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In Celebration

Professor Adrian Bejan on his 60th birthday

Good theory grows out of freedom and fun. Adrian Bejan was born and raised on the Danube, in Galati, Romania, under a dictatorial communist regime. The son of a veterinarian (his father) and a pharmacist (his mother), he quickly showed inclination for analytical work, excelling in school. Freedom was not known to him, until he won one of only six scholarships in a national contest, and got a chance to migrate to the United States of America. He arrived at the MIT, as a shy, 19-year-old, tall boy who seemed more apt for basketball (in fact, he was a very good basketball player in Romania, having been a member of the national select team) than for science.

Freedom. Upon his arrival, and due to a bureaucratic mistake, Adrian was enrolled in the graduate program in Mechanical Engineering at the MIT, even though he was a beginning undergraduate in Romania. The mistake was quickly corrected by Prof. Rohsenow, and Adrian soon demonstrated that his skills in science were at least as good as in basketball. He went through to get all degrees (B.Sc. with Honors, M.Sc. with Honors, and Ph.D.) from the MIT in Mechanical Engineering, with specialization in cryogenics and heat transfer, being mentored by people of the caliber of Profs. J.L. Smith Jr., W.M. Rohsenow, J.P. Den Hartog, A.H. Shapiro, R.F. Probstein, H.M. Paynter, S.H. Crandall, J.H. Keenan, G. Hatsopoulos and E.P. Gyftopoulos. His eight years at MIT taught Adrian the importance of freedom as a fundamental component to stimulate curiosity, which eventually blossoms into ideas, new ideas. This lesson was, and still is, evident in his professional work.

From MIT Adrian went on to the University of California Berkeley where he had the privilege to work as a post-doctoral Miller Fellow with Prof. Chang-Lin Tien during 1976–1978. Tien's openness, curiosity and new ideas only amplified Adrian's natural instincts. The more application-driven science learned at the MIT was now being balanced by the more fundamental-driven research of Berkeley. The MIT-Berkeley combination would shape Adrian's future, leading to a well balanced scientific pursuit characterized by an application-driven fundamental research. This characteristic was already presented in his early papers with Prof. Tien.

Make it simple. The beginning of Adrian's academic career was marked by his prolific writing ability. Four years after beginning his academic career at University of Colorado, Boulder, Adrian published his first book, Entropy Generation Trough Heat and Fluid Flow (Wiley, 1982). A fresh look into the ideas behind the second law of thermodynamics, but applied to the important field of heat and fluid flow, this book brought down the intimidating barriers of second law analysis. It downplayed the philosophical concepts of thermodynamics in favor of a practitioner's view, with an innovative way to apply the same ideas to engineering. We can say that his Entropy Generation book popularized (among engineers) concepts such as irreversibility, availability and exergy analysis by making them look simple. Moreover, this unique book brings out not only the strong Thermodynamics influence of MIT, but also Adrian's ability to generate novel ideas and concepts, which others follow today. This ability became one of his teaching trademarks.

Pencil and paper. While in Berkeley, Adrian was also influenced by Prof. Jorg Imberger who exposed Adrian to new concepts of scale analysis. In Boulder, just two years after the publication of his first

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book, Adrian had his second book published, Convection Heat Transfer (Wiley, 1984). One of the most important books in the field, Convection Heat Transfer brought not one, but three new research methods to the forefront: Scale Analysis, Heatlines, and Intersection of Asymptotes. At a time when most heat transfer researchers were preoccupied with tackling very complicated differential equations using laborious numerical methods and supercomputers, Adrian was championing the back-of-the-envelope method. This method had two immediate effects: some established researchers reacted as if threatened, and students with limited numerical background were made to feel hopeful. One should not infer from these effects that Scale Analysis is "against" more exact methods, or a panacea that somehow replaces them. It is simply a method to teach the physics and correct scales of the problem at hand, which is a very useful first step toward more exact engineering solutions. By revealing to the user what dimensionless groups and scales are important in a problem, and how they are related, the Scale Analysis method reveals the fundamental physics characteristics and it allows for estimated results and trends, which are true in an order of magnitude sense.

While simple, Scale Analysis requires a deep understanding of the physics of the problem, more so than many other existing methods. When studied carefully as a solution method, Scale Analysis reveals Adrian's desire to look at what is really important in heat transfer, the physics. As a landmark, *Convection Heat Transfer* established Adrian in the heat transfer community as a man of scientific character, one who is a free thinker, and does not hesitate to question and evaluate the established work of others based on purely scientific grounds.

In 1984, Adrian was appointed as full Professor at Duke University. In 1989 he was appointed to the prestigious J.A. Jones Chair.

Irreversibilities. Adrian's third seminal book was Advanced Engineering Thermodynamics (Wiley, 1988). Some of us, his students, lived through the years anteceding the publication of this book. From the many trips to Washington, DC (to research the original manuscripts at the US Library of the Congress, since electronic access to literature was practically nonexistent), to the requests for paper copies from the Duke Library, the effort was Herculean. Those of us who were his doctoral students and have had the privilege to witness this period of Adrian's creativity, took away a very important lesson: scientific controversy is good when based on merit, and should not be avoided simply to avoid possible conflict. The main controversy of the first edition of this book was to challenge the view that thermodynamics is a boring, dead subject.

Adrian brought together the theory and practice of thermodynamics in line with the practical subjects of heat transfer and fluids engineering. Two details should not pass unnoticed in this book: (1) the use of graphical representation to visualize entropy generation; and (2) references to the history behind the field. One of the main contributions of this treatise is the contemporary method of Entropy Generation Minimization presented by Adrian as a method of engineering optimization (also known as "thermodynamic optimization" or, more recently, as "finite-time thermodynamics"). By combining basic principles of thermodynamics, heat transfer, and fluid mechanics, the method allows the modeling and optimization of practical systems and devices by minimizing the predicted entropy generation rate. This characteristic sets the method apart from the known exergy analysis, and highlights the limitations of classical thermodynamics.

Adrian's first three books, already published in new editions, have been followed by additional books such as *Convection in Porous Media* (Springer, 1992, 1999, 2006), *Heat Transfer* (Wiley, 1993), *Thermal Design and Optimization* (Wiley, 1996), *Entropy Generation Minimization* (CRC Press, 1996), *Shape and Structure, from Engineering to Nature* (Cambridge University Press, 2000), *Porous and Complex Flow Structures in Modern Technologies* (Springer, 2004), and *Constructal Theory of Social Dynamics* (Springer, 2007).

Constructal theory. We see Adrian's career as a building process, with a distinct first phase leading to the publication of his Thermodynamics book. This first phase was preparation for his second phase, which is undoubtedly marked by his discovery of the Constructal Law in 1995.

Since then, Adrian's research focused almost exclusively on constructal theory and its applications. He unveiled constructal theory in the second edition of *Advanced Engineering Thermodynamics* (Wiley, 1997), and reviewed the emerging field in *Shape and Structure, from Engineering to Nature* (Cambridge University Press, 2000). The impressive growth in this new domain is reviewed again in the new book *Design with Constructal Theory* (Wiley, 2008, by A. Bejan and S. Lorente) and at www.constructal.org.

Adrian postulated that "For a finite-size flow system to persist in time (to live) its configuration must evolve *in time* in such a way that it provides easier and easier access to its currents". Accordingly, (i) the generation of flow configuration is a universal *phenomenon* in physics and (ii) this phenomenon should behave in accordance with the constructal law (1996).

According to constructal theory, the phenomenon of generation of flow configuration is like an animated movie, where one screen is replaced by another screen on which the currents flow with greater ease. The constructal law is the time direction of the movie: toward flow configurations (designs, drawings) that flow more easily. Adrian sees the constructal law as a universal principle of evolution, which applies in many fields, from physics to economics.

Indeed, the constructal literature of the past decade has focused on showing that the constructal law covers "natural design" phenomena across the board, from biology and geophysics to social dynamics and technology evolution, for example: tree-shaped architectures, river-basin and animal scaling laws, animal locomotion, the distribution of city sizes, dendrite crystals, vegetation, turbulent structure, the evolution of power and refrigeration plants, machine flight, etc.

Adrian sees the constructal law not as a statement of final drawing, optimum, maximum, minimum and "entropy". He sees it as a compact summary of common observations, the tape of evolution running in one direction, which may be expressed in *physics* terms simply as: time and configuration. He believes that it predicts natural phenomena, and it also covers the results that in the past were attributed to ad hoc statements of "optimality".

Engineering science. A detailed look at Adrian's scientific contributions, revealed in the close to 500 papers that he has published, shows a cornucopia of important discoveries, such as the unification of three different theories concerning the ideal conversion of enclosed radiation, the scaling theory of melting with natural convection in an enclosure, the theory of heat transfer-irreversible refrigeration plants, the fundamentals of sliding contact melting and friction, the buckling theory of fluid flow, the scales of natural convection in porous media, and many more. Adrian is ranked among the 100 most highly cited authors worldwide in engineering (all fields, all countries, living or deceased), by the Institute for Scientific Information.

By all measures, the depth and breath of Adrian's contributions are in a class by themselves. For this reason he has been recognized on numerous occasions and in many forms, for example, with two distinct dimensionless groups discovered by his peers and named the "Bejan number (Be)": the dimensionless pressure difference group in forced convection, electronic cooling, contact melting, and second law analysis of heat transfer, and for the dimensionless ratio of fluid friction irreversibility divided by heat transfer irreversibility, in convection.

The 15 doctorates *Honoris Causa* received by Adrian from universities in Switzerland (ETH), France (Université Henri Poincaré), Brazil (UFPR), Portugal (University of Évora), South Africa (University of Durban-Westville), and many others, are evidence of the international impact of his work.

Adrian was honored with the Max Jakob Memorial Award in 1999, given jointly by the American Institute of Chemical Engineers and the American Society of Mechanical Engineers, "for highly imaginative and inspiring ideas in the thermal science and design of engineering and nature."

He also received the Heat Transfer Memorial Award – Science (1994), Worcester Reed Warner Medal (1996), Robert Henry Thurston Lecture (1999), Gustus L. Larson Memorial Award (1988), James Harry Potter Gold Medal (1990), Charles Russ Richards Memorial Award (2001), and the Edward F. Obert Award (2004), all from the American Society of Mechanical Engineers.

From the AIChE he received the Donald Q. Kern award (2008). From the International Center of Heat and Mass Transfer he received the prestigious Luikov Medal (2006) and the James P. Hartnett Memorial Award (2007).

An excellent educator (in the classroom as witnessed by all the undersigned, and through his textbooks used worldwide), Adrian has been honored with the Ralph Coats Roe Award (2000), from the American Society for Engineering Education.

With all these accomplishments, Adrian still found time to participate extensively in volunteer activities, such as organizing many national and international conferences and symposia, helping students in less advanced countries and participating in the editorial boards of 20 journals such as *International Journal of Exergy*, *International Journal of Energy Research*, *International Journal of Heat and Mass Transfer*, *International Communications in Heat and Mass Transfer*, *International Journal of Thermal Sciences*, *Journal of Heat Transfer*, *Journal of Porous Media*, *Acta Mechanica*, *International Journal of Green Energy*, *Heat Transfer – Asian Research*, *International Journal of Transport Phenomena*, *Numerical Heat Transfer*, *International Journal of Applied Thermodynamics*.

On behalf of his many students, colleagues, collaborators and friends, from all around the world, including the editors of this journal, we feel honored to pay tribute to such a truly pioneering and trend setting spirit in engineering science. Happy 60th birthday, Adrian, and we are looking forward to your future ideas!

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