THE IMPERATIVE OF HEAT TRANSFER ENHANCEMENT WHEREVER THERE IS A TEMPERATURE DIFFERENCE: THE LIFE AND LEGACY OF PROFESSOR ARTHUR E. BERGLES

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The heightened significance of enhanced heat transfer, and the application of the different techniques that have been devised to achieve augmented performance, is perhaps unequivocally underscored by the crisis reflected in the current energy-water nexus debate. The need for energy and water conservation urgently requires integration of high-performance heat exchangers across the entire spectrum of engineering applications: from large-scale exchangers in the power and process industry to microscale devices in microelectronics and biomedical systems. Professor Arthur E. Bergles, or Art, as he was affectionately known to his multitude of friends worldwide, was a pioneer of this field and perhaps its most passionate advocate. Art's passing on March 17, 2014 has left an irreplaceable void. His very large body of trailblazing contributions to heat transfer and its enhancement epitomizes, in many different ways, his life and times. Art's life (1935–2014) and professional journey are celebrated in this essay because they are not only inspirational but also instructive in suggesting possible energy-water conservation pathways in the times to come.

KEY WORDS: *enhanced heat and mass transfer, passive techniques, active techniques, compound techniques, biography, literature survey*

1. PROLOGUE

It was a cool, crisp autumn day in 1987 in Troy, New York, on the hilltop campus of Rensselaer Polytechnic Institute (RPI) overlooking the ponderously flowing Hudson. The late-evening sun reflected the red, orange, and brown of meditative maples, interspersed with the green of pensive pines, in the murky river waters as a glistening interjection. In the Heat Transfer Laboratory (HTL) inside the engineering building on the hill, a group of graduate students and researchers was punctiliously tending to many different experiments that were churning out new data. An evaporating refrigerant was revealing new enhancement vistas as it flowed inside microfinned tubes at different vapor qualities. The dancing swirl patterns of multiple counter-rotating vortices, generated in the helical partitioned pathways of tubes fitted with twisted-tape inserts, were producing very high heat transfer coefficients in viscous liquid flows. In another corner, the controlled flow boiling with burnout in millimeter-sized tubing

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was laboring to find the upper limits of ultra-high heat flux dissipation. The staggered electrically heated tube banks in a shell chamber stood in another corner, puzzling over the question of heat transfer efficacy with increasing void fraction in flow boiling over their surfaces. A tiny simulated microchip surveyed all this activity from an elevated benchtop chamber as it ebulliently tried to set burnout limits by boiling a pool of dielectric liquid. The excitement among the young researchers was palpable and infectious.

The whirring, clanking, murmuring, and clicking of motors, pumps, digital gauges, and computerized data loggers provided a mechanized symphonic backdrop to the conversation. The animated discourse centered on the idea of designing a mascot and logo for the laboratory. Obviously the applications of enhanced heat transfer and their historical antecedents were the focus of discussions in the effort to come up with an image that would signify both the importance and the long-term relevance of the field. Artifacts of the late-nineteenth century and the groundbreaking experiments conducted by J. P. Joule (1861) and J. M. Whitham (1896), or the theoretical constructs of R. Gregorig (1954), were considered. In the first case, structured roughness in the form of a wire wrap over a cold-water-flow tube was found to enhance steam condensation. The use of a twisted-tape insert in the flue-gas tubes of a "fire-tube" boiler, in the second case, was found to improve the fuel consumption and performance of a steam locomotive. In the third case, a theoretical model was proposed for condensate film drainage via surface tension forces from a profiled fin.

Having the privileged insight that came from managing the enhancement bibliography, first at Iowa State University (ISU) and then after its migration to RPI, I interjected with the stegosaurus plates cooling story and how perhaps the plates served as fins (Farlow et al., 1976). Voilà! Thus the finned *Steggy* was chosen to be the mascot logo of the HTL with the motto "Wherever there is a Δt ..." as depicted in Fig. 1.[1] The implication was that heat transfer enhancement, represented by the fin-like stegosaurus plates, has a role in any natural or engineered temperature-difference-driven thermal situation (Manglik and Bergles, 2004; Manglik and Kraus, 1996).

The plates arrayed on the arched back of the stegosaurus (Fig. 1) have long been considered to serve a thermoregulatory function by acting as fins and allowing forced convection heat transfer from their surface and from the blood flowing through them (Farlow et al., 1976). That these plates have an extensive vascular network has been shown in recent studies (Farlow et al., 2010; Hayashi et al., 2012). Using X-ray tomography and petrographic sectioning, many large openings and vestibules, which branch off in multiple pipe-like channels, have been found inside the bony fossils. This suggests an elaborate circulatory system to facilitate blood cooling/warming and thermoregulation. Moreover, the plates are set in a slightly offset or staggered manner,

[1]The lowercase t, instead of the more common uppercase T, was used to denote temperature because it was suggested that using ΔT might clash with Greek letters already been used for college fraternities and sororities; we, of course, did not wish to go through the lengthy exercise of exploring this and settled on using the lowercase t.

FIG. 1: Mascot and logo for the Heat Transfer Laboratory at Rensselaer Polytechnic Institute; devised and commissioned 1987–1988.

which is desirable in high-performance heat exchangers (Manglik and Bergles, 1995), and they have the preferred triangular profile of high-efficiency fins (Kreith et al., 2011). All this gives much credence to the claim of "first-known" usage of enhanced heat transfer, and so the stegosaurus is an appropriate mascot for this field.

While nature has had numerous manifestations in its evolution that represent enhanced heat and/or mass transfer, it is the engineered or technologically devised history that has grown into an extremely important science (Bergles, 1999; Bergles and Manglik, 2013). The effort to document and categorize the work of this field began in the early 1960s and was pioneered by Art Bergles at the Massachusetts Institute of Technology (MIT) (Bergles and Morton, 1965). Over the next two decades, the worldwide literature on heat/mass transfer enhancement (also referred to as augmentation or intensification) was compiled, with hard copies filed in an elaborate library, and the first comprehensive bibliography of 3,045 citations in a computerized catalogue was published in 1983 (Bergles et al., 1983). This effort journeyed with Art as he moved from MIT to Georgia Tech and then to Iowa State University (ISU), the home of the

1983 report. The literature cataloging was carried out using a taxonomy developed by Art to classify the techniques that intentionally "increase 'normal' heat transfer coefficients." Two broad groups were identified: passive techniques and active techniques, with each having multiple functional subclassifications along with various compound techniques (Bergles et al., 1983).

The explosive growth in literature in this field in the latter part of the twentieth century, as seen in Fig. 2, was driven primarily by rapid developments in large-scale energy conversion and nuclear power, although thermal systems for space exploration, aviation, and electronic devices also played a role. This growth continued until mid-1995, when the literature expanded by more than 86% to 5,676 citations (Manglik and Bergles, 2004). The current generation of steady-state literature is estimated to be around 400 to 450 papers annually, but this prediction is challenged by the difficulty in searching and compiling citations despite advancements in digital information retrieval (Manglik et al., 2013). This difficulty stems from the complex nature of the enhancement literature and the associated semantics or key-phrase descriptors that tend to be diffuse and nonunique. A dedicated digital library with intelligent retrieval tools that search not only relevant citations but also the associated data and design information is clearly a critical and urgent need. An attempt to address this exigency is a slow work in progress (in need of sponsorship) at the University of Cincinnati (UC), which is the present home of the enhancement bibliography that Art pioneered.

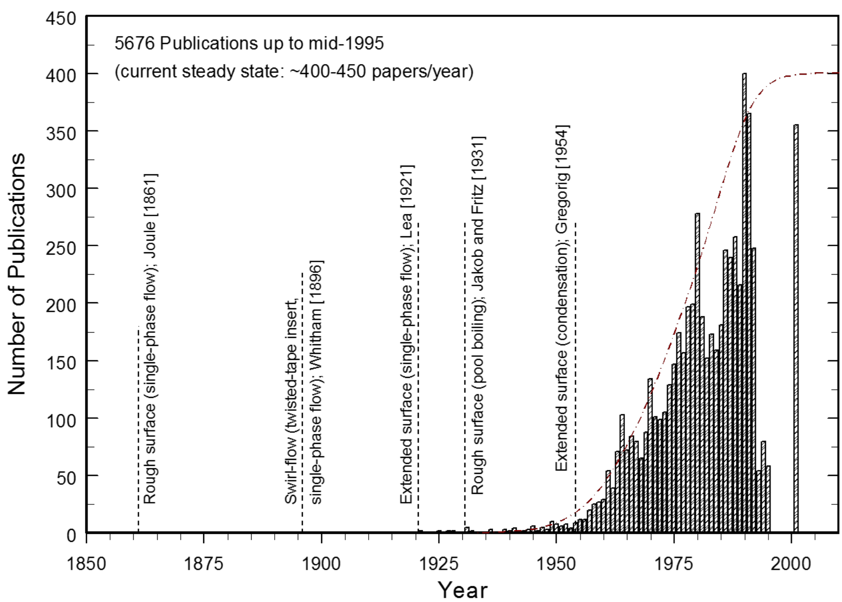


FIG. 2: Historical landmarks in the growth and documentation of the worldwide literature on enhanced heat and mass transfer. (historical markers are from Gregorig, 1954; Jakob, 1931; Joule, 1861; Lea, 1921; and Whitham, 1896.

I had the distinct privilege of joining Art in 1984 at ISU in this journey of documenting and disseminating enhancement literature. Two years later, the bibliographic library moved to RPI, and several newer updates and reports were published in the ensuing years, with some targeting very specific applications (Bergles, 1997; Bergles et al., 1991; Jensen and Shome, 1994; Jensen et al., 1997; Manglik and Bergles, 2002, 2004, 2013). I inherited the library in 1997–1998, when all of the files were shipped from RPI to UC. It has indeed been a cherished acquisition and an exhilarating journey all along, notwithstanding the arduousness of the compiling process (Manglik et al., 2013). This is a lasting legacy handed down by Art and his keenness "to bring order into this new discipline of heat transfer and reduce some of the entropy generation inherent in heat transfer communications."[2] That he was ahead of his time in his foresight is self-evident in his remarks almost two decades ago: "We are indeed facing a 'brave new world' in communicating heat transfer results. The internet will make available more data than any other technology … an information overload that is not alleviated by the computer."

The overload of paper generation is compounded by the prophetic observation Art frequently made (Manglik et al., 2010): "Everybody has time to write, but nobody has time to read." The growing emphasis on citations and other quantitative assessments of what now passes as "scholarship" has created new, but operose challenges for assessing and compiling the literature. Hopefully these are generational challenges that will pass and workable solutions will be achieved. The past is surely relevant, insightful, and foundational, and the present must learn from and build on it.

2. THE JOURNEY

It all began in New York City in the home of an Austrian immigrant couple, Edward and Victoria Bergles, when Art was born on August 9, 1935. Not long thereafter the family moved some 100 miles north to Rhinebeck, New York, where Edward, a self-taught engineer, completed the building of a hydroelectric power plant in 1938 on his farmland. The plant produced 25 kW of power and, with help from Art, operated almost continuously for the next 47 years. Evidently Art cultivated his interest in engineering, and energy conversion in particular, at a very early age (the photo in Fig. 3 endearingly captures this intimate association). His formal schooling began in a one-room schoolhouse, as was the norm at that time (Zimmerman, 2014), and continued in the Rhinebeck Central School System, where he graduated as valedictorian and became an eagle scout. In 1953, he entered Massachusetts Institute of Technology (MIT) where he would receive a combined SB and SM (1958) and a Ph.D. (1962) in mechanical engineering. An intervening year (1958–1959) was spent as a Fulbright Scholar at the Technische Universität München (TUM) in Munich, Germany. Engineers Rudolf Diesel and Ludwig Prandtl, chemist Ernst Otto Fischer, physicist Heinrich Hertz, and

[2]See interviews with Art by the Late William Begell published in *Heat Transfer Engineering* 1983;4(3-4):10-12, 141-143; and in Manglik RM, Kraus AD. *Process, Enhanced and Multiphase Heat Transfer*. New York (NY): Begell House, 1996.

novelist Thomas Mann, were a few of TUM's many famous alumni. Art was a visiting graduate student of the illustrious Professor Ernst Schmidt. TUM was then known as Technische Hochschule.

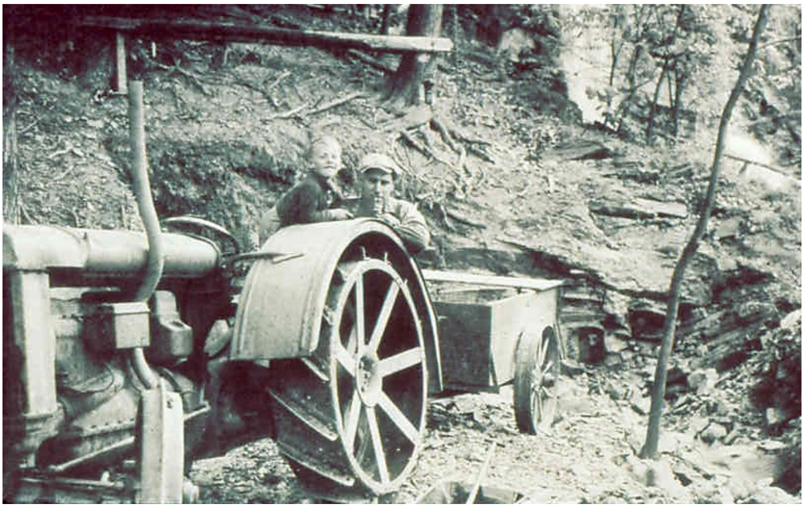


FIG. 3: An engineer in the making: Art as a very young boy on a tractor with his father, Edward, when the family hydroelectric plant was being built.

Art's undergraduate years (1953–1958) at MIT and the time spent assimilating fundamental engineering concepts and resolving associated problems with the ubiquitous tool of that period, the slide rule (Fig. 4a), were interspersed with rowing practice and regattas as a member of MIT varsity heavyweight crew (Fig. 4b). His doctoral studies in and dissertation on two-phase flow and heat transfer began at MIT with Professor Joseph Kaye. His project was on the cooling of high-field magnets, which was part of the solid-state research being conducted at the MIT National Magnet Laboratory. Unfortunately, Professor Kaye passed away in the early stages of Art's doctoral work. At this rather unsettling juncture, Professor Warren Rohsenow became his mentor and his research then focused on boiling heat transfer.

While at MIT, Art met his future wife, Priscilla (Penny) Maule, who was also working at the National Magnet Laboratory. He and Penny married in 1960, and two years later Art graduated from MIT with his doctoral degree (Fig. 5) and set off on a remarkable journey charting exemplar and unique pathways of contributions to science, engineering, education, and professional service. Art and Penny celebrated their 50th anniversary on June 19, 2010: a joyous occasion for a family of two sons (Eric and Dwight), their spouses, and five grandchildren!

Art began his professional academic career at MIT in 1962, first as a research staff member at the National Magnet Laboratory and then, beginning in 1963, as faculty in mechanical engineering and as the Ford Assistant Professor. He was also associate director of the Heat Transfer Laboratory and chairman of the Engineering Projects

(a)

(b)

FIG. 4: Art's undergraduate years at MIT: (a) at his desk tackling engineering problems and (b) as a member of the varsity heavyweight crew (standing extreme right with sunglasses).

Laboratory. After a seven-year stint at MIT, he moved to Georgia Tech as a professor in 1969. He moved again in 1972 to become the chair of mechanical engineering at ISU, where he was later named Anson-Marston Distinguished Professor of Engineering in 1981. He stepped down as chair in 1983, but continued to direct the Heat Transfer Laboratory at ISU until his next move in 1986 to RPI. There he was appointed

Clark and Crossan Professor of Engineering and later served as dean of engineering (1989–1992). Ill health forced Art to retire from RPI in 1997. In 1996, he had been celebrated with a Festschrift (Manglik and Kraus, 1996) and a two-day symposium held at Georgia Tech to celebrate his career and contributions.

FIG. 5: Art Bergles with his wife Penny and his mother Victoria at his MIT doctoral commencement in 1962.

Art was also a visiting professor at the University of Hannover, the Danish Technical University (twice), and the Technical University of Munich, as well as an academic guest at Lodz Technical University in Lodz, Poland. Even in retirement, he continued to engage extensively with various educational and research appointments: Clark and Crossan Professor of Engineering Emeritus (RPI), Glenn L. Martin Institute Professor of Engineering (University of Maryland), and senior lecturer in mechanical engineering (MIT). The MIT appointment, of course, brought him full circle to the institution where his academic career had begun.

To say that Art's research spanned the field of convective, two-phase flow and boiling heat transfer would be inadequate. It was multifaceted and multidisciplinary and addressed a variety of engineering systems and all modes of heat transfer. Much of his work involved careful experimentation and theoretical modeling, sometimes coupled with computational simulations, which were invariably conducted in the context of practical applications. He would assiduously stress the importance of rigorous experimentation, which he found "necessary to resolve complex problems" (Bergles, 1990), and the critical need to translate research results in order to address "the necessity to solve practical problems" (Manglik and Kraus, 1996).

Art had a unique ability to deduce and extract the physics of a process from its experimental data and scale it into correlations that provided insights that other researchers could use to advance not only further investigations but also as practical design tools. He was one of the few very early investigators of, and an ardent advocate for, improved microelectronics cooling (Bergles, 1986). Art's foresight in this field was remarkable, as it is now unequivocally recognized that many of the electronic devices and computers we take for granted would be inoperable without effective cooling. He carried out wide-ranging investigations in boiling, condensation, and laminar and turbulent single-phase flows that addressed both fundamental issues and applied problems. This research was anchored by a strong interest in the antecedents of engineered devices, seen in the several papers on the history of heat transfer he authored or co-authored (Bergles, 1981, 1986; Kandlikar, 1996; Manglik and Jog, 2009).

The thermal science and engineering field that is perhaps synonymous with "Art Bergles" is heat transfer enhancement (also referred to as augmentation or intensification). Not only was Art pivotal in enunciating the field's research imperative and advocating widespread adoption of the technology; he also contributed extensively with seminal and groundbreaking research. He devised an insightful taxonomy for the classification of different enhancement techniques and devices (Fig. 6) that continues to be used, developed thermal-hydrodynamic performance evaluation and optimization methods for these techniques (Bergles and Morton, 1965; Bergles et al., 1974; Marner et al., 1983), and produced the very first large-scale review of worldwide heat transfer enhancement literature with a computerized bibliography (Bergles et al., 1983). His pioneering effort led to the use of enhancement technologies in wide-ranging applications: power boilers and condensers, heat exchangers and reactors for thermal processing of chemical media and biomaterials, evaporators and condensers for HVAC systems, microscale heat sinks and microelectronic cooling systems, aircraft and space-based recuperators and cooling systems, and biomedical devices. This is to name just a few.

It would be apt to say that Art spearheaded a generational evolution of the field: from its origins and exponential growth in the 1960–1970s of what he termed second-generation heat transfer technology (Webb and Bergles, 1983) to current frontiers in third- and fourth-generation heat transfer technology (Bergles, 1999, 2002). He undeniably defined and set a trailblazing standard for the science and art of enhanced heat transfer.

The large body of work on heat transfer that Art published, which includes numerous extended review papers, also reflects his strong belief in providing direction

FIG. 6: Art with an array of enhancement devices in his office at the Heat Transfer Laboratory at Iowa State.

to and encouraging younger colleagues and in ensuring a meaningful future of heat transfer education and research. To advance this, in 2003 he and the late professor Warren Rohsenow (MIT) very generously endowed and established the annual Bergles-Rohsenow Young Investigator in Heat Transfer Award, administered by the American Society of Mechanical Engineers (ASME), which has been given to date to 10 outstanding young professors. Moreover, in 1997 Art and Penny endowed the Bergles Professorship in Thermal Science in the mechanical engineering department at ISU to attract and retain an outstanding senior faculty.

This shared commitment to scholarship and research, with gifts from friends, faculty, colleagues, and corporations, led to the endowment of the Dr. Arthur E. Bergles Scholarship at RPI in 1996 on the occasion of his retirement. Art's passion for education and fostering the careers of young scientists is eminently reflected in the fact that he was advisor for 82 thesis students and also volunteered his time on numerous fellowship and award selection committees. His research with students and colleagues resulted in more than 400 papers, 26 books and monographs, and over 400 invited lectures around the world.

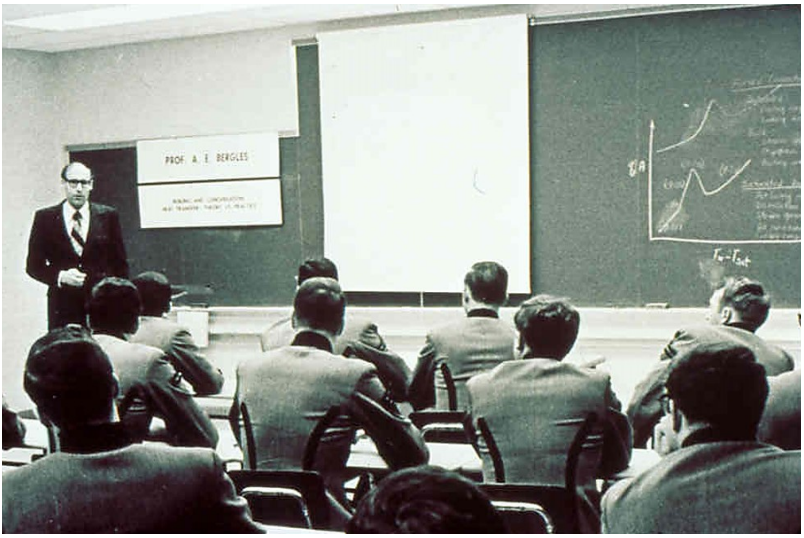
Professor Bergles was a lifelong educator, and his entire career was in universities (MIT, Georgia Tech, ISU, TUM Germany, RPI, and the University of Maryland). Learning was central to his engagement with students, not just in the classroom but in research as well. In graduate research, his supervision always balanced the need to educate with meeting the demands of the project. He would challenge students to reach for high levels of scholastic achievement, to delve deeper into the physics and scaling of the process or phenomenon under study, and, at the same time, to engage in discussion in order to grow professionally.

Art's educational approach extended into the numerous courses, both undergraduate and graduate, that he taught (Fig. 7). His lectures were always well prepared with clear explanations of major concepts, and his classroom served as a canvas for articulating his keen desire to educate and nurture professionally. One of the first courses offered at RPI on enhanced heat transfer was developed by Art, although most of the other courses he taught invariably included some discussion of this field.

Art's commitment to education extended far beyond the classroom through the many short courses (more than 50) that he conducted for industry practitioners and professional societies. His presentations always emphasized the applied aspects of fundamental research and the transfer of laboratory findings and technology development to industry applications. In fact, he persistently encouraged frequent interaction between researchers and universities on the one hand and designers, practicing engineers, and industrial organizations on the other.

That Art Bergles was acknowledged as the world's leading expert in thermal sciences is amply evident in the exceptional collection of honors, awards, and felicitations that marked his distinguished career. Art was a member of the U.S. National Academy of Engineers (NAE, 1992), the Polish Society of Theoretical and Applied Mechanics (1987), the Union of Mechanical and Electrical Engineers and Technicians of Yugoslavia (1993), the U.K. Royal Academy of Engineering (2000), the Academy of Sciences and Arts of Slovenia (2001), and the Italian National Academy of Sciences (2003). He was a fellow of ASME, AAAS, AIChE, ASEE, and ASHRAE and an associate fellow of AIAA. Also, he was awarded four honorary professorships (University of Ljubljana, Slovenia, 1997; Technical University of Denmark, 1998; Beijing Polytechnic University, 2001; and St. Petersburg State Polytechnic University, 2008). He received honorary doctorates from the University of Porto, Portugal (1998), Rand Afrikaans University, South Africa (1999), and Sapienza–Università di Roma, Italy (2009).

Art received all of the major awards in heat transfer, including the ASME Heat Transfer Memorial Award, the AIChE D. Q. Kern Award, the ASME-AIChE Max Jakob Award, the ICHMT Luikov Medal, the Nusselt-Reynolds Prize, the ITherm Achievement Award, the ASHRAE F. Paul Anderson Medal and Holladay Distinguished Fellow Award, and the International SFT Award given by the French Thermal



(a)

(b)

FIG. 7: Art Bergles lecturing in the classroom: (a) at West Point and (b) in his last class at RPI in 1996.

Society. There were many others: for excellence in engineering education, he received the SAE Ralph R. Teetor Education Award, the Benjamin Garver Lamme Medal, and the ASEE Centennial Certificate and Medallion.

Underscoring the very high esteem of his many friends and colleagues, Art was fêted many times on his birthday (Jensen et al., 1996; Manglik, 2001; Manglik et al., 2010, 2006) and for his extensive professional contributions. A particularly joyous occasion was his 75th birthday (2010; see Fig. 8), celebrated in Washington, D.C., during the 14th International Heat Transfer Conference.

FIG. 8: At the 75th birthday celebration during the 14th International Heat Transfer Conference in Washington, D.C., in 2010.

Not only did Art passionately pursue education and research, he also gave back extensively and unconditionally to the community by being very active in professional organizations. He was named a life member of ASEE and ASHRAE and 50-year member of ASME. Other achievements and recognitions included election as president of ASME (1990–1991) (Fig. 9) and as an honorary member—the latter being the society's highest recognition; winner of the ASME Medal (2000); member of the ASME board of governors; and winner of both the ASME Heat Transfer Division's 50th Anniversary Award (1988) and its 75th Anniversary Award (2013). He was a member of the Visiting Committee in Mechanical Engineering at the University of Maryland and of the Engineering Advisory Committee at the University of Connecticut, chair of numerous committees in ASME, AIChE, ASHRAE, ASEE, ICHMT, and the National Science Foundation, and editor or editorial board member of virtually all of the prominent archival journals in heat transfer and thermal science engineering.

Even in retirement, Art continued to give his time and energy to professional service: chair of the Leadership Development Intern Subcommittee for the Committee of ASME Past Presidents; chair of the Executive Committee of the International Center for Heat and Mass Transfer; member of both the ASHRAE Honors and Awards Committee and the ASME Committee on Honors; chair of and AIChE representative to the Max Jakob Board of Award; National Research Council (NRC) liaison for the

FIG. 9: Penny and Art Bergles at Art's investiture as president of the American Society of Mechanical Engineers in 1990.

Mechanical Engineering Section of NAE; and member of the NRC panel to select Ford Doctoral Fellows—again, these are but a few from an extensive list of activities. Art also served on the board of directors of the MIT Club of Cape Cod for four years, co-chaired the MIT Class of 1957 50th Reunion Committee, and was elected class president. He was also president of the Osterville, Mass., Rotary Club in 2010–2011.

Given the exhaustive list of Art's professional involvements, it is not surprising that he availed himself of only two sabbaticals in his entire career. The first was in Germany in 1979, where he worked with Professor Franz Mayinger at the Institut für Verfahrenstechnik of the University of Hanover; he was joined there by his family for some time (Fig. 10). This visit renewed an association that had begun 21 years earlier when Art was at TUM as a Fulbright Scholar and Professor Mayinger was completing his dissertation under the supervision of Professor Schmidit. The second sabbatical was a "terminal" one prior to his retirement in 1997 from RPI. This time he again worked with Professor Mayinger and, as predestination would have it, at TUM, where their long friendship had begun. Needless to say, this visit was a fitting culmination to an association with TUM, which had begun in 1958–1959 during Art's early graduate study.

Of course, retirement did not put a damper on his global travels. The following years were crowded with visits to Denmark, Italy, Poland, Portugal, Slovenia, and Switzerland. Art was certainly an enthusiastic globetrotter and thoroughly enjoyed his varied cultural experiences (Fig. 11). It would not be hyperbole to say that there is hardly any region of our globe (from the North-South to the East-West geographical quadrants) where he had not traveled. Moreover, even with this whirlwind schedule

Art would invariably find "spare time" to golf and enjoy driving his vintage Corvette, as well to enjoy his shared interests with Penny in swimming, snorkeling, skiing, gardening, and traveling!

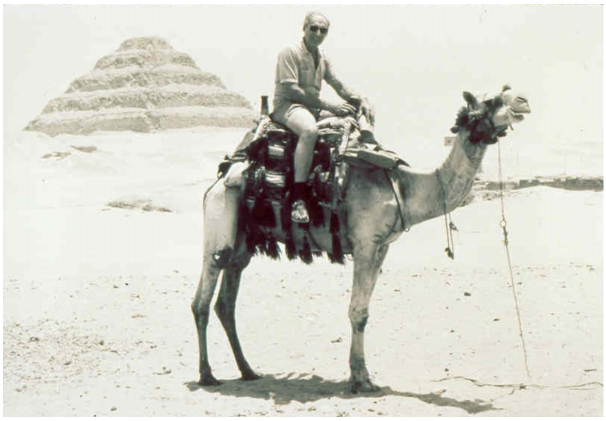
FIG. 10: Art with his family on sabbatical in Germany in 1979 (left to right: Eric, Penny, Dwight, and Art).

Alas, the journey that wove in its path to all corners of the world — a spectacularly colorful tapestry of scientific contributions, student mentoring, technological leadership, professional service and giving, community engagements, and lasting friendships — came to its final destination. It was an uncommon journey, where there were no "stops" but only destinations of continuous collaborations for advancing the science and engineering of heat transfer, nurturing and promoting engineering education, and expanding engineering practice. Art made his journey with exemplary resoluteness to overcome seemingly overwhelming challenges — from the passing of his initial dissertation advisor in the early years of his doctoral studies at MIT to ill health in later years at RPI and post-retirement. He was always in the midst of change, which he sought, embraced, and engaged in the vicissitudes with remarkable alacrity.

Sadly, on March 17, 2014, Art passed away after an extended but tenacious battle with a malignant brain tumor. More than a decade ago, while equating his life's journey with the art of riding a bicycle, he commented, "If you do not keep pedaling, you will fall." He surely pedaled far over many, many miles in a truly exceptional and inspirational journey. RIP Arthur E. Bergles!

3. EPILOGUE

The idea that our world is and should be one interconnected community was profoundly exemplified by Art. He was resolutely committed to international cooperation



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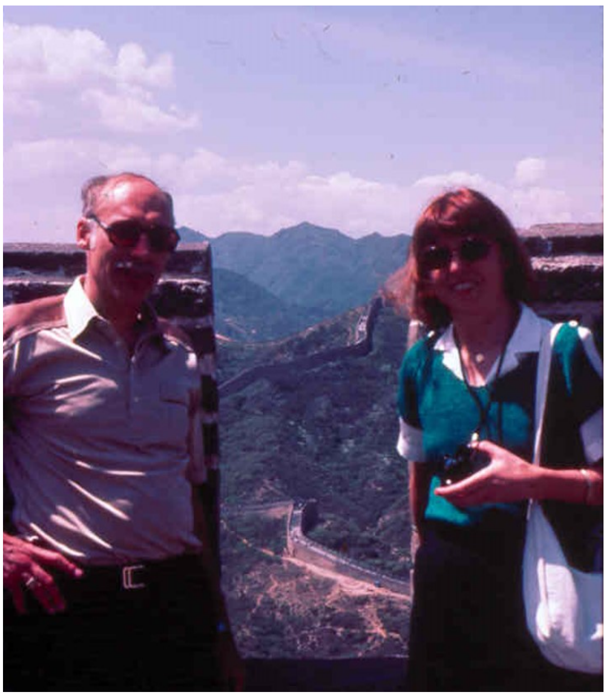

(b)

FIG. 11: Avid global wayfarer: (a) Art on a camel by a pyramid and (b) with Penny at the Great Wall of China.

and, in early 1979 was appointed by President Carter to head the U.S. team participating in a heat and mass transfer program under the auspices of the USA/USSR Agreement in Science and Technology (S&T). After groundbreaking meetings in Moscow and Minsk to define the protocol for collaboration, the first ever research cooperation agreement was signed (Fig. 12). The political events later that year, and the ensuing escalation of the Cold War saw a changed world: the S&T agreement expired in 1982 and was not renewed; however, informal contact continued via the International Heat Transfer Conference and later through the International Center for Heat and Mass Transfer (ICHMT; then headquartered in Belgrade and Dubrovnik). Even with the breakup of Yugoslavia, when ICHMT moved to Turkey, this cooperation continued. Moreover, Art's international collaborations extended to France, the United Kingdom, Japan, India, South Africa, China, Argentina, Brazil, Bulgaria, Poland, Slovenia, Bosnia-Herzegovina, Ukraine, Denmark, Switzerland, and other countries. As the late Bill Begell[3] remarked while interviewing Art in 1983 (Manglik and Kraus, 1996), "Every time I telephone, your secretary says, 'Professor Bergles is out of town and will not be back until next Monday.'" The need for greater global cooperative engagement is perhaps even more warranted today than ever before in our conflict-ridden world.

FIG. 12: Art (at right) with his Soviet counterpart signing the USA/USSR Cooperative Agreement in Heat and Mass Transfer in 1979.

The major part of Art's national and international involvement was devoted to the expansion of both fundamental research and technology transfer in enhanced heat and mass transfer. He presented over 400 invited lectures and seminars and conducted countless short courses across the world to disseminate state-of-the-art research as well as industry applications. A frequent collaborator in the latter endeavor was the late professor Ralph L. Webb (Fig. 13). This partnership, which began during the

[3]William Begell (1927–2009) was the founding publisher (1991) of Begell House, Inc., which now publishes the *Journal of Enhanced Heat Transfer* among many other science and engineering journals, monographs, books, handbooks, and the Begell Digital Library.

compilation of the first large-scale bibliography of literature (Bergles et al., 1983) and patents (Webb et al., 1983), continued with the launch of the *Journal of Enhanced Heat Transfer* in 1993–1994, of which Ralph was the founding editor-in-chief and Art was the founding advisory editor. With Ralph's passing in 2011, I was privileged to inherit his role (Manglik et al., 2011). The *Journal of Enhanced Heat Transfer* is the first scholarly publication solely dedicated to both fundamental research and applied advancements in high-performance heat exchange processes, devices, and systems. Now in its 21st year, it continues to thrive as the field's primary scholarly archive.

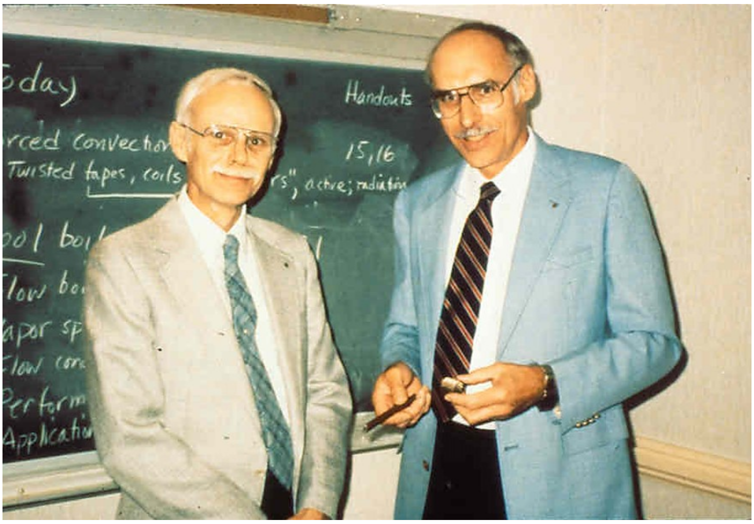

FIG. 13: With the late professor Ralph L. Webb (1934–2011) at an ASME short course.

In an insightful reflection on the past and the contemporary progression in thermal sciences and engineering, Art believed "the future to be bright for heat transfer." The essential role of advanced research and engineering in enhanced heat transfer is unquestionably part of the urgency to address global energy and water-energy nexus issues (Bergles, 2012). To emphasize this imperative, Art often paraphrased Coleridge's onerous dilemma[4]: "Energy and water everywhere, but not a drop . . . " The conundrum of our energy-centric world today[5] does often seems like a metaphorical albatross. Nevertheless, the viability of enhanced heat and mass transfer in addressing the

[4]"Day after day, day after day, / We stuck, nor breath nor motion; / As idle as a painted ship /Upon a painted ocean. // Water, water, everywhere, / And all the boards did shrink; / Water, water, everywhere, /Nor any drop to drink." *The Rime of the Ancyent Marinere, in Seven Parts* by Samuel Taylor Coleridge, written in 1797–1798 and published in the first edition of *Lyrical Ballads*, W. Wordsworth and S. T. Coleridge, printed for J. & A. Arch [etc.], London, 1798 (also see a later edition published by Duckworth, London, 1920).

[5]See the opening keynote (R.M. Manglik, "A Pathway to Sustainability: The Enduring Relevance of Enhanced Heat Transfer") presented at the 2013 ASME Summer Heat Transfer Conference and the 75th Anniversary Celebrations of Heat Transfer Division, Minneapolis, July 2013.

engineering challenges of this “energy crisis,” to use the popular idiom of the 1970s, as a means of providing near-term solutions cannot be overstated. It was to this endeavor to find and champion sustainable solutions that I hitched my own wagon three decades ago. That this association with Art was not always about research and work is very much a delightful commentary on his varied interests and talents. There was clamming near his home on Cape Cod, with a seaside picnic and grilled clams for dinner along with brews of the choicest hops during my family’s visit in the late summer of 1997 (Fig. 14). And there was a splendid spicy Indian dinner in Las Vegas to celebrate a well-received presentation during the 2003 ASME Summer Heat Transfer Conference (Fig. 15). Art surely lived a full, fun-filled, and extraordinarily fruitful life!

FIG. 14: At home on Cape Cod in 1997: (a) Art after a very successful clamming effort and (b) Art and Penny on a picnic with the author and his two children.

In the autumn years, confronted by health troubles, Art would often quip, with a characteristic twinkle in his eye and a slightly curving smile: “The spirit is willing, but the flesh is weak or, as my friends in Russia translate it, ‘The Vodka is good, but the meat is rotten.”’ Still, he was ever optimistic even when he knew that “the warranty [was] running out” and continued to interact professionally, addressing new research frontiers for tackling energy, water, and environmental issues, among many others. And just as in a relay race, an endeavor’s “warranty” baton passes on to the next generation. Indeed, Art’s pioneering contributions and legacy endure, with exciting new application landscapes that span the spectrum of the very small thermal systems (micro- and miniscale heat sinks, miniature exchangers, biomedical implants,

FIG. 15: The author with Art at the ASME Summer Heat Transfer Conference in Las Vegas, July 2003.

etc.) to the very large ones (steam condensers, air coolers, refrigerant heat exchangers, compact recuperators, etc.) that benefit from the enhancement of heat and mass transfer.

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