CHAPTER FOUR

Vehicles, Ships, Aircraft, and Weaponry

What about technical trends in systems such as tanks, ships, jets, and missiles? Chapter 3 focused primarily on electronics and sensors, which are clearly important in major combat weapons and platforms. But the performance of these weapons and platforms also depends heavily on their propulsion systems, armor, and related characteristics. These mechanical, chemical, and structural technologies are surveyed in this chapter. Nonlethal and biological weapons are also considered, as are defense systems against ballistic and cruise missile attack.

The approach taken in this chapter differs from that of chapter 3. Here, it is generally less useful to rely on the fundamental constraints and realities of physics. Instead, this chapter attempts to discern trends in various types of technology and extrapolate their future capabilities and uses. Its approach is therefore more impressionistic and more subject to error than that of chapter 3. But it is far more systematic than relying on anecdotes, pure conjecture, and false analogies with trends in computers and electronics—as many proponents of a contemporary revolution in military affairs (RMA) tend to do.

Although this chapter does not downplay the pace of progress in military technology, it does highlight a number of sobering themes for consideration by those purporting to discern an RMA on the horizon. Most important, the chapter argues that most developments in propulsion and the basic designs and dynamics of vehicles, ships, and airplanes are clearly occurring at incremental and evolutionary—not revolutionary—rates. This prognostication applies to rates of advance in the speed of ships and airplanes, the efficiency of rockets, the basic functioning of the internal-combustion engine, and the power of explosives.

These findings do not by themselves disprove the possibility of a near-term RMA. A number of modest new capabilities combined with a couple of key breakthroughs in defense technologies, all integrated in a real-time information network, may indeed make possible an RMA, at least in theory. That possibility is considered in chapter 5. In other words, the specific case-by-case technology assessments of this chapter do not rule out the possibility that the broad conclusions offered by RMA proponents, as laid out in chapter 1, may be right.

This chapter does provide grounds for skepticism, however. Taken in conjunction with chapter 3, it strongly suggests that it will be much harder to increase greatly the speed, lethality, and rapid deployability of U.S. combat forces than documents ranging from *Joint Vision 2010* to the National Defense Panel's 1997 report to a number of other RMA proposals often claim. In light of this, the second and third technical premises of the RMA movement, as spelled out in chapter 1, appear to be exaggerations at best and downright inaccuracies at worst.

Aircraft

Jet engines have improved considerably over the past several decades, becoming more efficient, powerful, and reliable. For example, in the period of roughly two decades, between the development of the F-15 and the F-22 aircraft, engine technology improved so much that the latter fighter has roughly twice the power of the former. Among the reasons for this improved performance are engine materials that allow much higher temperatures within the turbines than previously possible—around 3,400 degrees Fahrenheit, in contrast to temperatures 1,000 degrees lower in previous-generation aircraft. At the same time, the F-22 and F-15 are similar in weight, both in the aircraft as a whole and in the engines specifically—a combination that makes for a significant improvement in performance capability for the newer aircraft.[1]

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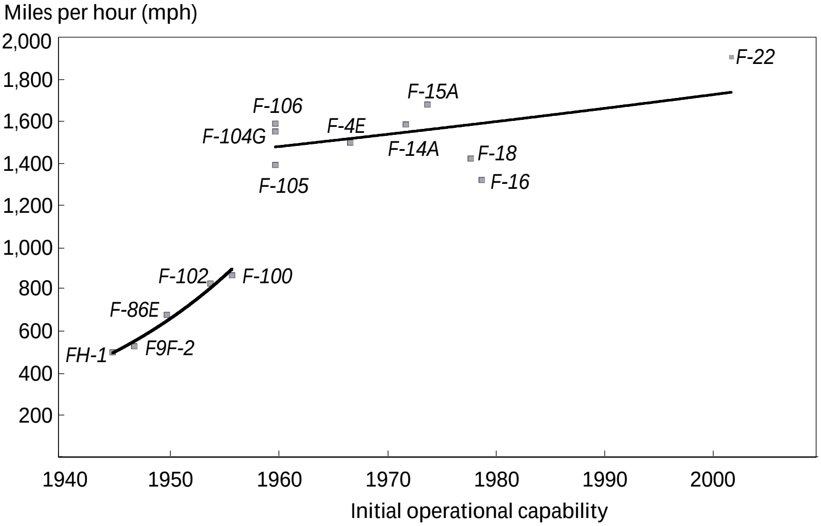
[1] Bill Sweetman, "The Progress of the F-22 Fighter Program," *Jane's International Defense Review,* quarterly report no. 1 (1997), p. 8. The improvements in engine technology have largely to do with the bypass ratio of air flowing through the jet engines; much more air flows through modern designs. Other efforts focus on using engine materials capable of tolerating higher temperatures, such as silicon carbide and titanium. See Eugene E. Covert, "Evolution of the Commercial Airliner," *Scientific American,* September 1995, p. 112; and Lane Pierrot, *A Look at Tomorrow's Tactical Air Forces* (Congressional Budget Office, 1997), p. 38.

Figure 4-1. ***Aircraft Speed since World War II***[a]



Source: Enzo Angelucci, *Rand McNally Encyclopedia of Military Aircraft: 1914 to the Present* (Harrisburg: Crescent Books, 1990), pp. 398–423.

a. Mach 1 (speed of sound) = 740 mph at sea level. Aircraft speeds indicated are measured at optimum flying altitude and weight, which differ for each aircraft. The maximum estimated speed for the F-22 remains classified. The prototype YF-22 has achieved Mach 1.58 (1,203 mph) at 30,000 feet without afterburning. Using available open-source data, the author estimates the maximum speed of the F-22 at Mach 2.5 (1,903 mph) with afterburning.

(Figure 4-1 presents a longer-term perspective on improvements in combat aircraft speed.) Yet this improvement in performance is far below the rate of innovation in computers, where doublings of capability typically occur every eighteen to twenty-four months.

New aircraft materials include titanium and a number of composites, some of which have the added benefit of stealthiness. These materials will constitute about two-thirds of the total mass of the F-22, reducing the aircraft's weight by about 25 percent, as compared to an all-aluminum frame. The benefits of such materials are considerable, yet a 25 percent reduction is better thought of as evolutionary than revolutionary change.[2]

It is illuminating to think of how these types of changes in aircraft compare with those of the interwar years, when almost all would agree that a revolution in military affairs truly did occur. As Andrew Krepinevich has emphasized, the U.S. Navy experimented with many different types of carriers, not knowing which would prove most effective. Wisely, it developed

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[2] Sweetman, "The Progress of the F-22 Fighter Program," p. 6.

three classes of carriers but produced a total of only four ships. By contrast, the British Royal Navy put most of its eggs in one basket—that of small carriers. As aircraft improved, larger carriers became necessary to accommodate them.[3] In the last several decades, however, it has not been necessary to change the size of carriers, and future carrier aircraft will not demand it either. Today, basic propulsion systems and designs for aircraft, ships, and internal-combustion vehicles are changing much more gradually than in the early twentieth century, when two of those three technologies had only recently been invented. As Martin Libicki put it in regard to the specific example of jet engines, changes are now of degree rather than of kind.[4]

Breakthoughs in stealth technology over the last three decades have been quite impressive, as suggested in figure 4-2 and table 4-1. Progress continues to make aircraft less observable, not only against radar but also against other types of sensors. Modern aircraft like the F-22 have conformal nozzles, high-bypass engines that keep exhaust temperatures low by mixing hotter air with cooler air before expunging the mix, and various types of paints and surface coatings that absorb solar infrared radiation and limit infrared emissions from friction-generated heat. The goal with these types of technologies is to ensure that infrared signatures constitute no more of a vulnerability for stealth aircraft than do their radar signatures.[5]

Helicopters are becoming more stealthy, too. For example, the Comanche helicopter is to have only one-fourth the infrared signature, one-half the acoustic signature, and less than one-hundredth of the radar signature of current helicopters like the Apache. The radar cross section of the Comanche is thus probably less than one square meter—quite modest, albeit greater than the 0.01 square meter range that probably typifies the F-117, B-2, and F-22 fixed-wing aircraft.[6] (The joint strike fighter, or JSF, reportedly has just as small, or even smaller, a head-on radar cross section, though it may not wind up being quite as stealthy from certain side and rear angles as the B-2 and F-22. In addition, the JSF is reportedly being designed to have small radar reflectivity even against lower-frequency radars.[7])

[3] Andrew F. Krepinevich Jr., testimony before the House National Security Committee, Subcommittees on Military Procurement and Research and Development, 105 Cong. 2 sess., October 8, 1998 (Washington, D.C.: Center for Strategic and Budgetary Assessments, 1998), pp. 6–7.

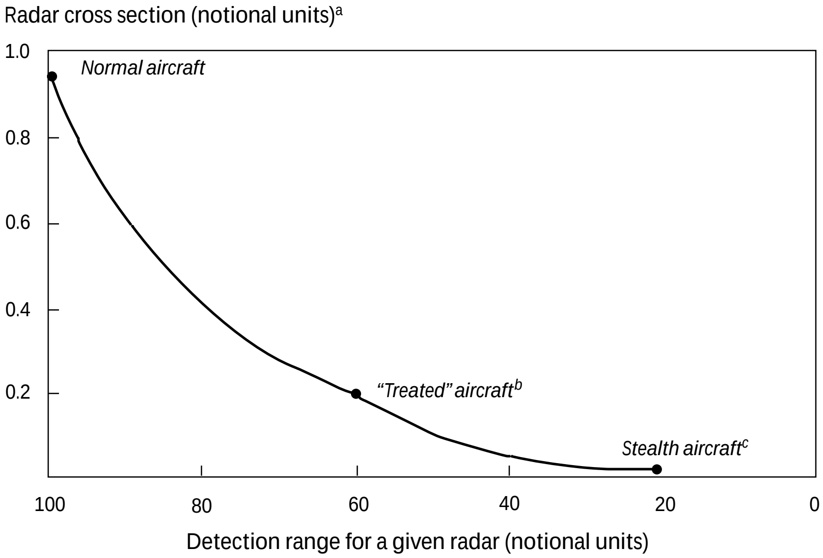
[4] Martin Libicki, “Technology and Warfare,” in Patrick M. Cronin, *2015: Power and Progress* (National Defense University, 1996), p. 120.

[5] Sweetman, “The Progress of the F-22 Fighter Program,” pp. 9, 17.

[6] Stanley W. Kandebo, “U.S. Army Ponders Comanche Restructure,” *Aviation Week and Space Technology*, June 1, 1998, pp. 26–27.

[7] David A. Fulghum, “JSF Reflection Is Golf-Ball Sized,” *Aviation Week and Space Technology*, February 15, 1999, p. 27.

Figure 4-2. ***The Benefits of Stealth***



Sources: Adapted from Office of Naval Intelligence, *Worldwide Challenges to Naval Strike Warfare* (Office of Naval Intelligence, January 1996), p. 18; David A. Fulghum, "Secret Upgrades Target Stealthy Cruise Missiles," *Aviation Week and Space Technology*, August 24, 1998, pp. 22–23.

a. Roughly speaking, the scale for radar cross sections corresponds to square meters for fighter aircraft. From certain angles, however, nonstealthy aircraft such as the F-15 can have radar cross sections of between 5 and 10 square meters.

b. The exterior surfaces of "treated" aircraft have been slightly modified to reduce radar cross sections. An example might be the F/A-18E/F Super Hornet.

c. An example might be the F-22 Raptor.

Progress with transport aircraft is occurring at a modest pace. The V-22 Osprey tilt-rotor aircraft is an impressive new capability. With a top speed of more than 300 miles per hour (roughly 500 kilometers per hour), it is at least 50 percent faster than modern helicopters. With a normal mission radius of more than 200 miles (more than 300 kilometers), it also has greater range than most current helicopters (though much less of an advantage than the Marine Corps routinely claims when comparing it against one particular shorter-range system).[8] The Osprey is not particularly fast, large, efficient, or stealthy, however. Its reduced vulnerability to enemy action has often been overstated. It is notably better than modern helicopters equipped with

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[8] Marine Corps briefing on V-22 Osprey, June 13, 1997.

Table 4-1. ***Visibility of Selected Objects to Radar***

Object	*Radar cross section (square meters)*	*Typical SAM tracking range*[a] *(kilometers)*
Large transport aircraft	100	250
Conventional fighter plane	10	210
B-1B bomber	1	125
Cruise missile	0.1	80
Large bird (or B-2, F-22?)	0.01	50
Large insect (or B-2, F-22?)	0.001	35

Source: Congressional Budget Office, *A Look at Tomorrow's Tactical Air Forces* (January 1997), p. 77.

a. SAM = surface-to-air missile.

similar countermeasures only when being shot at by small arms.[9] Thus it is an important new technology but probably not a revolutionary one.[10]

The Pentagon hopes to field a transport helicopter by 2015 or so that would require 40 percent less fuel, weigh 60 percent less, and travel about 50 percent faster than existing models. It would certainly be nice to achieve those goals. However, they are precisely that—goals, not realities—and actual aircraft could well fall short of them. Even if attained they are not particularly striking for aircraft that will fly in the 2020s and beyond. The Pentagon clearly expects helicopter transport in the early decades of the twenty-first century to be better than, but in the end similar to, helicopter transport of the late twentieth century.[11]

Fixed-wing transport aircraft may be able to fly more efficiently by 2020 by reducing the effects of turbulence on their airframes. A plethora of microsensors and small flaps or holes in the wings connected to suction pumps may be used to detect turbulence and selectively modify airflows to reduce it.[12] Large tilt-rotor aircraft may someday be possible for long-range strategic transport missions, but these technologies lie well in the future.[13] In addition, even if perfected, they will not change the fact that airplanes will possess only modest payloads by comparison with the weights of major

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[9] Assistant Secretary of Defense David S. C. Chu, comments at a special hearing before a subcommittee of the Senate Committee on Appropriations, 101 Cong. 2 sess., July 19, 1990 (Government Printing Office, 1990), p. 51; L. Dean Simmons, "Assessment of Alternatives for the V-22 Assault Aircraft Program," Institute for Defense Analyses, June 1990, Alexandria, Va., p. 17.

[10] Chu, comments before a subcommittee of the Senate Committee on Appropriations, p. 47.

[11] George I. Seffers, "Rotorcraft Design to Target All U.S. Services," *Defense News*, May 17, 1999, p. 14.

[12] See Covert, "Evolution of the Commercial Airliner," p. 113.

[13] Colin Clark and David Mulholland, "Pentagon Science Chief Pushes Leap-Ahead Research," *Defense News*, November 9, 1998, p. 6.

Table 8. Availability of Catholic Secondary Schools, 1974–99[a]

City	*1974*	*1979*	*1984*	*1989*	*1994*	*1999*
New York	84	71	68	66	61	60
Chicago	51	45	36	32	29	27
Los Angeles	24	24	23	22	20	18
Philadelphia	24	22	21	20	16	14
New Orleans	20	20	19	17	14	14
Boston	19	15	13	13	8	7
Detroit	17	15	11	10	7	8
Washington	15	12	12	10	6	7
Pittsburgh	14	12	8	6	5	6
San Francisco	14	13	12	10	7	7
Buffalo	13	11	10	7	7	7
San Antonio	12	10	10	10	9	8
St. Louis	12	8	9	7	7	7
Omaha	11	10	9	9	6	6
Cincinnati	10	10	9	9	9	9
Baltimore	10	10	10	9	9	8
Milwaukee	9	8	7	6	5	6
Louisville	9	7	8	9	8	8
Cleveland	9	8	7	7	5	5
Indianapolis	9	6	6	6	6	6
Columbus	8	7	7	6	5	5
Kansas City	8	8	5	5	5	4
Houston	7	8	8	8	7	7
Toledo	7	7	6	5	5	5
Honolulu	6	6	6	6	5	5
Miami	6	5	3	3	3	3

a. Sample includes all the cities that had more than five Catholic secondary schools in 1974. The numbers for 1979 differ in some cases from those reported in Neal (1997). Neal used the city listed in each school's mailing address to calculate city-specific totals. This procedure led to false counts for two reasons. First, some schools in suburbs use a central-city name in their mailing address. Second, some schools located in unincorporated communities within cities list the community name in their mailing address—for example, East Boston, Massachusetts, actually lies within the Boston city limits.

omitted category includes small towns with populations less than 25,000 in 1990. The results indicate that cities with more than 500,000 residents lost about five schools more, on average, than small towns. Column B highlights the relationship between population changes and changes in the supply of Catholic high schools. We use the difference in the number of children under age fourteen between 1970 and 1990 to measure changes in the youth population for cities, and include separate measures for black, Hispanic, and white youth.[26] Two interesting results emerge from this regression. First, the measures of youth-population change account for a large portion of the school closings in large cities. Holding changes in youth population constant, cities

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[26] The "white" category includes all nonblack and non-Hispanic youth.

Table 9. Change in the Supply of Catholic Secondary Schools (OLS)[a]

Variable	*A*	*B*	*C*
Population			
More than 500,000	–5.24	–1.13	–1.18
	(0.31)	(0.24)	(0.25)
250,000–500,000	–1.09	–0.30	–0.33
	(0.24)	(0.16)	(0.17)
100,000–250,000	–0.24	–0.08	–0.10
	(0.17)	(0.11)	(0.11)
50,000–100,000	–0.12	0.02	0.01
	(0.14)	(0.09)	(0.09)
25,000–50,000	0.14	0.21	0.21
	(0.14)	(0.09)	(0.09)
Change in youth (units of 10,000)			
White	...	0.42	0.42
		(0.02)	(0.02)
Black	...	0.74	0.74
		(0.06)	(0.05)
Hispanic	...	0.23	0.23
		(0.04)	(0.04)
Region			
Northeast	...	...	–0.001
			(0.13)
North-central	...	...	0.26
			(0.12)
South	...	...	0.34
			(0.11)
Change in Catholic adherents	...	...	0.004
(Units of 10,000; counties: 1980–90)			(0.0017)
N	764	764	764
R^2	0.30	0.71	0.72

a. We include cities with at least one Catholic high school in 1974 and population data for 1970 and 1990. We also dropped cities in Virginia because the SCCM data on Catholic adherents provide nonstandard county codes for Virginia. Numbers in parentheses are standard errors.

in the largest population category experience a net loss of between 0.83 and 1.34 schools relative to cities of other sizes. Second, the racial composition of changes in youth populations matters for changes in school availability. In table 9, population changes are measured in units of 10,000 persons. Therefore, the coefficient of 0.42 in column B implies that a decline of about 24,000 in the white-youth population is associated with the loss of one Catholic high school. However, the corresponding effect for black youth implies that changes in the supply of Catholic high schools are more highly correlated with changes in the population of black youth. Here the estimated coefficient associates a one-unit change in school availability with a change of approximately 13,500 in the black youth population.

Column C adds region dummies and controls for changes in the number of Catholic adherents in the county associated with the city in question. We measure the change in adherents between 1980 and 1990 because data are not available for 1970. Further, we measure the change at the county level because the Survey of Churches and Church Membership does not provide data for units smaller than counties. The introduction of these variables does not greatly affect the other coefficient estimates. However, the region dummies are interesting in their own right. The omitted region is the West. Cities in the North Central and Southern regions exhibit a small edge in maintaining Catholic-school availability. The coefficient for change in Catholic adherents is quite small in magnitude. A change in Catholic adherents of 2.5 million is associated with only a one-school change in supply. We conjecture that this coefficient understates the actual correlation between changes in Catholic adherents and changes in school availability. The measure of adherent change is quite noisy for two reasons. First, it only captures changes over the period 1980–90. Second, it measures changes at the county rather than at the city level. Thus far we have not found data on Catholic adherents that will allow us to construct more accurate measures.

In sum, the NCEA data on Catholic-school availability show a marked decline in Catholic secondary schools through 1994 and little change since then. While the supply of these schools has diminished generally, the supply has declined most dramatically in large cities, the places in which they have their greatest value added. Changes in youth populations account for much but not all of the additional school losses in large cities.

Several questions become apparent in light of the NCEA data. Is the recent growth of both publicly and privately funded voucher programs in part a response to the loss of Catholic-school or other private-school options over the past three decades? Does the reduction in school closings after 1994 reflect support or expected support from publicly or privately funded voucher programs that have been proposed, started, or expanded in recent years? Answers to these questions lie beyond the scope of this paper, but the 1994–99 data should not be ignored. For some reason, a decline in the number of Catholic secondary schools that had continued for at least two decades came to a halt during the last five years. Understanding the reason for this turnaround may be an important step toward understanding how the supply of Catholic and other private schools will change in response to future changes in education policy.

Conclusion

Analyses of the NELS data provide results that are fairly consistent with previous results reported by Neal and by Evans and Schwab.[27] Catholic secondary schooling is associated with attainment gains for urban students generally and for urban minorities in particular. Suburban whites in Catholic schools do not enjoy significant attainment gains. There is some evidence that Catholic schooling enhances college attendance among suburban minorities but little evidence that Catholic schooling raises high-school graduation rates among these students. With respect to gains in math achievement, the effect of Catholic schooling on median scores is large among urban minorities, although the OLS results imply smaller gains in mean scores. Among whites, Catholic schooling is generally associated with modest achievement gains. There is little evidence, however, that Catholic schooling enhances math achievement among suburban minorities.

Overall, the univariate results suggest that urban minorities gain the most from Catholic schooling, and the bivariate analyses provide no evidence that the univariate results for urban minorities are driven by positive selection into Catholic schools on unmeasured student traits. Nonetheless, we rely primarily, and in many instances exclusively, on assumptions concerning functional forms and error distributions to identify the bivariate models, and we do not offer these results as definitive proof that the univariate results for urban minorities are not affected by selection into Catholic schools on unmeasured student traits.

We noted above the possibility that students in NAIS schools experience small gains in attainment and achievement because their next best option is an elite public school. Similar reasoning may yield some insight into the differences between the estimated gains from Catholic schooling among urban minorities and the estimated gains from such schooling among other groups. Catholic schooling should yield larger benefits among urban minorities if public schools differ greatly in quality and urban minorities face a particularly poor menu of schools within the public sector.[28]

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27. Neal (1997); Evans and Schwab (1995).

28. Neal (1997) provides some evidence that this is the case. Within the public-school sector, predicted graduation rates for whites and minorities are similar, except in large cities. Urban minorities in large cities graduate at lower rates than expected relative to urban whites, given the similarity between the graduation rates of minorities and white students elsewhere.