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DISTINGUISHING MOTION AND WORK IN MECHANICS AND ENGINEERING THERMODYNAMICS

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To fully appreciate Bejan's engineering thermodynamics, it is important to distinguish it from the Clausius, Boltzmann, Gibbs (CBG) mechanical rendering of thermodynamics. Concepts of motion and work occur in both formulations but have different meanings.

The aim here will be to distinguish Bejan's concepts from CBG's classical mechanical exposition. The latter reason is classical Newtonian mechanics. Focusing on motion and work also allows us to trace the historical antecedents of Bejan's thermodynamics, including the contributions of Lazare and Sadi Carnot.

1. INTRODUCTION

To fully appreciate Bejan's engineering thermodynamics, it is important to distinguish it from the Clausius, Boltzmann, Gibbs (CBG) mechanical rendering of thermodynamics. Concepts of motion and work occur in both formulations but have quite different meanings in each.

The aim here will be to distinguish Bejan's concepts from CBG's classical mechanical exposition. The latter reasons in terms of classical Newtonian mechanics. Focusing on motion and work also allows us to trace the historical antecedents of Bejan's thermodynamics, including the contributions of Lazare and Sadi Carnot.

That there were two versions of thermodynamics from nearly the beginning is evident from Clausius's comments. First noting that "[Carnot] says expressly that no heat is lost in the process [when work is produced], and [Carnot] adds, "This is a fact which has never been disputed; it is first assumed without investigation, and then confirmed by various calorimetric experiments. To deny it, would be to reject the entire theory of heat, of which it forms the principal foundation." Clausius then completely rejects Sadi's 'principal foundation' in favor of a mechanical interpretation: "I am not, however, sure that the assertion, that in the production of work a loss of heat never occurs, is sufficiently established by experiment. Perhaps the contrary might be asserted with greater justice."

It is not difficult to imagine that Clausius and Carnot might be speaking in two different conceptual languages. Clausius is talking about 'mechanical work' while Sadi is talking about 'engineering work'. Clausius sees the driving force as declining as mechanical work is produced. Carnot does not see heat as a mechanical driving force but as a 'living force' that is always conserved. Sadi's 'principal foundation' is the conservation of living force.

Clausius needed to resolve the difference between the conservation of mechanical energy and the decline in the potential to perform work. Mechanical energy is conserved as is required by the presuppositions of rational mechanics. And yet the 'potential to perform work', another common definition of energy, declines as work is performed. In his Second Law, Clausius introduces the novel term 'entropy' to represent 'the potential to perform work', a non-symmetric, non-conservative change. There is no Second Law in Carnot's engineering thermodynamics. One characteristic of Bejan's engineering thermodynamics is that entropy is eliminated. The non-symmetric, non-conservative irreversibility of change is newly understood as the constructive generation, the design evolution, of reality's dynamic structures and functions.

From a general overview the differences between CBG and Bejan's engineering thermodynamics can be seen in the nexus of concepts associated with each. The nexus of interconnected concepts in classical mechanics centers on force, mass, and motion, conservation of energy and time-reversibility. With the CBS mechanical thermodynamics entropy and the principle of least action are added. The concept of work is not a 'natural' concern in classical mechanics. Global change is simply a continual directionless re-arrangement of atoms. Even in CBG thermodynamics, at least since Boltzmann, the entropy of the universe can increase to its maximum without any work having been performed.

The nexus of interconnected concepts in Bejan's engineering thermodynamic centers on flow, design evolution (replacing entropy), the principle of optimality (replacing the principle of least action) and purposeful engineering work. Most distinct from the nexus of the mechanical framework are Bejan's concepts of freedom,

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choice, and purpose. Per hypothesis, in engineering thermodynamics work is understood to result in design evolution. Work embodies the generation of the recursively enabling dynamic structures and functions of reality.

In an earlier presentation at CLC23 I followed Bejan's 'clue' that in engineering thermodynamics ' is by finite-size steps that occur in finite-times. Bejan strongly rejects the reality of infinitesimals. Historically, there are two ways of reasoning about infinitesimals. Analytic calculus argues for completed infinitesimals. For instance, the area of a circle, or the area under a curve, can be found by taking the sum or integral of an infinity of infinitesimal linear constructions. The early Greeks shared Bejan's 'horror of infinitesimals'. Archimedes reasoned in terms of two opposite finite processes, inscribing and circumscribing the circle with polygons with an increasing number of sides. The steps in each process were always incomplete. He expressed the area of the circle as a ratio of these two converging but incomplete sequences.

The problem with the completed infinitesimal reasoning characteristic of analytic calculus is that it claims to express the area of a circle in terms of linear constructions. In effect this erases the real conceptual difference between lines and circles. In terms of motion, it erases the difference between translational and rotational motion. In Greek physics as in Bejan's engineering thermodynamics the conceptual difference of translational and rotational components of 'change' is preserved. Consequently, all 'real' motion has an irreducible component of both the translational and rotational. Erasure of the difference between conceptual 'opposites' is at the heart of the difference between mechanical and engineering thermodynamic conceptions of motion and work.

The paradigm of mechanical motion is Newton's straight-line motion that proceeds by infinitesimal linear steps. The rotational component is not even addressed in Newton's three laws. The experienced features of rotational motion, such as the force felt when turning a corner travelling in an automobile, has sometimes been referred to in classical mechanics as due to a 'fictional' force. This because such experiences of rotational forces, cannot be reduced to or made sense of in terms of linear forces. Force in mechanical is literally defined as linear in Newton's three laws.

In classical mechanics composite motion, where an object experiences two forces from different directions simultaneously, is reasoned in terms of the parallelogram of forces. The resultant motion is reasoned to be the diagonal of a parallelogram whose sides are the linear vectors of the two forces from the common point where they impact the object.

In the history of engineering thermodynamics, including the antecedents, from Huygens' compound pendulum and d'Alembert's vibrating strings, up through Bejan's 'two regimes', motion and work always incorporate two components. These are qualitative distinct and conceptually discontinuous opposites. From Leibniz through Planck the 'new' concept of 'change' with its dual components was referred to as an 'action'. All actions, all motions and work, properly understood, are composites. They are ratios with, for instance, both a linear (translational) and a curvilinear (rotational) component. These two components of motion and work are conceptual opposites undermine the parallelogram's reasoning in classical mechanics.

Per hypothesis, in engineering thermodynamics, the parallelogram takes on the more general form of a cycle. The two sides representing the opposite components have opposite curvature, reminding one of Sadi's 'indicator diagram'. Since the two phases of the cycle are not mechanically symmetric, the cycle forms a dynamic equilibrium and is net productive. The resultant is the area (or volume) between the cycle phases. The resultant has a direction perpendicular to the motion of the cycle and represents the thermodynamic work.

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