964, for example, the EJC was instrumental in creating an Engineering Division within the National Science Foundation, and placing an engineer on NSF's governing board as well. Of course our presence in NSF cut both ways. We reaped the benefit of increased funding, but that funding bore the name of science. It was clearly intended to support only the more basic engineering work.

Like the proverbial camel who got its nose into the tent, engineers steadily expanded their base, not only in NSF, but in other government granting agencies as well. Military R & D did not just continue to expand, but it did so in the direction of increasingly basic engineering work -- paralleling the physical sciences. The military, like the NSF, was quite willing to see its grantees doing work that was increasingly separated from engineering applications.

E.W. Hartung (1966), president of the University of Idaho, wrote of the situation, even as it was unfolding:

> "A [major] problem is the increasing demand for research which society is placing upon our universities. The knowledge explosion is a self-catalyzing process.....the more we know the more we need to know..... research and development began the process of erosion of the Ivory tower which is now [almost] complete, and which has left Mr. Chips more of a hallowed memory than a [familiar] character on our campuses."

The death of Mr. Chips was at the center of a problem that was soon to reach beyond the universities. We had ridden into the 1960's on euphoria and we rode through it on expanding resources. But faculty began to play the game somewhat blindly. They sometimes became overspecialized, overly focused on research that was detached from the engineering world, and too concerned with research funding. They often failed to understand that their students were being demoralized by the draft and the war in Viet Nam. Students of the late 1960's badly needed Mr. Chips.

The swing in emphasis, as well as the deterioration in excitement, is devastatingly captured in the following entry from S. Levy's minutes of the 1966

> "Dr. Kern...stated that the industry participation in the exhibits has not been very high and that such exhibits could be eliminated. He also indicated that not enough applied papers are being presented. The general feeling was that the National Heat Transfer Conferences [might] 'dry out' in several years..."

That sort of worried self-analysis was wholly absent in the 1940's and 1950's. You find little but action item after action item in the earlier minutes of Division.

The decade of the '60's began as a wonderful, willful, exciting time; but it ended in a revolution -- almost a civil war -- centered on university campuses. Viet Nam was the nominal target, but Viet Nam was an abstract evil to most students. The universities and their faculties were the enemy they knew. They burned buildings and turned their rage on professors. At some level, they at least understood that we were no longer propelled by the glorious flood of discovery that marked the 1950's. They saw us grinding out government sponsored work that served the development of our own reputations better than it served external good.

The student cry for "relevance" gradually percolated upward from the streets and found its way into the seats of power. The first victim was the aerospace industry and the wonderful array of heat transfer work associated with it. The public response to landing a man on the moon was to ask why poverty and pollution still infected the earth. Research funding for anything but objectives bred in the soil was slashed. We were in Tagore's words, "brought down to the hard earth," and we are to some extent still there today.

IX RETRENCHMENT AND THE SEARCH FOR NEW FRONTIERS

One might be tempted to argue that the history of the Division ended in the 1960's. There have, after all, been no major structural changes. We have grown, but our growth has largely reflected growth in the exterior world. The business of the Division has changed in ways that reflect the public and agency pressures which bear chiefly on the academic and investigatory branches of our profession.

Yet what has been going on strongly parallels what was afoot during the 1930's and early 1940's. For almost two decades our intellectual establishment has been under a sustained attack and our objectives have been splintered and muddied.

During the 1930's and 1940's our mission was portrayed in murderously practical terms. Times were hard and intellectual excitement was limited -- both in heat transfer and in engineering as a whole. But a few, very wise people really saw how to serve public need with their own intellectual excitement during that period.

With great insight, Eckert (1971) identified the quality of this vision in Boelter during his talk at the dedication of the Boelter Library at Purdue University. He drew two remarkable nuggets from Boelter's writings[3] First Eckert said of Boelter:

> ".....he concluded that an engineer is in general at the peak of his decision making strength 25 years after graduation from the University and that in this period the technology has radically changed, so that a student benefits little from being taught

3 The emphases are ours.

contemporary technology. What he will still use after 25 years are the basic laws.....the problem solving techniques, and the ability to systematize those for engineering systems."

Boelter was making a plea for a latter-day revitalization of the classical concept of general education, and our universities today are sore tested to keep this idea intact.

Later in the paper Eckert quoted from Boelter's lecture notes, which he had obtained and studied. Here Boelter addressed freshman students at UCLA in 1963:

"The products of your mind are the most precious things you own, that you possess. And you must protect them, and must not do wrong with them, you must do the right thing. You must always have in mind that the products of your mind can be used by other people whether for good or for evil, and that you have a responsibility that they be used for good, you see. You can't avoid this responsibility, unless, as I've said, you decide to become an intellectual slave and let someone else make all of these value judgements for you. And this is not consonant with our democratic system in this country. You must accept the responsiblity yourself, for yourself, and for others."..."

Those who knew Boelter portray him as a distant man, someone they did not fully know, a shy man, a man who might be overlooked in a room, on the personal level -- a closed man. Yet what a majestic impassioned statement this is! If you do not look closely, the text first seems redundant; but then you catch its rhythm. You perceive that he is using the kind of antiphonal emphasis you find in the Book of Psalms.

"The products of your mind are the most precious things,
That you own, that you possess.

And you must protect them,
And must not do wrong with them,
You must do the right thing."

Here Boelter spoke to his students and he speaks to us with great power. If Boelter was diffident in advancing himself he was not so inadvancing principle. Here we catch some of the vision, eloquence, and high principle that were the building blocks of our subject and our profession.

The subject of heat transfer as represented by the Division has served this nation in many ways. It has responded to public needs and served those needs well. It has changed the face of American technology. It has altered engineering education. Yet we do well to remember the origins of the Division. The energy, excitement, and zeal that gave it birth traded on external need but were born of something more personal. They were born of Nottage's "spirit essence." For a small group of people, the "products of their minds" were "the most previous things they owned." For these people those products of their minds carried the "responsibility that they be used for good."

Today the field is wracked by exterior pressures to serve the public in this way and that. It is easy to forget Boelter's wonderful sense of purpose and to forget that the "products of our minds are the most precious things we own." Boelter is, after all, not very far from Franklin who as a young man said, "What signifies Philosophy that does not apply to some Use?" and fifty years later said in defense of a seemingly useless new idea, "What good is a new born baby?"

We can reclaim the strength of our founders by looking in the right place, and by being in the right place -- by placing ourselves in the world of real needs at the same time we look inside ourselves for mental adventure. The people who made our Division and our field knew how to nurture, and play with, a new born baby, right in the middle of the marketplace.

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