ments interesting and informative, and the book clearly benefits from his experience as an insider in many of these developments.

I found it striking that a book on commerce contained very few numbers. For communications satellites, which are by far the most important element of space commerce, McLucas reports that revenues in the US amount to about $3 billion per year. After noting that about $2 billion a year is spent on construction of the satellites and about $1 billion on launching them, he describes this as a $6 billion per year industry!

One good reason for not giving many numbers is that there is so much misinformation in NASA figures. McLucas writes, "As the cost of the shuttle grew, all financial realism in pricing policy went out the window, and prices were set for purely political reasons." This is true for all spacefaring countries. In all cases we deal with command economies. It is therefore not surprising that the cost of launching payloads into orbit has grown as the space bureaucracies have aged. Remember that the energy to launch into low-Earth orbit is about 4.5 kilowatt-hours per pound. That energy was purchased for $1000 in the early 1960s, and the cost declined somewhat for a few years as would be expected for a healthy new industry. "Then in 1978," McLucas writes, "when the Carter Administration threatened to cancel the shuttle because of delays and cost overruns, the shuttle's protectors came up with a proposal that the government should close down every other launch program and force all payloads—commercial, civil, military and foreign—to fly into space aboard the shuttle."

After enforcing the shuttle monopoly on US space launches, the aging bureaucracy has now driven the real costs up by about an order of magnitude. This "central planning" control of the gateway to space has stifled space commerce. The Challenger disaster broke the monopoly and permitted a revival of the more economical expendable launch vehicles of the sixties. But the bureaucracy survives.

I am convinced, and McLucas has strengthened my conviction, that to realize the dreams that have always driven the space program, we must first learn how to dismantle an entrenched command economy. We must profit as much as possible from the painful experiences of Eastern Europe and the former Soviet Union. Only an approximation to a free market can properly exhibit America's capabilities in space commerce.

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Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance

Donald MacKenzie
MIT P., Cambridge, Mass., 1990. 464 pp. $29.95 hc
ISBN 0-262-13258-3

The subtitle of *Inventing Accuracy*, that it is a "sociological history of nuclear missile guidance," seems designed to raise the hackles of half of its potential readers—hard scientists. Indeed, it leads with the author's chin: How dare a historical sociologist, whatever that is, take on a subject of such technical complexity as inertial guidance? And, since it deals with a politically sensitive topic from a viewpoint that is obviously extremely dovish, how fair to the developers of nuclear missiles can the reader expect the book to be?

Inventing Accuracy may seem to have two strikes against it—its title and its author's background—but the book itself hits a triple, if not a home run. The author, most definitely a sociologist with no claims to a former life as a hard scientist, has taken an arcane topic, the subject of much mythological history handed down through the years, and made the technical brilliance of the *solutions* arrived at not only understandable to a physicist but also to someone from his own discipline. Indeed, figure 2.2, which was adapted from another book, may be the most lucid explanation ever of why a gyroscope precesses; it deserves far wider circulation, in popular and technical works.

MacKenzie asserts and then demonstrates that technical choices have strategic consequences, and he illuminates the roads taken and those passed by. Perhaps, he suggests (and he makes a persuasive case), other simpler and less elegant solutions might have been preferable. In no sense were today's inertial guidance systems the inevitable result of technological movement along a uniquely possible path. Different choices in guidance design might have led to a generation of intercontinental missiles with lower accuracies and lower costs; mutual deterrence enforced by explicitly holding cities hostage might have provided more strategic stability than we have in today's world when many missiles are aimed at other missiles to "limit" damage. However, the political task of explaining such a choice would be even harder than demonstrating the flaws in the concept of strategic defenses.

At the beginning, in 1945 or so, the whole idea of inertial guidance seemed an impossible dream. Of particular interest to physicists will be MacKenzie's tale of "the problem of the vertical," when it was realized that the equivalence principle appeared to rule out a pure inertial guidance system, since acceleration and gravitation could not be distinguished. A plumb bob, MacKenzie recounts, would no longer indicate the true local vertical in an accelerated black box; if one could not know the vertical, then it would be impossible to know whether or not accelerometers intended to be horizontal really were. George Gamow entered the battle with a paper called "Vertical, Vertical, Who's Got the Vertical?"; and P. M. S. Blackett objected to inertial navigation schemes using physical arguments similar to those of Gamow. The solution to the problem is elegant; the reader can work it out or read the book. But a hint may be in order: Consider what would happen if one tried to determine the vertical direction using a plumb bob whose string was equal to the radius of the Earth so that the bob always remained at the center of the globe.

The chapter on Soviet guidance systems, while necessarily far less detailed than those on Western technology, is of extraordinary interest. The author demonstrates that engineers and scientists starting from the same point (the V-2 guidance system) and having access to roughly similar sets of ideas do not necessarily wind up with technically similar solutions to the same problem. And it is not easy to say which solution set is truly better.

The most controversial chapter is entitled "The Construction of Technical Facts." MacKenzie traces the competition between bomber proponents and missile enthusiasts in the US Air Force, shows how the "bomber lobby" eventually lost (although with the B-2 and B-1b they may be making an ill-deserved comeback) and demonstrates that "accuracy" may be more a theological construct than a technical one. The problem in defining a missile's accuracy is not with the reasonably well debunked question of "bias" arising from unknown components of the gravitational field over the Earth's poles or from still-undiscovered electromagnetic forces. Instead, MacKenzie's doubts arise from fundamental questions about the abi-

lity to infer performance of a large group of missiles fired in haste and anger from tests of a far smaller number of rockets that have been tuned, primped and launched at leisure. Even if one could make such inferences, problems of measurement, pushed nearly to the limits of modern instrumentation, remain. The politically engaged, of whatever persuasion, will find in this chapter infuriating ideas as well as a wealth of material to support their own points of view.

MacKenzie has done many strategic analysts a tremendous service by compiling an enormous set of unclassified data, derived from open sources, and using that information to arrive at realistic values for the accuracy and range of most Soviet and American missiles, from the Atlas D of 1958 to the Trident D5 of 1990. He has carefully compared relative figures given freely by many sources, extracted a "best fit" from slightly differing data and then sought out the few accurate and absolute values that have ever slipped into the open to calibrate the entire data set. Appendix 1 may be the most valuable resource in this extraordinarily useful book.

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Wave Mechanics Applied to Semiconductor Heterostructures

Gérald Bastard

Halsted (Wiley), New York, 1991 [1988]. 357 pp. $44.95 pb
ISBN 2-86883-092-7

It is often said that the behavior of electrons in semiconductor quantum wells provides one of the clearest venues for observing quantum mechanical phenomena in their simplest textbook form. Nowhere else can one "see" those particle-in-a-box energy levels as clearly as in the interband absorption spectrum of a quantum well or in the beautiful transmission resonance of a double-barrier diode seen in the current–voltage trace on an oscilloscope. However, the analyses of these systems found in textbooks do not take one very far, and the necessity to go beyond the simple plane-wave model soon becomes apparent. This book by Gérald Bastard of l'Ecole Normale Supérieure in Paris is designed to help the researcher and the advanced student take this step.

The book was first published in