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Book Review

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Analytical Dynamics

Haim Baruh, McGraw–Hill, Boston, 1999, 744 pp., $120.00, ISBN 0-07-365977-0

Despite the fact that this dynamics text contains much excellent material, most of it adapted from previously published work by other authors, our overall impression is that the book is misleading and flawed as either a textbook or a reference book. In what follows we discuss in detail several specific examples of the book's shortcomings.

To begin, the author's treatment of angular velocity leaves much to be desired. He gives three different definitions of the angular velocity ω of one reference frame with respect to a second reference frame, namely, Eq. (2.5.11) on p. 109, Eq. (2.5.18) on p. 111, and Eq. (7.7.48b) on p. 389. These are as follows:

$$\omega = \lim_{\Delta t \to 0} \frac{\Delta \boldsymbol{\theta}}{\Delta t} \tag{2.5.11}$$

$$\omega = (\dot{\boldsymbol{e}}'_2 \cdot \boldsymbol{e}'_3)\boldsymbol{e}'_1 + (\dot{\boldsymbol{e}}'_3 \cdot \boldsymbol{e}'_1)\boldsymbol{e}'_2 + (\dot{\boldsymbol{e}}'_1 \cdot \boldsymbol{e}'_2)\boldsymbol{e}'_3 \tag{2.5.18}$$

$$\omega = \frac{\mathrm{d}\Phi}{\mathrm{d}t}\boldsymbol{n} \tag{7.7.48b}$$

Two of these definitions, Eqs. (2.5.11) and (7.7.48b), are defective in that they are not operational. That is, except for the simple case in which the angular velocity of the first reference frame with respect to the second is parallel to an axis of rotation that is fixed in both reference frames, the symbol $\boldsymbol{\theta}$ on the right-hand side of Eq. (2.5.11) and the symbol Φ on the right-hand side of Eq. (7.7.48b) are meaningless. In contrast, every quantity on the right-hand side of Eq. (2.5.18) is a meaningful one that can be readily formed in connection with any angular velocity problem. However, the author does not provide an angular-velocity-independent definition of the time-derivative of a vector in a reference frame, which means that the reader has no way of forming the vector derivatives $\dot{\boldsymbol{e}}'_1$, $\dot{\boldsymbol{e}}'_2$, $\dot{\boldsymbol{e}}'_3$ in order to make use of Eq. (2.5.18). Furthermore, the fact that the author sees no difference between a true, operational definition, as given by Eq. (2.5.18), and useless nondefinitions, such as Eqs. (2.5.11) and (7.7.48b), is troubling.

Particularly objectionable is Section 9.8. Here the author states, "It is clear that the Gibbs–Appell and Kane's equations are identical." This is misleading, for what the author fails to describe is the much more important question of exactly what it is that distinguishes one method of formulating dynamical equations from another. Why do we say, for example, that Lagrange's method is different from Hamilton's, and that the Newton–Euler method is different from both, when all three methods lead to precisely the same description of a system's motion? The answer is that a method for formulating equations of motion is a "recipe," or sequence of tasks to be performed, which leads to correct equations of motion; and, when one such sequence of tasks differs from another, it merits the distinction of being regarded as a separate method. This is certainly the case in connection with Kane's method, for his method bears strikingly little resemblance to the Gibbs–Appell method when both are examined critically. Moreover, when applied to the formulation of equations of motion for complex systems, the sequence of tasks to be performed with Kane's method involves significantly less labor than does the sequence of tasks to be undertaken with the Gibbs–Appell method. The following thought experiment is intended to make this clear:

Imagine that you have absolutely no knowledge of anything written by or stated by Kane or by anyone influenced by him. Imagine further that you have access to the papers by Gibbs and Appell on formulating equations of motion, that you have been given the task of producing, by means of the method described in these papers, explicit equations of motion for a specific mechanical system, for example, a multibody spacecraft, and that you must carry out the derivation using an algebraic manipulation program, for example, MACSYMA. What would you do? Consider first the "generalized inertia forces" portion of the job. Here, the Gibbs–Appell papers tell you first to form a scalar function; call it S. To form S with MACSYMA, you would require the program to follow the recipe given in the papers; that is, you would first select appropriate generalized coordinates and/or generalized speeds, and then tell MACSYMA to form for each rigid body in the system a scalar function of the form $(m\boldsymbol{a} \cdot \boldsymbol{a} + 2\alpha \cdot \omega \times \boldsymbol{I} \cdot \omega + \alpha \cdot \boldsymbol{I} \cdot \alpha)/2$, where $\boldsymbol{a}$ is the acceleration of the mass center of the body, ω and α are the angular velocity and angular acceleration of the body, m is the body's mass, and $\boldsymbol{I}$ is the inertia dyadic for the body's mass center; and, for each particle, you would have MACSYMA generate a scalar function of the form $m\boldsymbol{a} \cdot \boldsymbol{a}/2$, where m and $\boldsymbol{a}$ denote the mass and the acceleration of the particle, respectively. Next, you would instruct MACSYMA to take partial derivatives of S with respect to the time-derivatives of the generalized speeds, as described in the Gibbs–Appell papers, to arrive at generalized inertia forces.

Moving on to the formulation of "generalized active forces," what would you tell MACSYMA to do? You would be forced to write an algorithm for constructing generalized forces by means of virtual work, unless the system possessed a potential energy, because virtual work was the only *general* method for deriving generalized forces that was known at the time of Gibbs and Appell. How you would write such an algorithm is a major consideration in its own right, but one that you would have to come to grips with in implementing the Gibbs–Appell method with MACSYMA.

Now contrast these tasks with the ones you would tell MACSYMA to perform using Kane's method. After inputting basic kinematical quantities as before, you would instruct MACSYMA to dot-multiply the appropriate partial angular velocities, found by symbolic inspection of the corresponding angular velocities, with the inertia torque for each body, and to dot-multiply partial velocities, obtained by symbolic inspection of velocities, with each mass-center acceleration and particle acceleration. This has nothing whatsoever to do with forming Gibbs–Appell functions and taking partial derivatives of them. In this connection, several points need to be made. First, it is well-known that, when one forms generalized inertia forces by means of the Gibbs–Appell method, some labor can, at times, be saved if one performs partial differentiations implicitly. For a particle, this amounts to writing $S = m\boldsymbol{a} \cdot \boldsymbol{a}/2$, and then partially differentiating S as $\partial S/\partial \dot{u}_i = m\,\partial\boldsymbol{a}/\partial\dot{u}_i \cdot \boldsymbol{a}$, u_i being the ith generalized speed, which is tantamount to squaring $\boldsymbol{a}$ to form S and then "unsquaring" it to take the derivatives. The corresponding penalty in wasted effort is more severe in connection with rigid body contributions to S. What one does when one forms generalized inertia forces in this manner with the Gibbs–Appell method is equivalent to deriving Kane's generalized inertia force formulation procedure from the Gibbs–Appell one, again and again, during the course of an analysis. This is one reason why dynamicists who have actually applied both methods to industrial problems regard Kane's method as significantly superior to the Gibbs–Appell method, as far as labor is concerned. Second, it is not true that Kane's partial velocities are always equal to the functions $\partial\boldsymbol{a}/\partial\dot{u}_i$. Indeed, it is precisely the fact that the partial velocities and $\boldsymbol{a}$ are distinct entities, *not* the former extracted from the latter, that gives Kane's method a considerable advantage over the Gibbs–Appell method in many important tasks, such as finding internal forces, solving impulse-momentum problems, and forming linearized equations of motion.

With regard to using MACSYMA to produce generalized active forces with Kane's method, you would instruct MACSYMA to dot-multiply Kane's partial angular velocities with torques, and dot-multiply Kane's partial velocities with forces. This is a far cry from using the virtual work of Gibbs and Appell. In fact, the author cheats on precisely this issue in making his comparison. Because there is no legitimate way to claim that Kane's method of obtaining generalized active forces is identical to the virtual work method of Gibbs and Appell, the author resorts to employing Kane's version of the generalized active forces [see the author's Eqs. (9.7.7)] in what he calls the Gibbs–Appell equations—Eqs. (9.7.8)—but attributes it falsely to Gibbs and Appell, rather than to Kane. Thus, on the issue of generalized active forces, the author is comparing Kane with Kane, not Kane with Gibbs–Appell, and it is no surprise that he finds them to be identical.

The author makes several other false statements about the Gibbs–Appell equations. He claims on p. 519 that "... for holonomic systems, the Gibbs–Appell equations have no advantage over Lagrange's equations. The Gibbs–Appell equations are more cumbersome; they require the calculation of acceleration terms, as opposed to the velocity terms needed for Lagrange's equations." In fact, the opposite is true. The Gibbs–Appell equations are far less cumbersome than Lagrange's equations for several reasons. First, Lagrange's method forces one to employ generalized coordinates as dependent variables. These lead with much gratuitous labor to unnecessarily large equations for many systems of practical interest. Second, Lagrange's method employs the squares of velocities, not velocities themselves, and forming accelerations for the Gibbs–Appell method requires no more labor, and frequently less labor, than forming the squares of velocities for Lagrange's method. Third, Lagrange's method forces one to perform three separate differentiations of kinetic energy functions in the formulation of each equation of motion, whereas the Gibbs–Appell method requires only a single differentiation of the Gibbs function in connection with each equation.

The author's treatment of the dynamics of "lightly flexible bodies" (Chap. 11) is pedagogically unsound. The author considers rotating beams, but in discussing "centrifugal softening," he fails to make the crucial point that the spurious prediction of this effect is due to the necessary premature linearization inherent in the use of modes. He does not show by means of examples or even mention that failure to deal effectively with the premature linearization issue can lead to drastically incorrect predictions of motion, including false predictions of unbounded elastic deformations. The author also fails to make the key point that the ad hoc approach he takes in accounting for foreshortening in beams is untenable for general elastic structures. The only known viable approach for correctly compensating for spurious predictions of centrifugal softening due to the necessary premature linearization of the equations of motion of a general flexible structure undergoing arbitrary motion is the use of geometric stiffness matrices, and this is given no mention in the book.

Although there are many other flaws in this book in addition to the ones discussed above, we see no point mentioning them. We believe that the deficiencies of this book far outweigh its merits. Consequently, we do not recommend it either to students or to practicing engineers.

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