Chapter Six

LESSONS FROM THE COMMERCIAL AEROSPACE MARKET

The case study evidence presented in Chapters Three through Five of this report suggests that, in the critical area of radar-related microwave and millimeter-wave technologies, the dual-use promise of CMI and related acquisition reform measures is real. The technological breadth and depth necessary to support a comprehensive CMI strategy appears to be emerging, and there is some evidence to suggest that commercial-grade parts and components can be successfully inserted into RF/microwave military avionics systems without degrading system performance.[1]

But the evidence also indicates that to take full advantage of the overlap between commercial and military products and processes, DoD and its contractors must adopt a more commercial-like approach to weapon system acquisition. For example, it may be necessary for DoD to grant configuration control and change authority to contractors, at least at the subsystem and parts level, throughout the life of the system. This practice, widespread in the commercial world, will require that DoD and contractors alike be fully aware of the performance, schedule, and cost priorities for different weapon systems.

DoD may also benefit from adopting other mechanisms commercial firms—and particularly the "best" commercial firms—have developed to minimize the risks of inadequate product performance and

[1]Legitimate concerns remain about the long-term reliability and durability of commercial-grade parts and components.

excessively high costs. Many of these mechanisms are now being tested in DoD pilot programs; others have already been widely embraced. For example, to reduce the chance that weapon systems will fail to meet high-priority performance and cost objectives, Integrated Product Teams (IPTs) are being implemented throughout the DoD acquisition process to the maximum extent practicable. "Best value," as opposed to "lowest bid" source selections are now DoD policy. And many military specifications and standards documents have been either inactivated or cancelled. Other mechanisms appear to be underused. For example, DoD rarely engages in R&D risk-sharing arrangements with its contractors, although this practice could discourage some of the program cost escalations that have plagued it in the past. In addition, in large part because of the continued prevalence of cost-type R&D contracts, stringent cost-reporting requirements still apply to "noncommercial" items; these have a considerable cost impact on most weapons programs.

Nevertheless, there are legitimate reasons for caution. Before throwing out such important policy instruments as TINA, CAS, and various audit and oversight requirements, for example, DoD should evaluate the alternative mechanisms commercial businesses use to control costs and deter fraud. Similarly, before relinquishing ownership and control of technical data, DoD should consider the long-term implications for the reliability and supportability of its systems.

More broadly, some of the questions that DoD must consider before choosing to adopt wholesale a commercial-like approach to acquisition include:

1. To what extent can system cost be reduced without sacrificing performance?
2. Will qualified contractors be willing to absorb more of the market and technical risk associated with new aircraft system and subsystem development?
3. Can DoD promote and maintain adequate levels of competition in the absence of heavy regulation?
4. Can DoD ensure the supportability and maintainability of systems over time if contractors retain configuration control and change authority?

In this chapter, we examine ways in which U.S. participants in the market for large transport aircraft have approached similar questions, highlighting their relevance to DoD. Combining information from a variety of sources, including interviews with industry professionals, on-site plant visits, and various published and unpublished materials on commercial practices and processes, we draw an analogy between commercial and military aircraft manufacturers and between commercial airlines and DoD.

We choose the large transport aircraft market for our case study for three reasons. First, the commercial airliner market has many structural similarities to the market for military aircraft. These similarities suggest that the same sorts of strategies may be effective in both markets. Second, in the 1980s and 1990s, a fundamental movement toward price-based competition among U.S. airlines, airframe integrators, and aircraft system and subsystem suppliers has forced all firms in the industry to rethink the way they do business. Their responses to the pressures introduced by airline deregulation and to the emergence of strong foreign competition provide useful lessons both for DoD and military contractors who must learn how to operate in a world that is now severely cost-constrained.[2] Third, because many aircraft manufacturers operate in both commercial and military markets, their responses to changes in the commercial sphere may tell us a great deal about how they will respond to changes in the military sphere.

We suggest that, as DoD's approach to airborne weapon systems acquisition begins more closely to resemble the approach used by commercial airlines to purchase airliners, military contractors will respond by adopting many of the same strategies now prevalent among commercial aircraft manufacturers. In sum, DoD may expect to see an acceleration of the following trends:

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[2]Although the number of firms in the commercial aircraft industry has declined, competition as measured by price pressure has increased with the entry of Airbus, a point that is discussed in more detail below. The situation is similar to that of the U.S. auto industry, which underwent a period of consolidation at the same time as—and partly because of—Japanese entry into the market in the 1970s. Unless otherwise noted, our use of the term "competition" refers to the degree of downward pressure on prices, not the number of competitors.

1. Greater emphasis by contractors on lowering the cost of purchasing and operating military aircraft as opposed to improving their performance characteristics.
2. Greater market and technical risk-sharing between prime contractors and suppliers of military aircraft systems, subsystems, parts, and components.
3. More intense competition accompanied by increased industry consolidation and greater foreign participation at all levels of the industry supply chain.
4. Greater integration of military aircraft R&D with maintenance, repair, and overhaul activities.

STRUCTURAL SIMILARITIES: MILITARY AND COMMERCIAL AIRCRAFT MARKETS

As discussed in Chapter Two, the structural characteristics of the markets in which transactors operate in large part determine the types of risks that they face. For example, in markets where there are many possible buyers for a product, market risk is relatively small. Stated another way, the risk that a firm will have to write off an investment because no one buys the product is higher in markets where potential buyers are few. Similarly, in markets involving new and complex technologies, technical risk is higher than in markets where technologies are well known. That is, the risk of being forced to write off an investment because the product fails to meet buyers' desired performance capabilities is higher in markets where technologies are still being developed.

Table 6.1 provides a generalized characterization of three types of markets: military aircraft markets, mass commercial product markets, and commercial aircraft markets. As the table makes clear, military aircraft markets do not look much like mass commercial product markets such as those for consumer electronics, automobiles, or microprocessors. Military aircraft markets generally have small production runs; potential buyers are few and their requirements specific; technologies tend to be expensive and untried; performance requirements at initial purchase and beyond are stringent; and the tolerance for performance variability is extremely

Table 6.1

Structural Characteristics of Commercial and Military Markets

Characteristic	Type of Market: Military Aircraft	Mass Product	Commercial Aircraft
Output Quantity			
Total production	Small	Large	Small
Rate of production	Small	Large	Small
Nature of Demand			
Number of buyers	One buyer	Many buyers	Few buyers[a]
Who defines product?	Buyer	Seller	Seller, with significant buyer input
Demand stability	Highly uncertain	Fairly stable	Cyclical
Nature of Technology			
Technological challenge	Very high	Generally low	High
Learning effects	Important throughout production run	Modest at mature production	Important throughout production run
Performance and Service Requirements			
Level of performance	Stringent	Nonstringent	Stringent
Variability of performance	Nontolerant	Tolerant	Nontolerant
After-market service	Extensive	Limited	Extensive

NOTE: The description of markets is highly generalized. Many exceptions exist.

[a]Although there are well over 100 airlines, a few of the largest effectively determine the success of a new aircraft model.

low. To a large extent, these characteristics are inherent to the nature of the demand for military aircraft, and will not be affected by the introduction of commercial approaches to acquisition. To identify the commercial business practices that are potentially most useful to DoD, therefore, we should look to markets whose structural features most closely resemble military markets.

As Table 6.1 suggests, the military aircraft market has few features in common with commercial mass markets, but has several features in common with commercial aircraft markets. For example, as with military aircraft, low rates of production for and small total outputs of commercial airframes, aircraft systems, and subsystems result in high per-unit costs. Further, commercial airliner production is characterized by strong learning effects. Average production costs decline steeply over time in part because design changes may continue to be introduced well after the start of full-scale production.[3] Although commercial aircraft are not made-to-order in the same way as military aircraft, manufacturers must still be highly responsive to the needs of airlines, who are able to influence many performance aspects of the aircraft they buy. Finally, firms in the commercial aircraft industry employ stringent measures to limit the performance variability of the aircraft they build, and have after-sales service and maintenance requirements comparable to those found in the military aircraft sector.

There are, however, at least two important ways in which the market for military aircraft differs from the commercial aircraft market. First, unlike DoD, airlines rarely request that new airliners incorporate dramatic technology innovations. Instead, their approach to improving aircraft performance tends to be incremental, with a heavy emphasis on cost. Thus, although commercial transports are technologically complex by the standards of most consumer products, they generally involve less technical risk than military aircraft.[4] Because commercial airframe integrators and their suppliers can be fairly certain of meeting the performance requirements called for by airlines, they are willing to invest huge sums in new aircraft development. To get military contractors to do likewise, it may be necessary for DoD to lower the technical risk of military aircraft development by taking a more incremental approach to the introduction of new technologies.

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[3]For this reason, early studies of production learning curves such as Berghell (1944) often focused on the aircraft industry. In recent years, investments in computer-aided design and manufacturing programs have been largely motivated by a desire to reduce expensive last-minute design changes.

[4]On the commercial side, possible exceptions include Pan American World Airways' role in encouraging the development of the Boeing 747 and the supersonic transport, discussed at greater length below. On the military side, new military transports are generally less technologically challenging than new fighter aircraft. An additional explanation for airlines' generally more conservative approach to innovation is their desire to maintain commonality of equipment—and thus lower maintenance costs—on their fleets.

The second way in which the military aircraft market differs from the commercial market concerns the unpredictability of demand even under conditions of no technological uncertainty. In the commercial sector, multiple independent airlines represent possible buyers for commercial aircraft. If one airline chooses not to buy a newly developed aircraft, the manufacturer has—at least in theory—plenty of other opportunities to convince others of the advantages of purchasing the plane. In contrast, defense contractors must rely on DoD and on the often variable political factors that influence both the level and composition of DoD's budget to make a sale. Defense contractors' inability to diversify their customer base for military aircraft significantly raises the market risk they face relative to firms operating in the commercial world.

In this respect at least, the difference between the commercial and military worlds is not quite as big as it may at first seem. One reason is that DoD does not act entirely as a single buyer: The different military services have different requirements for aircraft, so that failure to sell to one does not preclude success with another. Foreign military sales, although restricted, provide another possible market outlet. A second reason is that airlines do not act entirely as independent buyers: Although there are many commercial airlines, a few very large carriers are responsible for the majority of aircraft sales.[5] As we discuss in more detail below, it is often in the interest of these airlines to cooperate with each other both with respect to defining performance requirements and actually choosing which new aircraft to buy. Further, because airline demand for equipment is heavily influenced by movements in broad macroeconomic variables such as energy prices and economic growth, these carriers' requirements tend to be quite similar in terms of what they want and when they want it. This means that shifts in the demand for different types and quantities of aircraft tend to be synchronous, effectively mimicking the behavior of a single buyer. Market-risk-management mechanisms developed by the commercial aircraft industry, therefore, may still have relevance to the single-buyer military world.

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[5]In the U.S. domestic market, 10 airlines accounted for 93 percent of revenue passenger miles in 1994 (Kaplan, 1995, p. 151). Because U.S. trunk airlines are among the only carriers able to make single orders of 20 or more aircraft, they are critical to the successful launching of new airliners (Zhang, 1996, p. 2).

THE RISE OF "MUST COST"

Not so long ago, the U.S. commercial aircraft industry exhibited many of the features still common to the military aircraft industry: widespread use of simple cost-plus R&D contracts, substantial government-financed R&D applicable to commercial air transport, long development cycles, and limited price-based competition.[6] In the past two decades, however, two events have combined to change the industry dramatically: the passage of the Airline Deregulation Act of 1978 and the emergence of strong foreign competition for U.S. commercial airframe integrators and their U.S. system and subsystem suppliers.[7] The transition of the U.S. airline industry, and by extension, the U.S. commercial aircraft industry, from an environment dominated by government regulation to an environment of free and fierce competition provides a useful model for DoD and its military contractors, who are undergoing a similar and no less profound transition as a consequence of severe defense budget constraints.

The Airline Deregulation Act of 1978 forced a profound shift in the way that U.S. airlines (and to a lesser extent airlines worldwide) operate.[8] Prior to 1978, the regulated fare structure set up by the Civil Aeronautics Board (CAB) required all airlines to charge the same fare for the same service.[9] Furthermore, entry into the air transport in-

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[6]We use "simple cost-plus" contracts as a shorthand for contracts in which the buyer assumes all the risk associated with cost overruns. The percentage of total U.S. aerospace industry R&D financed by the private sector was just 11 percent in 1960, reaching 22 percent by 1975. Since approximately 1985 it has hovered around 34 percent (AIA, various issues). These calculations include defense R&D as well R&D related to space vehicles, so they overstate the government's contribution to commercial aircraft development. However, in basic research where multiple applications are possible, the overstatement is not so severe.

[7]Less important, but still significant, has been the sharp decline in U.S. government-financed aerospace R&D over the period, which in real terms fell by over 50 percent between 1987 and 1996 (AIA, 1998/99).

[8]Deregulation of air cargo service, which occurred one year earlier, also had an impact on the industry by encouraging the expansion of highly competitive all-cargo carriers such as FedEx and United Parcel Service (UPS). FedEx and UPS have been launch customers for all-cargo versions of Boeing, McDonnell Douglas, and Airbus transports as well as smaller aircraft.

[9]Not all U.S. airlines were subject to CAB regulations: Intrastate carriers, such as those operating entirely within California, were regulated by state public utilities commissions. See Jordan (1970).

dustry was strictly controlled. Because competition based on price was not allowed, carriers competed largely on the basis of other performance characteristics, such as their route structures and the quality of their in-flight service. Equipment cost-minimization was important but not critical because airlines were often able to pass higher equipment costs onto consumers by petitioning for higher fares from the CAB.[10] For example, as jet engine technology began to be commercialized in the late 1950s, the CAB allowed airlines to impose a $10 per ticket surcharge for travel on jet aircraft (Jordan, 1970).

When the barrier provided by protective regulation was abruptly removed in 1978, a flood of new low-cost airlines entered the air transport industry. Intense competition from these new entrants forced several of the established, high-cost airlines into bankruptcy.[11] Those that survived did so in large part by tightening their control over costs. Because of the difficulty of reducing labor costs, which account for a major share of the total costs associated with running an airline, reducing costs associated with the purchase and operation of aircraft and aircraft equipment became a major priority for U.S. airlines.

U.S. carriers' ability to put downward pressure on the cost of buying new aircraft was greatly aided by the emergence of strong overseas competitors to U.S. builders of commercial aircraft. In particular, by the late 1970s the European consortium Airbus Industrie had become a viable alternative to the U.S. commercial airframe integrators—Boeing, Lockheed, and McDonnell Douglas. Offering a product that was extremely price-competitive, by 1979 Airbus had won 26 percent of the market by volume for twin-engine wide-bodied jets. By the end of 1997, Airbus accounted for almost 50 percent of new orders for airliners, or 43 percent by value (Sutton,

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[10]For example, according to Mann (1982), a 1980 survey conducted by the U.S. International Trade Commission found that price ranked fifth among 15 criteria cited by commuter airlines as important to their aircraft purchasing decisions. The first four criteria, ranked in descending order, were passenger capacity, fuel efficiency, quality, and technology.

[11]Between 1978 and 1985, more than 250 new airlines tried to enter the U.S. market, while 260 airlines went bankrupt (Zhang, 1996). Arpey (1995) estimates that bankrupt carriers controlled nearly 20 percent of U.S. airline capacity between 1990 and 1994.

1998).[12] Airbus' success also helped its own preferred system and subsystem suppliers, non-European as well as European, to grow strong. Although many of these suppliers are relatively new to world markets, they now challenge the dominance of the U.S.-based industry leaders.[13]

The combined effect of airline deregulation and increased foreign entry has been to encourage intense competition between airlines and between rival teams consisting of the airframe integrators and their preferred aircraft system, subsystem, and parts suppliers. At all levels of the industry, a new hard-line costing approach, called "must cost," is spurring firms to adopt radical cost-cutting measures.[14] In an environment where failure to achieve price and performance targets incurs enormous financial penalties—and ultimately loss of contracts—suppliers at every level have scrambled to find innovative ways to get their costs down without sacrificing quality.

Under the "must cost" approach to buying aircraft, the airframe integrator first conducts market research to determine potential customer requirements for a new airplane, collecting information about the price per plane as well as other performance- and operating-cost-related objectives desired by airlines. Using the price suggested by the airlines as a guide, the airframe integrator chooses a price and profit target for the finished aircraft, and by a combination of past experience and analysis of technical trends, determines the cost share of each major aircraft system. In consultation with prospective suppliers, the integrator then allocates rigorous price targets based

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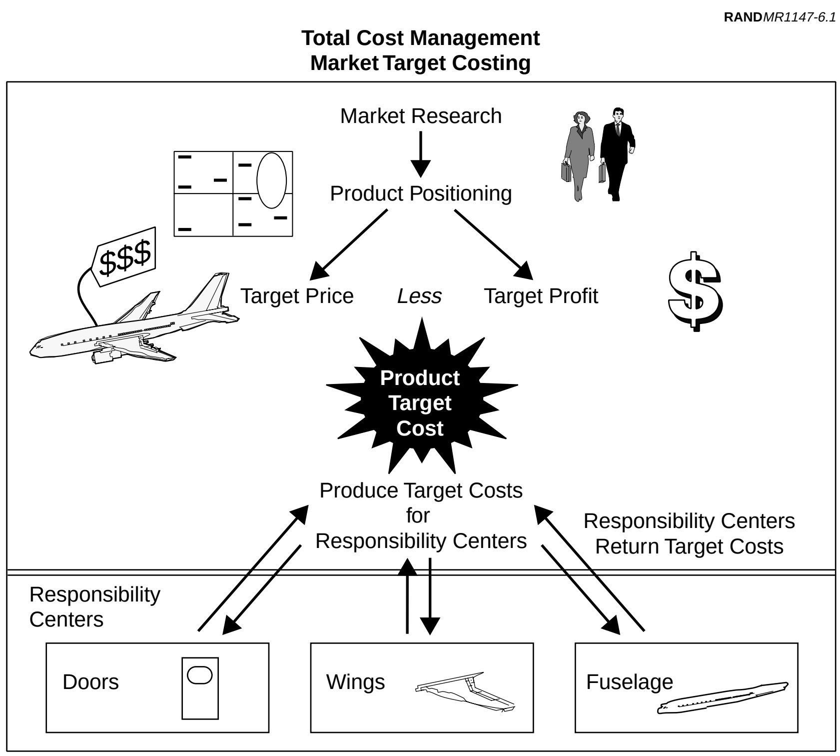
[12]These shares can change significantly depending on whether the measure is new orders, confirmed orders, or aircraft delivered. In 1998, for example, Airbus' share of new aircraft delivered was just 25.5 percent by value, in part reflecting Boeing's acquisition of McDonnell Douglas in 1997 (Flanigan, 1999, p. C-1).

[13]The European avionics firms that form Sextant Avionique, for example, had previously addressed only national military needs. Sextant is a preferred supplier for most Airbus aircraft and competes head-on with U.S. avionics suppliers. See Charles and Ghobrial (1995, p. 607).

[14]Although "must cost" does not mean that price targets are always binding—firms can and do sometimes exceed them—the term illustrates the new emphasis on cost that is found throughout the industry. See, for example, the discussions in Wilson (1996) describing the structure of "must cost" and its importance to McDonnell Douglas. Boeing's term for the "must cost" concept is "market-driven target costing" (Schwendeman, 1997); a description of the "must cost" process at work during development of the Boeing 777 is presented in Sabbagh (1996).

on those shares. In the case of Boeing, for example, this approach to aircraft development differs significantly from Boeing's previous linear approach of design, followed by engineering, and finally cost-estimating.[15] Figure 6.1 illustrates the new approach for Boeing's 757-300.

Figure 6.2 illustrates how "must cost" pricing is passed down the supply chain, using a stylized representation of the cost structure for



SOURCE: Schwendeman (1997).

Figure 6.1—Market Target Costing for the Boeing 757-300

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[15]As described by David Schwendeman of the Finance and Business Management team within the Boeing Commercial Airplane Group (Schwendeman, 1997).

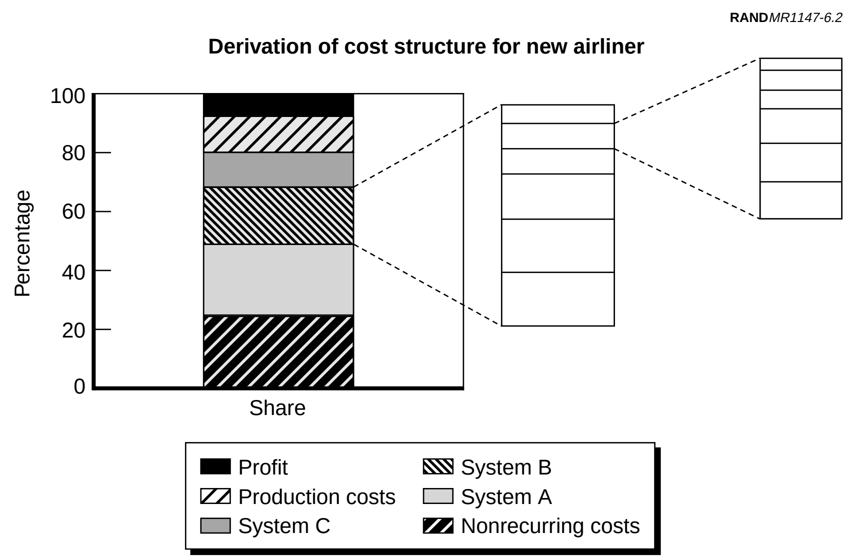

Figure 6.2—"Must Cost" Environment: Airframe Integrator's Cost Structure for New Aircraft Production

a new airliner. In this example, the price that the airframe integrator expects to receive from the airline is allocated among six major categories: nonrecurring costs such as those associated with EMD and program management; prices paid to suppliers for aircraft systems A, B, and C; production costs; and profits earned by the airframe integrator. As illustrated for system B, a similar breakdown exists for each aircraft system and subsystem. Each box represents a target cost share for the prime, system, or subsystem integrator.

The major difference between the "must cost" approach and that taken in the prederegulation environment is that, under "must cost," price targets and not costs tend to drive the size of each box. If, for example, the box representing the cost share for system A gets too big, the system A integrator will find it difficult to pass on the increase to the airframe integrator.[16] In most cases, its most likely

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[16]Even under the old regulated system limits on cost pass-through imposed bounds on the sizes of the boxes.

options are either to find a way to reduce costs or to take a hit on profits.[17] For very large cost overruns that cannot be sufficiently reduced, and where attempts to renegotiate the contract fail, the system integrator must either undertake a discretionary breach of contract or file for bankruptcy.

Because of the priority placed on meeting price targets, "must cost" can only function well if integrators allow suppliers to choose how to design, manufacture, and service their own particular system, subsystem, or part. Instead of detailed technical specifications, products are defined in terms of generic performance requirements, form-fit-and-function (FFF) specifications, and the Federal Aviation Administration (FAA) safety standards required for new aircraft certification. This approach gives suppliers sufficient flexibility to respond to unexpected cost increases as well as to introduce new and more-cost-effective technologies. It represents a significant change from the old system, whereby the airframe integrator provided detailed product designs to manufacturing subcontractors who bore little responsibility for the product's ultimate performance.

The shift in technical responsibility from integrator to supplier under "must cost" has been accompanied by a parallel shift in financial responsibility: Suppliers now pay an increasing share of the R&D and certification costs for new aircraft. The increased financial commitment required to do business has encouraged aircraft industry suppliers to adopt one of two strategies—to "bulk up" by merging or allying with suitable partners or to become small niche players. The "bulk-up" strategy has been widely adopted, resulting in a profusion of business partnerships of every sort at every level, from simple risk-sharing arrangements to full joint ventures to outright mergers.

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[17] A recent example described in *Flight International* (1998, p. 13) is an agreement between FedEx and Israeli Aircraft Industries (IAI), a licensed manufacturer of the 150-seat Fokker F-27. FedEx agreed to buy 100 specialized cargo versions of the F-27 developed by IAI provided that the unit price on each aircraft did not exceed $10 million. When IAI found that it would be difficult to meet the price target set by FedEx, it tried to convince FedEx to pay slightly more for the plane. FedEx refused to change the terms of the deal, and IAI is now looking for additional customers for the plane in order to increase the production run and so reduce per-unit costs. The company is also looking for additional subcontractors willing to share IAI's financial risk in return for the opportunity to manufacture major sections of the airplane.

Thus, "must cost" has contributed to an extensive financial restructuring and consolidation of the U.S. commercial aircraft industry.

Foreign firms have also played a role in the industry's restructuring. In addition to their financial capital and market access advantages, foreign firms provide U.S. firms with cutting-edge technologies and a wide range of products. In the avionics market, for example, the two biggest firms, both U.S.-based, have sought out foreign partners: Honeywell has teamed up with the British firm Racal Avionics to become the leading producers of satellite communications equipment, whereas Rockwell-Collins has joined with Dassault Electronique of France on ground collision-avoidance systems.[18] Well-financed and technologically sophisticated foreign firms counterbalance the growing market power U.S. firms are achieving through widespread industry consolidation. The presence of such European heavyweights as Airbus Industrie and Sextant Avionique, for example, greatly reduces the chance that airlines will be victimized by price-gouging on the part of the U.S. market leaders.

Finally, under "must cost," system and subsystem suppliers have increasingly sought cradle-to-grave arrangements with the airlines, whereby they agree to design, develop, manufacture, and provide after-sale support for the final product. The most extreme manifestations of this trend are "power-by-the-hour" and "fly-by-the-hour" contracts for engines and other aircraft systems that are offered as packaged solutions to airlines by the original equipment manufacturers (OEMs). In these types of arrangements, OEMs agree to maintain and service their systems on a long-term basis for a fixed fee based on the number of hours actually flown.[19] Such arrangements benefit the airlines because the promise of a fixed-price maintenance contract gives OEMs an incentive to improve the reli-

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[18]AlliedSignal, the former third member of the avionics "Big Three," announced its merger with Honeywell in June 1999. The combined company is to be called Honeywell (Honeywell, 7 June 1999).

[19]For example, according to the Canaan Group (May 1994), Continental Airlines was able to secure a five-year, no-escalation contract from its maintenance, repair, and overhaul service providers. One reviewer commented that, given the menu-like character of these fixed-price maintenance, repair, and overhaul (MRO) contracts, in many particulars they closely resemble time-and-materials contracts. Time-and-materials contracts are not allowed under FAR Part 12, which governs DoD procurement of commercial items.

ability of designs and so reduce life-cycle costs for the aircraft. They benefit the OEMs because long-term relationships with airlines stave off competition from independent after-market suppliers toward the end of a system's life.

The "must cost" pricing constraints imposed on the commercial aircraft industry by the airlines in many ways parallel the DoD budget constraints that military aircraft manufacturers now face. The commercial industry's response to "must cost"—and the factors that are driving it—thus may provide important lessons to DoD. In the sections that follow we discuss how this highly constrained commercial pricing environment has led to

- a shift in emphasis from the performance to the cost of commercial aircraft;
- a reallocation of risk between buyers and suppliers;
- a stronger role for foreign firms as both competitors and allies of U.S. commercial aircraft and aircraft equipment manufacturers; and
- an enlarged role for OEMs in the long-term support and maintenance of commercial airliners.

STRIKING THE BALANCE BETWEEN COST AND PERFORMANCE

The promise of CMI is that applying commercial approaches and technologies to military aircraft development will improve performance while at the same time dramatically lowering life-cycle costs. A major concern is that the performance of U.S. military aircraft (and weapon systems more generally) will be compromised as a result of the commercial-market emphasis on minimizing costs. The concern is twofold. First, for any given system, there is the question whether technologies developed for commercial applications will perform as well in military environments, either because military environments are too rigorous or because the performance variability of commercially derived items is too great. The question here is the extent to which commercial technologies can truly be "dual use." We address this primarily in the first part of this report.

The second concern about CMI is in some ways more profound than whether commercial technologies can be dual use. It pertains to the nature of commercial-world tradeoffs between cost and performance. Can commercial approaches predicated on cost-minimization produce the highly innovative, high-performance technologies embodied in U.S. military aircraft?[20] To shed light on this question, in this section we examine how the rise of "must cost" has affected the cost-versus-performance tradeoffs chosen by the manufacturers of large transport aircraft.

Prior to airline deregulation, low cost was not a highly weighted objective of commercial aircraft manufacturers. A more important objective was to build technically sophisticated aircraft that could outperform those built by industry competitors.[21] Giving greater emphasis to performance, rather than cost, was legitimate from a business point of view because, under a unified fare structure, airlines could usually be persuaded to buy a more expensive but technologically superior new aircraft if convinced that their competitors were going to do so too. Cost increases associated with improved performance could be passed on to the flying public via the CAB. Thus, although contracts between airlines and aircraft manufacturers were not set up formally as cost-plus, the effect on incentives was similar.

The case of the Boeing 747 provides a prominent example of the airlines' "follow the technology leader" approach. In the 1960s, the only major airline pushing for the development of the 747 was Pan American Airways (Pan Am), whose strong-minded chief executive had already become a legend in the commercial aircraft industry. According to other airline industry executives, many U.S. and foreign carriers only reluctantly bought 747s because they feared the potential marketing advantages the plane might give their competitors,

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[20]As discussed in Chapter Two, some CMI advocates believe commercial approaches lead to performance that is superior to performance achieved through traditional military approaches. Other observers claim that, at least in the commercial aircraft industry, the emphasis is on reliability at the expense of complex features, leading to performance that is "good enough" rather than "superior."

[21]Some authors argue that the aircraft industry's traditional emphasis on performance over cost developed because engineers—rather than professional managers—have tended to dominate top management. See, for example, Irving (1993, p. 201).

especially Pan Am. They bought the 747 despite their concern that the plane's immense size would make it uneconomical to operate. Newhouse (1982, pp. 121–22) quotes the former chief executive of Trans World Airlines (TWA) as saying: "We were reluctant participants in the 747. But we couldn't afford to sit it out. Had we known that the DC-10 and L-1011 were coming along, we might well have sat it out." Similar stories are told about American, Delta, and Eastern Airlines.[22]

Another example of technology and marketing outweighing cost concerns was the U.S. effort in the 1960s to develop a supersonic transport (SST). Although most U.S. airlines were not strong supporters of the SST, none was willing to concede the potential advantages of super-fast flight to a rival. As with the 747, Pan Am had expressed keen interest in such a plane.[23] Further, because the British and French were moving ahead with their own supersonic airliner, the Concorde, it seemed certain at the time that European carriers would soon be flying Concordes. According to Heppenheimer (1995, p. 229), "Boeing and the FAA estimated that even if the SST were restricted to overwater [supersonic] flights it could still sell five hundred airplanes." With no restrictions, their sales estimate was closer to 1200 planes. Thus, despite a lack of enthusiasm on the part of airlines (as well as potential passengers), Boeing and the FAA embarked on a $1.3 billion development program confident that by the time the SST was ready to fly, the demand would be there.

In the end, environmental concerns forced the FAA to abandon its efforts to develop the SST. Because the government had been paying for roughly 90 percent of the SST's development, when the FAA dropped the program in 1971, so did Boeing. After spending more than $130 million of its own funds, Boeing was unwilling and unable to assume the remaining technical and market risks associated with such an ambitious development program. Boeing's decision was

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[22]Heppenheimer (1995, p. 223) suggests that, with the 747, Pan Am had "coerce[d] the domestic airlines into buying equipment they didn't need and could barely afford." Rodgers (1996, p. 251) argues that Pan Am "always set the standard for the latest in air travel, and other airlines had to order the new airplane to keep up."

[23]In June 1963, the President of Pan Am, Juan Trippe, challenged the U.S. government to increase its commitment to the program by announcing that Pan Am would take options on the European-built Concorde (Heppenheimer, 1995, p. 207).

validated when the European threat proved to be a chimera: With the onset of the first oil crisis of 1973–1974, any demand there might have been for the highly fuel-inefficient Concorde disappeared. Of the 20 Concordes that were built, all were sold to the (then government-owned) British and French national airlines.

In today's highly competitive, deregulated environment it is possible that such inherently risky projects as the 747 and SST might never have reached full-scale development. Rodgers (1996, pp. 243–244) claims that neither Boeing nor Pan Am conducted detailed analyses of projected costs and revenues for the 747 program. Apparently, Boeing executives preferred to rely on their own informal judgments about the plane's prospects. In 1996, by way of contrast, market analyses convinced Boeing executives not to risk going ahead with an approximately $10 billion program to develop a "superjumbo" version of the 747 with seating for between 500 to 1000 passengers.[24] Their prudence was rewarded on Wall Street with an immediate jump of over 6 percent in Boeing's share price (*The Economist*, 1997). And in February 1998, Airbus decided to delay its planned 1999 launch of a similarly sized aircraft, the Airbus A3XX, by at least nine months. Some analysts question whether, as a result of both technical and marketing problems, the A3XX will also eventually be drastically downsized or even cancelled (Lane, 1998).[25]

Efforts to develop a modern-day SST are also in jeopardy. Although NASA is bearing the technical risk associated with development of the High-Speed Commercial Transport (HSCT), an aircraft designed to carry 300 passengers at over twice the speed of most modern jetliners, the program is supposed to be privately funded after it reaches its targeted 2002 "technology readiness" date. But the HSCT is expected to reach profitability only if airlines can charge on average a 30 to 40 percent surcharge over subsonic fares (Saounatsos, 1998). This profitability constraint makes it doubtful whether the privately

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[24]Boeing has since indicated that it may still be interested in developing a 550-seat transport that would have a high degree of commonality with the 747-400 and 777. One very large common feature could include the engines that were developed for the 777 (Proctor, 26 April 1999).

[25]In December 1999, Airbus announced plans to "gauge the potential demand" for a new 650-seat airliner, but many experts still believe such a large plane will be economically unviable (*Los Angeles Times*, 9 December 1999).

funded second phase of the program will ever be implemented (Sweetman, 1996).[26] Market research suggests that the aircraft's intended market—primarily first- and business-class passengers—are not willing to pay much of a premium for supersonic service (Sweetman, 1996; Saounatsos, 1998).

Consumers' preferences for cheap fares above all else—except for air safety and the frequency and convenience of flights—are driving airlines to adopt new aircraft acquisition strategies that strongly emphasize cost.[27] Under "must cost," carriers generally are not willing to pay for technology innovations that improve the performance of aircraft or aircraft equipment unless they believe those improvements will contribute to their immediate bottom-line profitability.[28] In November 1998, high-ranking representatives from up to 40 world airlines and aircraft leasing companies, including the largest, met to petition Airbus and Boeing to build less-expensive "no frills" transports. The two airframe integrators were asked to estimate how much of a price reduction the airlines could expect if they agreed to buy basic versions of airliners with many current options removed.[29]

Despite these indications that performance innovations are taking a back seat to cost containment, it would be misleading to argue that "must cost" has stifled technological improvements in the aviation industry. In some ways it is quite the opposite: Many cost-saving product redesigns and technology applications might not have taken place without the pressure of "must cost." In fact, the "must cost"

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[26]Environmental concerns relating to noise levels are also reportedly placing the program in jeopardy.

[27]Consumers of air travel, and especially business travel, often strongly prefer the convenience of nonstop flights. On low-density intercontinental routes, however, large long-range aircraft such as 747s have relatively high seat-mile costs. The response to the airlines' requirement for long-range aircraft with lower seat-mile costs has been the development of twin-engine, twin-aisle planes such as the Boeing 777.

[28]In one industry interview, it was suggested that the required payback period for investments in older aircraft retrofits can be as short as six months.

We distinguish here between technology innovations that are strictly performance-related (such as increasing an aircraft's speed or range) and innovations that reduce operating costs. Innovations designed to increase an aircraft's fuel efficiency or operational reliability fall into the latter category.

[29]Customized features now account for approximately 4 percent of an average aircraft's price (*AWST*, 1998).

pricing system has so successfully met the basic requirements of high quality at low cost, it has been widely adopted throughout the commercial aircraft industry. From builders of all-cargo freighters to builders of business jets there has been a willingness to enforce and accept rigorous price and quality targets. The results can be seen in new aircraft prices. Zhang (1996), for example, estimates that prices for new jet aircraft, adjusted for quality differences and relative to the prices in the economy overall, fell by more than 12 percent between 1978 (one year before airline deregulation) and 1990.[30]

By and large, the "must cost" approach has delivered what consumers seem to want: Between 1979 and 1994, the average fare per passenger mile fell by more than 8 percent in real terms on U.S. domestic flights. In western and southwestern states, where many low-cost carriers have entered the market, fares on some routes have fallen by as much as 20 percent.[31] Further, the total number of scheduled departures from U.S. airports has increased by more than 50 percent and flights have become more reliable as well as more convenient.[32] Airline safety records have also improved since deregulation: According to the FAA (1996, p. 3), "in the 16 years prior to deregulation, there was an average of one fatal accident for every 814,000 flights. By 1994—16 years after deregulation—that figure dropped to one for every 2 million flights."[33]

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[30]Calculated relative to the gross domestic product (GDP) deflator. For aircraft as a whole, that is, including military aircraft as well as single-engine piston-powered aircraft and business jets, new aircraft prices rose quite strongly relative to prices for all other commodities over the same period. Unadjusted for quality improvements, the real price increase for all new aircraft was 43 percent between 1978 and 1990 but approximately zero between 1986 and 1998. Authors' calculations based on producer price data from the Bureau of Labor Statistics.

[31]Based on GAO (April 1996) estimates. On some routes, fares have increased since deregulation.

[32]One study found that, since airline deregulation, there has been a significant increase in the number of engine hours between major overhauls, but in-flight shutdowns have not increased (Kennet, 1993).

[33]Nevertheless, some critics believe that aircraft manufacturers have been allowed to sacrifice safety for reductions in cost. For example, the move from three to two pilots on long-haul aircraft and the FAA's decision to allow two-engine aircraft to fly transoceanic routes have both been sharply criticized. See, for example, Galipault (1991).

What consumers have not gotten for the most part are planes that are significantly faster or more comfortable.[34] Technology innovations have focused overwhelmingly on two goals: reducing airline operating costs and maintaining airline safety records in the face of huge increases in air traffic. Improved engine and airframe technologies employed on Boeing's 777-300, for example, allow it to fly from San Francisco to Tokyo for up to one-third less fuel and 40 percent lower maintenance costs than similarly sized early-model 747s (Boeing, 1996–1998a). The time it takes the 777-300 to reach its destination, however, is not significantly different from that of early 747s, and in several important ways there are fewer passenger amenities than on earlier planes.[35]

Airlines have also been cautious about adopting innovations to onboard passenger services, and even ground operations. For example, multichannel satellite communications (SATCOM) systems were first developed in the late 1980s, making it technically possible for airlines to offer passenger services such as in-air fax transmissions and computer modem hookups. Most airlines, however, have only recently installed the necessary passenger equipment. Apparently, they were waiting for SATCOM prices to fall far enough to justify the installation cost. And although the reduction of operations and maintenance costs is clearly important to airlines, Boeing's attempt early on to outfit the 777 with an electronic library system—a system of hyper-linked graphical presentations of maintenance manuals, diagnostic procedures, wiring diagrams, minimum equipment lists, and many other features—was frustrated by airlines' unwillingness to pay the approximately $1 to $2 million estimated cost of installation per shipset (Charles and Ghobrial, 1995). Instead, Boeing decided to provide the plane with a much less ambitious onboard maintenance computer, leaving the electronic library system as an option available from the developer.

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[34]Admittedly, incremental increases in aircraft speeds lead to far more than incremental increases in costs as speeds approach the sound barrier.

[35]On most if not all airlines the average seat size is smaller on newer planes, and there is less leg room in coach class (Gordon, 1990, pp. 124–129). Most airlines have also replaced the 747's optional upper-deck cocktail lounge with business and first class seating. Passenger entertainment systems, on the other hand, are far more elaborate than they used to be.

In fact, even many of the safety innovations introduced by the airlines may have been developed in the expectation that FAA mandates would force the airlines to buy them, rather than in response to market demand. For example, the traffic alert and collision avoidance systems (TCAS) and windshear detection equipment—now standard on all U.S.-registered transport aircraft—have been mandated by the FAA. Similarly, increased air traffic density, especially in the crowded skies over Europe, is causing the FAA to consider whether to require more precise navigation equipment on large transport aircraft. Many airlines are replacing their old long-range navigation and instrument landing system receivers with technologically more advanced global positioning system (GPS) navigation receivers, but it may be because they anticipate a government mandate.[36] Further, many of the innovations introduced on commercial airliners were derived from technology development programs sponsored by the U.S. government. All three products mentioned above—commercial TCAS, windshear detection, and GPS—contain technologies developed with U.S. government support. In the case of GPS, subsidization of commercial users continues.[37]

Our observation is that the "must cost" approach is delivering safe, reliable aircraft to the airlines at extremely competitive prices. However, a budget-induced design conservatism may also be reducing both the size and scope of purely performance-related technological innovations in the commercial aircraft industry. This implies that commercial approaches predicated on cost-minimization will not produce the kind of innovative, high-performance military aircraft desired by DoD unless performance considerations are given a higher weight in decisionmaking than is usual in the commercial world. Even before deregulation, most of the truly big innovations in aviation, such as supersonic aircraft or

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[36]See, for example, market forecasts by Frost and Sullivan (1996). GPS reduces navigational drift from approximately two miles an hour to one mile an hour. This improvement becomes extremely significant for longer transoceanic flights.

[37]The Navigation System Using Time and Ranging (NAVSTAR) satellites tracked by GPS receivers were developed and produced by the U.S. Air Force. They continue to be maintained by DoD. The National Aeronautical and Space Administration was the first to develop windshear detection technology; it then encouraged private manufacturers to commercialize (NASA, 1995). Other aircraft innovations developed in part with government money include the high-bypass turbofan jet engine.

high-bypass turbojet engines or even jet engines themselves, were financed in whole or in part by governments. With the move toward incrementalism introduced by "must cost," these types of innovations may be less likely to appear.

FROM COST-PLUS SUBCONTRACTING TO SHARED-RISK PRODUCTION

A second issue is how to get contractors to finance a greater share of military research and development. The current system, under which DoD pays for 100 percent of R&D costs, is becoming problematic in an era of tight budget constraints. As the number of firms that DoD can afford to support on any particular R&D program declines, competition on those programs is reduced. With less competition and no close customer-supplier relationship with DoD, contractors' incentive to control costs in the later phases of new aircraft programs is also reduced.

A key feature of a "textbook" approach to acquisition is that firms bear the risks—as well as reap the rewards—of their own product development. However, in most textbook-type product markets there are many possible buyers. Firms can reasonably suppose that, if they come up with an attractive product at an attractive price, sufficient buyers will be found to earn an acceptable rate of return on their investment. In contrast, to recoup its investment, a defense contractor must rely on a single buyer, DoD, whose demand depends on highly variable international military and political factors as well as domestic political ones. Further, the capital investment required for developing new weapon system platforms, and especially military aircraft, is substantially greater than for most commercial investments.[38]

It is not surprising, then, that defense contractors are reluctant to use their own money to develop new military aircraft. Nevertheless, as we argue above, in this respect the difference between the commercial and military aircraft worlds is not as large as it may at first appear. The experience of the commercial aircraft industry suggests

[38]An apparent exception to this general rule is the Airbus A3XX, for which the estimated $10 billion development cost is comparable to the estimated $15 billion development cost of the Joint Strike Fighter (JSF).

that DoD does have the ability to exert leverage in this area. Commercial airliners, too, are hugely expensive to develop, and commercial airlines are notoriously fickle customers. Yet, under "must cost," airlines contribute less than ever before to the financing of new aircraft development programs.[39] How do they do it? We next examine how financial restructuring of the commercial large transport aircraft industry, plus a strategy of greater cooperation with airline customers and preferred suppliers, has helped commercial prime integrators adapt to the post-deregulation "must cost" environment.

Despite producing over half the value of most large airliners, aircraft system and subsystem suppliers generally absorbed few of the financial risks of development prior to deregulation. Most contracts between airframers and their suppliers were simple cost-plus arrangements, with a significant proportion of the cost of all design changes covered by the integrator. To keep suppliers honest, integrators spent large sums tracking and documenting changes.[40] There were occasional exceptions: Douglas Aircraft, for example, financed the development of the DC-9 (which became the MD-80 after the merger with McDonnell) by persuading some 20 equipment and component manufacturers to share in its development costs.[41] However, Douglas proposed these risk-sharing arrangements out of financial necessity and did not continue with them in its next major development program, the DC-10.

Simple cost-plus–type arrangements between the airframe prime integrators and suppliers of aircraft systems, subsystems, and parts were possible because, as we noted above, contracts between airlines and airframe integrators were also effectively cost-plus. In addition, airlines shared some of the risk of development by placing substantial downpayments on their orders for new aircraft. In the case of the Boeing 747, for example, just two months after agreeing on basic de-

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[39] Information about the financing arrangements between airlines and airframers is highly proprietary, and arrangements also vary from purchase to purchase. This statement is based on descriptions provided in Rodgers (1996, pp. 351–353), Newhouse (1982, pp. 37, pp. 54–56), Heppenheimer (1995, pp. 307–311), and Sabbagh (1996, pp. 50–54).

[40] Based on industry interviews.

[41] See Bilstein (1996, p. 190).

sign concepts such as shape and approximate size, Pan Am signed a contract promising to pay Boeing half the total purchase price for 25 aircraft—with the first payment to be made well before delivery of the first aircraft. This was perceived to be a large amount even at the time, as downpayments of up to 25 percent were the general rule. Further, the 1966 contract between Pan Am and Boeing to build the 747 included a cost-escalation clause that allowed the initial unit price paid by Pan Am ($18.7 million in 1966 dollars) to rise with increases in labor and wholesale costs over the term of the contract. This type of cost-indexing soon became a standard feature of most aircraft purchase agreements.[42]

But in the 1990s, when the design and development of a new airliner has become a multi-billion-dollar enterprise, contracts for new aircraft are more likely to contain cost *de*-escalation clauses whereby manufacturers promise to reduce aircraft prices as manufacturing efficiencies grow. Further, because of the financial problems that have plagued the airline industry since deregulation, manufacturers frequently find themselves extending credit to the airlines for new aircraft orders instead of receiving downpayments.[43] Airframe integrators can not afford to take on full technical and financial responsibility for new aircraft development now that their ability to pass on unexpected cost increases is extremely limited. This is especially the case in a "must cost" pricing environment, where integrators often guarantee their price, schedule, and performance targets.[44] Boeing's recent difficulties with commercial aircraft production, for example, which included a 20-day shutdown of the 747-400 assembly line in November 1997, are estimated to have cost the company at least $2.6 billion in penalties (Lane, 1997).

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[42]The basic unit price Pan Am agreed to pay for the 747 in April 1966 ($18.7 million) seems low considering that the price now listed by Boeing for the 747-400 is $167.5–$187.0 million in 1999 dollars, or approximately $45–$50 million in 1966 dollars. We do not have information on the unit price finally paid by Pan Am for delivery of its 25 aircraft, but Newhouse (1982, p. 120) hints that increases in the prices of labor and materials raised it considerably. For list prices on Boeing commercial transport aircraft, see www.boeing.com/commercial/prices/index.htm

[43]For example, Rodgers (1996, pp. 431–434) describes how the "airline recession" of the early 1990s affected the financing and sales of the Boeing 777.

[44]These targets are usually quite specific. On the 777, for example, Boeing offered separate weight, drag, and fuel consumption guarantees to each of its airline customers (Sabbagh, 1996, p. 191).

Given the enormity of the sums needed to finance the development of a new airliner, plus large penalties for failure to deliver on guarantees, airframe integrators have found that simple cost-plus–type contract arrangements with suppliers are no longer viable. These types of contracts not only do not solve the integrators' financing problems, they also do not provide suppliers with powerful enough incentives to meet aggressive cost and schedule targets. So today, integrators are asking the suppliers of major aircraft systems to become risk-sharing partners in new aircraft development programs.[45] In turn, the major systems integrators are demanding that their own subsystem, parts, and components manufacturers accept greater financial and technological responsibility for their products. Financing capability now ranks with technical performance as a criterion for choosing suppliers. As a rule, all major aircraft industry suppliers now finance most of their own R&D unless a prime integrator (or more often an airline) requests them to incorporate highly specialized features into the product design.

The extent of recent risk-sharing arrangements is illustrated by the fact that not only research and development costs but also flight testing and certification costs are often borne by suppliers. These costs can be quite high—one hour of flight testing can cost as much as $50,000, while certifying a landing system can cost upward of $500,000.[46] For new engine certification, industry analysts estimate that the cost approaches $1,000,000; an engine upgrade certification may cost half as much.[47] Further, national regulatory agencies in other countries often require suppliers to fulfill their own certification procedures. The cost of certification, therefore, is a major variable input into a firm's decision whether to launch a new program or upgrade an existing system.

Why then are commercial aircraft system, subsystem, and parts suppliers willing to assume such enormous risks when they have never done so in the past? A simple but not entirely simplistic an-

[45]However, suppliers rarely put up sufficient capital to entitle them to an equity stake in the new aircraft.

[46]Landing system certification is particularly expensive because the FAA requires 100 problem-free landings at multiple airports in diverse weather conditions to certify an automatic landing system, and many rehearsals are usually required.

[47]Based on industry interviews.

swer is that it is the only game in town: With Airbus, Boeing, and (prior to its merger with Boeing), McDonnell Douglas all requiring suppliers to participate in risk-sharing arrangements, suppliers can either agree to put up their capital or get out of the business.

But the answer goes deeper than this. In any industry, competitive firms recognize the value of good suppliers. To convince suppliers to stay in the business yet assume more of the costs of development, including testing and certification, the airframe prime integrators and aircraft system integrators have taken two related actions. First, they have initiated much closer working relationships with their suppliers than was true in the past. Second, they are reducing the number of suppliers with whom they deal. In sum, commercial aircraft prime and system integrators are adopting many of the "best" commercial practices mentioned in Chapter Two.

Airframe prime integrators now work much more closely with their suppliers than they did in the past. They are also encouraging their suppliers to talk directly with the airline customers, both independently and as part of IPTs. Today, airlines, integrators, and suppliers often cooperate on new aircraft all the way from conceptual design to EMD. During the early stages of the 777 program, for example, Boeing set up 250 IPTs (called "design-build teams" by Boeing), each responsible for a section of the aircraft. Each IPT consisted of engineers and managers from system, subsystem, and parts suppliers, from the launch airline customers, and from Boeing itself.[48] The approach proved so successful that Boeing is using it on its next generation of 717, 737, 757, and 767 aircraft. Boeing is not alone in its approach: Before its merger with Boeing, McDonnell Douglas took a similar approach in the design and development of the MD-95, the now renamed B-717 (Boeing, 1996–1998b).

This closer relationship between system and subsystem suppliers, airframe prime integrators, and airlines necessarily relies on mutual trust to a greater extent than in the past. Suppliers must be convinced that mechanisms such as IPTs will reduce their technical and, especially, market risk, helping to ensure that they earn reasonable

[48]In the case of the 777, launch airlines were also invited to attend design-build team meetings. United Airlines, All Nippon Airways, and British Airways were among the carriers who participated in early design-build teams (Sabbagh, 1996).

returns on any program-specific R&D investments they now must make. For IPTs to work properly, prime integrators as well as suppliers must allow each others' engineers, as well as engineers from the airlines, to observe and even participate in sensitive corporate decisions regarding design and manufacture. A high degree of trust is necessary because all of the participants, including the airlines, gain tremendous insights into proprietary information about the nature and costs of aircraft development and production.

Closer relationships do not mean that relations between IPT members are always sympathetic, or even entirely cordial. With or without the IPT structure, the pressure put on suppliers to meet their cost and schedule obligations is enormous. Important long-time suppliers to both Boeing and GE Aircraft Engines, for example, have recently been heavily pressured to reduce costs and shorten cycle times—while at the same time being asked to dramatically reduce product defects.[49] The penalties for missing targets can range from financial slaps-on-the wrist to loss of contract. But when IPTs are in place, solving problems becomes a team effort: Suppliers are urged—if not required—to identify problems early so they can be shared with other members of the IPT. On the Boeing 777's IPTs, for example, each member of a team was required to sign-off on problem-solving decisions made jointly by the team (Sabbagh, 1996, p. 74). In fact, even without the formal mechanism of IPTs, integrators are helping their suppliers improve in areas such as process efficiency by regularly visiting their plants and working closely with managers and engineers. Suggestions from the integrators, although often critical, help to make suppliers more competitive in future contract bids.

Another step that airframe and system integrators have taken to make risk-sharing more attractive is to reduce the number of suppliers with whom they deal. In avionics, for example, airframers are moving toward the concept of selectable "supplier furnished equipment" (SFE) suppliers, allowing airlines to choose among a few suppliers whose products then become part of the standard aircraft package. The airlines like this concept because it offers them a choice of avionics equipment without requiring them to make inde-

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[49]In one case the response from a key supplier was deemed to be inadequate by the prime; the prime sent its own engineers to the responsible supplier facility and reviewed all costs associated with that facility down to an extremely detailed level.

pendent contract arrangements with suppliers.[50] The airframers like it because it allows them to eliminate the many "buyer furnished equipment" (BFE) suppliers whose equipment used to be available to the airlines as an option.

SFE suppliers are generally not required to bid for contracts at each phase of the design and manufacturing process, but are expected to be highly responsive to the needs of the integrator as part of a longer-term partnership. This strategy reassures suppliers of the integrator's commitment, avoids costs associated with frequent recompetitions, and puts SFE suppliers in a position to influence the establishment of future industry standards and specifications for new equipment. This last point in itself provides a considerable benefit to SFEs.

To conclude, the ability of aircraft industry suppliers to assume more of the risks as well as more of the benefits associated with new aircraft development has been a key element in the industry's success in controlling costs. Two factors have helped to make it possible: closer ties among airlines, airframe integrators, and aircraft industry suppliers, and growing consolidation of the supplier base. More than ever before, commercial airframe integrators, aircraft system integrators, and their subsystem, parts, and components suppliers are seeking to form partnerships and alliances, both U.S. and foreign. To the extent that DoD can also take advantage of these trends, it should be able to persuade contractors to accept a greater share of the costs of military aircraft development.

CONSOLIDATION AND COMPETITION

A major risk associated with DoD's adoption of a commercial approach to military aircraft acquisition is that there will be insufficient competition to prevent price-gouging by contractors. Under the current system, DoD regulations limit the profits that contractors can earn on most military contracts through the use of simple cost-plus contracts plus profit caps. But because simple cost-plus contracts

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[50] Under the old system, airlines who did not choose to accept the SFE avionics package could request "buyer furnished equipment" avionics. BFE avionics were offered as an option by the airframer, but airlines had to negotiate their own contracts with BFE suppliers.

also tend to reduce cost-cutting incentives, it is not clear that the total cost to DoD of acquiring aircraft is minimized by this strategy. The "best" practices strategy of encouraging suppliers to share the development risk for complex products promises to reduce DoD's acquisition costs by giving firms the right cost-minimization incentives. For it to work, however, incentives must be sufficient for firms to pass their cost savings on to DoD.

In recent years, the U.S. military aircraft industry has undergone widespread consolidation. On the face of it, this would appear to make CMI less attractive to DoD because fewer firms in the industry presumably mean less competition and therefore higher prices. But it may in fact be cost-effective for DoD to have fewer, healthier suppliers who are comfortable making the exceedingly expensive, capital-intensive investments required for designing and manufacturing military aircraft. And besides, because the recent spate of defense-related mergers and acquisitions is largely a response to defense budget cuts, the price implications of consolidation are not clear.

In this section, we examine the effects of airline deregulation and the rise of "must cost" on the structure of the commercial aircraft industry and on the prices of commercial large transport aircraft and aircraft equipment. The experience of the commercial aircraft market may be instructive to DoD because commercial airlines, who have long sought ways to encourage competition among U.S. airframe and aircraft system and subsystem suppliers, are also facing a wave of consolidation, especially at the lower tiers of the industry. This consolidating trend is in large part being driven by strong competition between the airframe prime integrators and their adherence to "must cost." One factor in keeping the industry competitive at all levels has been the growing participation of foreign firms, particularly with respect to generic equipment and parts.

The structure of the commercial aircraft industry has long been oligopolistic at its upper tiers—within each broad sector of the industry, such as airframes or engines or avionics, just two or three firms have traditionally dominated the market. But at the lower tiers, aircraft subsystem, parts, and components suppliers, there have typically been thousands of small firms. This is now changing: By some estimates, the number of firms producing commercial aircraft parts and components has fallen by a factor of three.[51]

Analysts propose several factors to explain this consolidating trend, including the need to "bulk up" in response to increased financial responsibility, the practice by system integrators of restricting contract awards to preferred providers, and suppliers' desire to increase profitability through the production of higher-value-added integrated systems. The first two of these factors suggest that "must cost" is playing an important role in the consolidation process. The ability to assume risk is now one of the primary qualities that airframe and aircraft system integrators look for when choosing suppliers, and this requirement is being passed down to the level of subsystems and even parts suppliers.[52] Integrators are also simply reducing the number of suppliers with whom they are willing to do business. Wilson (1996, p. 7), for example, quotes a former Douglas Aircraft executive as saying, "As we optimize our suppliers, we only will do business with certified suppliers. We want to increase the amount of business we do with high-performing suppliers. There will be some fallout in total numbers of suppliers used as a result of that."

To the extent that further consolidation of the commercial industry is being driven by the exigencies of "must cost," therefore, we should not expect to see anticompetitive behavior at the lower tiers of the industry putting upward pressure on the prices of airliners. Nevertheless, airlines face a highly concentrated industry. How then do they exert downward pressure on prices when there are relatively few suppliers?

One way has been to cooperate with each other on new aircraft acquisition. Although individual contract terms with manufacturers are a strictly kept secret, airlines generally work together to come up with common and compatible requirements for new aircraft. By doing so they not only hope to create a market large enough to take advantage of sharply declining average unit production costs, but also large enough to encourage rival manufacturers to compete for that

[51]Based on industry interviews.

[52]Aerospatiale, the French partner on Airbus, identifies a solid financial base, technological capability, and quick response time as the primary qualities it looks for when choosing a supplier/partner (Cook and Macrae, 1997).

market. When rival manufacturers propose aircraft designs with broadly similar performance characteristics, airlines may try to influence each others' ordering decisions. Since none wants to "split the market" and so increase per-unit costs, the timing of new aircraft orders is a highly strategic business decision.[53]

The importance of this last point is illustrated by a well-known case in which U.S. airlines did split the market.[54] During the late 1960s, the then "Big Four" U.S. carriers—American, United, TWA, and Eastern—all agreed on the need for a new three-engine widebody transport capable of flying nonstop across the United States. Lockheed and McDonnell Douglas came up with very similar designs, and their initial competing bids were very close. Failure to agree on which plane to order, despite last-minute personal calls and meetings by senior airline executives, resulted in the Lockheed L-1011 and the Douglas DC-10 development programs both going forward at the same time. This had ultimately disastrous implications for Lockheed's commercial aircraft operations.[55] The airlines suffered too: TWA, Eastern, and Delta, who bought the L-1011, were stuck with an aircraft that had a production run of only 250 units; American and United, who bought the DC-10, also were forced to bear much higher costs in the long run because of the divided market.[56]

The more highly competitive environment created by the deregulation of the airlines has probably discouraged airline executives from making personal efforts to coordinate their new aircraft acquisition strategies. However, airlines still cooperate through other forums, including those provided by manufacturers. Boeing, for example,

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[53]Choosing an aircraft manufacturer has become an even more strategic decision for the airlines now that there are only two manufacturers of large transport aircraft. Airlines must balance their immediate need for the best airplane at the best price with their desire to avoid a monopoly situation in the future.

[54]This example draws heavily on Newhouse (1982, pp. 141–160), who provides a highly readable account of the role of the airlines in the battle between the L-1011 and the DC-10.

[55]Many analysts argue that McDonnell Douglas was also financially crippled by the competition with Lockheed but simply took longer to die.

[56]Although the airlines were able to cut highly favorable initial deals with both Lockheed and Douglas, the manufacturers' failure to achieve significant economies of scale on their aircraft benefited no one in the end.

convened representatives of eight large airlines—United, American, Delta, British Airways, Japan Airlines, All Nippon Airways, Qantas, and Cathay Pacific—for nearly a year's worth of meetings to discuss design plans for the 777. Many of their suggestions were incorporated into the plane, and by November 1998 six of the eight airlines—and many more besides—had placed orders for the 777. In two key respects—requirements and aircraft choice—the airlines effectively turned themselves into a single buyer.

A second way in which airlines have tried to exert downward pressure on prices has been to promote standardization and interoperability of aircraft equipment and parts. In this way, they hope to ensure that no one firm has monopoly control over any crucial aircraft system, subsystem, or component. In avionics, for example, the airlines jointly established Aeronautical Radio Inc. (now ARINC) to develop commercial aviation standards for air transport avionics equipment.[57] One of the stated goals of ARINC is to establish "industry-defined products that can be produced on a competitive basis by various suppliers." A second goal is to "enable airlines and other avionics users to achieve economies of scale in the procurement of avionics . . . through the standardization of avionics form, fit and function and definition of aviation communication systems" (ARINC, 1998). Although in principle ARINC standards make entry into the avionics industry much easier, thereby encouraging competition, there are two limitations to this approach.

As in most industries, it has always been difficult for late entrants to a new avionics technology to compete with the technology leader. A well-publicized antitrust suit involving rival Inertial Reference Systems (IRS) produced by Honeywell and Litton provides a recent example. According to Carley (1996), in the 1970s Honeywell developed a new and much improved IRS based on a ring-laser gyroscope. The Honeywell IRS soon caught on with the airlines, and Litton, the former IRS industry leader, was forced to develop a competing ring-laser gyroscope. Unfortunately for Litton, its efforts proved to be too little, too late. Few airlines bought the Litton IRS, even though it was

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[57]Initially, their goal was to establish standard radio frequencies for aviation use.

ARINC-compatible with existing navigation systems.[58] Of the jets using laser gyro systems in 1993, Honeywell systems sat on 97 percent of Boeing planes, 100 percent of McDonnell Douglas planes, and 77 percent of Airbus planes. In 1993, two federal antitrust suits brought by Litton charged that Honeywell had unfairly wielded its monopoly power to discourage the airlines from buying Litton's IRS. Litton won both suits, but Honeywell retains its dominance of the market.

In avionics today it may be even harder to compete with the technology leader because the principle of federation, in which individual suppliers provide stand-alone systems that connect to other systems through FFF specifications, appears to be losing out to the principle of modular integration, in which multiple systems are controlled by one or more central processors.[59] Technical as well as economic reasons for this shift exist, and the two are related. Technically, advances in processor technology have allowed system integrators to consolidate related avionics systems into a single system. Economically, system consolidation is generating economies of scope and scale in marketing, R&D, and production. As a business strategy, therefore, the big avionics system integrators have been aggressively acquiring firms that supply relevant avionics subsystems and components. Independent system and subsystem suppliers are finding it increasingly difficult to compete against the comprehensive product lines offered by their larger competitors.

Commercial flight management systems (FMS), for example, coordinate several different types of navigation, communications, and instrumentation equipment into a single piece of equipment. At current prices, FMS are quite cost-effective, allowing airlines more flexibility and thus more efficiency in air routes and landing approaches. But the success of these systems has cut into the market for stand-alone products, including various sensors and displays. FMS systems are now standard equipment on current-generation large airliners and are becoming increasingly common on smaller business and commuter aircraft as well.

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[58]One reason is that early versions of the Litton system were plagued by technical problems (Carley, 1996).

[59]The concept of integrated modular avionics was originally developed for the F-22.

Flight management systems are just the tip of the iceberg. On the Boeing 777, Honeywell's Airplane Information Management System (AIMS) allows even greater modular integration of displays, flight management, flight-deck communications, airplane condition monitoring, thrust management, central maintenance, and digital flight-data acquisition. This eliminates the need for separate racks of Line Replaceable Units (LRUs) for each avionics subsystem, thus saving significant weight, space, and power consumption on board.[60] Although VIA 2000, the successor to AIMS, has yet to establish a solid market, many observers believe that its modular technology represents the wave of the future (Nordwall, August 1995).[61]

In sum, in the past ARINC standards appear to have promoted competition between avionics suppliers. However, they may become less relevant in an era of increasingly integrated digital avionics, where many ARINC-standard LRUs are likely to be replaced by plug-in cards.[62] Further, whereas once airframe integrators regularly provided BFE avionics suppliers with designs based on particular ARINC specifications, under the new "must cost" approach to airliner development, the role of BFE suppliers has been greatly reduced. And as SFE system suppliers accept more design responsibility, ARINC also decreases in importance. The result may be to increase the technological dominance of certain avionics suppliers—and especially the major system integrators—even more firmly than was true in the past.

The final and probably most important way in which U.S. airlines have put pressure on airliner prices has been to buy the best product at the best price regardless of where it is produced. In particular, af-

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[60]Honeywell (1997) estimates a weight savings of 510 lb and a volume savings of 104 MCUs (Modular Concept Units) for a typical widebody aircraft incorporating its VIA 2000 modular avionics, the follow-on to AIMS. For a narrowbody aircraft, the estimated weight and volume savings are 350 lb and 34 MCUs, respectively.

[61]"VIA" stands for Versatile Integrated Avionics. VIA 2000 has been selected as the avionics architecture for the Boeing 717's Advanced Flight Deck, but few of these planes have been sold so far (Honeywell, 7 September 1998).

[62]For example, it has been pointed out to us that Aircraft Communications Addressing and Reporting System (ACARS) units have always been designed to an ARINC FFF standard. In the AIMS cabinet on the 777, however, there has been no attempt to write an ARINC-type standard for the ACARS unit because the architecture is inherently proprietary.

ter nearly 10 years of ignoring Airbus—and continuing to buy their airliners exclusively from U.S. manufacturers—U.S. airlines finally decided that the European consortium was in the market to stay and that it had a good product. Although Airbus did not achieve its first U.S. sale until 1978, the year that the Airline Deregulation Act was passed, by the mid to late 1990s Airbus had established a significant market presence in the U.S. market.[63] In 1998, according to Airbus, "Eight out of eleven major airlines now operate or hold orders for Airbus Industrie aircraft. Customers placing some of the year's largest orders include United Airlines and US Airways."[64]

Both Boeing and Airbus—and prior to the merger with Boeing, McDonnell Douglas—have responded to the cost pressures introduced by the airlines by establishing international networks of suppliers. To some degree, the internationalization of their production lines may have been driven by concerns over foreign market access and the need for capital rather than comparative advantage. Greater foreign participation in the commercial aircraft industry does not necessarily mean it is becoming more efficient. The evidence suggests, however, that the pressure on prices is growing: For example, some economists estimate that Airbus' entry into the commercial airliner market may have lowered the average price of a long-range widebody airliner by more than 3 percent in the 1980s.[65]

In fact, some of the biggest competitive challenges to the primarily U.S.-based industry leaders are now coming either from foreign firms or from U.S.-foreign alliances. In some sectors of the industry, such as engines, this has long been the case. In other sectors, such as avionics and aerostructures, the growth of foreign competition is more recent.

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[63]Airbus' first potential U.S. customer was Western Airlines, a California commuter airline, but the deal fell through. Eastern Airlines was the first U.S. airline to consummate a deal with Airbus, leasing four A300B4s in 1977. Eastern decided to purchase its leased Airbus planes in 1978.

[64]United Airlines and U.S. Airways are among the four largest airlines in the world, as measured by numbers of passengers carried (Airbus Industrie, 1999).

[65]Percentage change calculated relative to a base-run model simulation by Neven and Seabright (1995). According to some analysts, aggressive marketing duels between Boeing and Airbus in the mid-1990s have resulted in price cuts of 35 to 40 percent off list prices (Flanigan, 1999).

Foreign firms, both as partners of and as rivals to U.S. firms, have long been important producers of commercial aircraft engines. The British firm Rolls-Royce, which produced its first aircraft engines in 1914, actively competes in all segments of the aircraft engine industry. Its 1990 joint venture with Germany's BMW and 1995 acquisition of the U.S.-based Allison Engine Company have given Rolls-Royce a market presence in the corporate and short-haul regional jet markets as well as its traditional markets for medium- and long-haul airliners. Similarly, CFM International, the alliance between General Electric and Snecma of France, has produced a highly successful series of engines since 1974.[66] CFM engines power nearly 40 percent of all aircraft with a capacity of 100 passengers or more (CFM, 1998).

In contrast, significant foreign competition has only more recently emerged in the commercial avionics sector. For example, an alliance formed in 1998 between Smiths Industries (UK) and Sextant Avionique (France) is providing competition for Honeywell in the FMS market. The new Sextant/Smiths FMS is being offered on all new Airbus A319, A320, A321, A330, and A340 airliners.[67] Similarly, Rockwell Collins' preeminence in the traditional radio communications equipment sector is being challenged by an alliance between Honeywell and Racal Avionics (UK), the market leaders in the growing satellite communications field (Frost and Sullivan 1996). At the level of generic components and parts, foreign competition is becoming well-established.

In commercial-transport aerostructures manufacturing, significant rivals to Northrop Grumman (U.S.) include Alenia Aerospazio (Italy) and Short Brothers (UK), as well as the Japanese giants Mitsubishi Heavy Industries, Kawasaki Heavy Industries, and Fuji Heavy Industries. More and more, these firms are sharing the development risk with the airframe prime integrators. On the Boeing 757/767, for example, the three Japanese firms and Alenia (then Aeritalia) were risk-sharing major participants in development and production. Similarly, firms from Australia, Canada, Europe, Japan, and the

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[66]Snecma stands for Société Nationale d'Etude et de Construction de Moteurs d'Aviation.

[67]Honeywell charges that the development of the Sextant/Smiths FMS for Airbus is being unfairly subsidized by the French government (Honeywell, 7 April 1998). Sextant is licensing the FMS technology from Smiths (Sextant, 1998).

United States provided sections of the 777 airframe to Boeing, with the Japanese firms alone designing and building roughly 20 percent of the airframe structure.[68]

In sum, the major subsectors of the commercial aircraft industry contain relatively few big players in the upper tiers, and the lower tiers of these sectors are consolidating. Nevertheless, there does not appear to have been a significant escalation in average prices for airliners. Airlines are helping to put downward pressure on the price of new airliners by pursuing the following strategies:

- Cooperating on new aircraft acquisition so as to avoid "splitting the market"
- Encouraging the standardization and interoperability of aircraft equipment and parts, but buying integrated systems where they are cost-effective
- Buying the best product at the best price regardless of where it is produced.

We believe that these strategies are also relevant to DoD, and that, despite recent consolidating trends within the military aircraft industry, there is still sufficient competition between the prime integrators to make CMI a viable strategy. DoD already coordinates weapon system acquisition for the military services, trying to ensure economies of scale whenever possible. This strategy should be continued, while remaining conscious that differences between the missions of the military services may not always allow for acquisition programs to be joint.

The nature of the economic and technical tradeoff between standardized federated systems and integrated modular systems for DoD is less clear. However, acquisition reform is allowing DoD greater latitude to make these choices on a system-by-system basis. In many cases, it may be in DoD's interest to ensure that Mil-Specs are not simply eliminated, but rather replaced by commercial standards and

[68]Originally, the three Japanese firms were also asked to become partners with Boeing on the 777, providing an equity stake of 25 percent. For political as well as economic reasons, the equity offer was later transformed into a fixed-price contract arrangement whereby the Japanese provided their own capital for development.

specifications. Issues concerning parts proliferation and support and maintenance are discussed at greater length in the section below.

Finally, DoD must also examine the tradeoff between its desire to keep sensitive military technologies out of the hands of potential enemies and the clear economic benefits of using dual-use commodities and technologies and pursuing best-value sourcing worldwide.[69] This issue pertains mostly to prime integrators and the suppliers of major systems. At lower tiers, it is probably already moot: Globalization of supply is almost as much of a fact for military aerospace as it is for the commercial aerospace world.[70] Further, we argue that relatively little information about military capability is revealed by commodity purchases because the security value-added lies in knowing how to integrate them into systems, as well as what the system requirements are.

PRESERVING SYSTEM SUPPORTABILITY

A sometimes underemphasized concern about adoption of a commercial-like approach to acquisition is the long-term supportability of military aircraft. One fear is that giving contractors increased control over aircraft and airborne weapon system configuration will encourage parts proliferation, creating severe inventory control problems for DoD. A deeper fear is that contractor configuration control could put DoD in a position where it is forced to outsource the long-term MRO of each system to its OEM. If standardized Mil-Specs parts and components are replaced by proprietary technologies, the argument goes, OEMs will be able to demand exorbitant prices for MRO services, effectively holding DoD hostage for future system support.

We discuss here how the competitive pressures introduced by airline deregulation have affected the market for commercial aircraft MRO

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[69] In fact, DoD must take into account domestic political factors as well as international strategic factors when considering the foreign sourcing of military aircraft. The U.S. government, like most governments, is reluctant to spend domestic tax revenues on items produced in other countries.

[70] See the discussion in Lopez and Vadas (1991).

services.[71] Once again, we believe the commercial experience is relevant to DoD because, in circumstances similar to those DoD now faces, airlines appear to be reducing their costs significantly through judicious outsourcing of MRO services.

In parallel with the restructuring of the market for new commercial aircraft, profound changes have affected—and continue to affect—the commercial aircraft MRO market. These changes are taking place within an evolving relationship between airlines and suppliers. On the demand side, a new focus on core competencies and cost control has led airlines to seek to become, in the words of Robert Crandall, former Chief Executive Officer of American Airlines, "virtual airlines." A virtual airline is a company that, in the extreme, performs only its core task of carrying people and freight from point to point. A fully virtual airline would not own its planes—it would lease them—and it would outsource all activities, including overhaul and maintenance, other than flying people and cargo. Ideally, the airline would deal with only one supplier, which would hold all inventory and organize the entire supply chain for the airline.

On the supply side of the market, MRO activities used to be performed primarily by the airlines themselves. Even for systems under warranty, airlines would often be given in-house warranty authority, allowing them to fix systems themselves and bill the OEM for technician time and parts. Following the 1978 deregulation, however, many airlines just entering the industry did not have existing MRO facilities or spare parts inventories. The growth of these new low-cost airlines encouraged the entry of independent MRO suppliers who offered relatively low-cost services ranging from line maintenance to inventory control. In a responding effort to cut costs, several of the established airlines, such as Southwest and American, began to outsource more of their MRO activities. Still other airlines, such as United, took a different tack, expanding their own MRO operations by offering MRO services to third-party airlines.

Each type of supply structure had its own competitive advantages. As shown in Figure 6.3, OEMs were the primary providers of MRO

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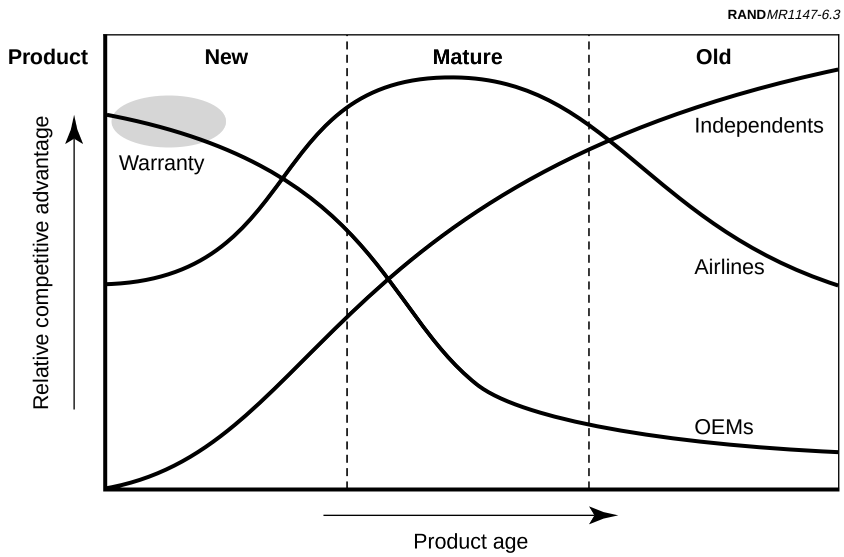
[71] We give a generic overview of the trends within the commercial MRO market. We recognize that there are distinct differences in the economics of MRO services for different aircraft systems (avionics versus engines, for example).



SOURCE: The Canaan Group (March 1996, p. 2).

Figure 6.3—Aftermarket Competitiveness

services during the early years of most systems because they offered warranties and controlled the spare parts pipeline.[72] In the middle years, airline MRO providers tended to be most competitive because their substantial inventory and geographic presence gave them the ability to serve customers around the clock. Finally, when the system went out of production and out of most inventories, specialized independents were often the least-expensive suppliers of MRO services. Independents achieve economies of scale by purchasing bulk inventories from airlines or OEMs, obtaining licenses from OEMs to maintain and repair specific systems, and specializing in state-of-the-art inventory control to reduce costs.

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[72]In addition, OEMs were—and still are—generally the only ones able to conduct major repairs because airline overhaul/maintenance (OH/M) facilities and independent vendors did not have the necessary equipment or training. For example, in the case of an inertial navigation system, only the OEM has the capability to calibrate the gyroscope. Simple electronic failures on the motherboard, on the other hand, can be fixed by the airline's OH/M facility or by a licensed vendor.

As the pressures of "must cost" continue to mount, however, this pattern of comparative advantage is beginning to change. Today, many large airlines no longer wish to accept standard warranty and maintenance clauses in new aircraft purchase contracts. Instead, they are asking for significant price reductions on new systems in return for reduced warranty coverage (in scope and in time), smaller inventories of spare parts, and fewer support services.[73] The result initially has been to put OEMs in a difficult position. With reduced warranty coverage, many of the costs associated with faulty systems are directly borne by the airlines. If an airline feels these costs are too high and that a system is unreliable, it might decide to switch suppliers. This creates an uncertain situation for the OEM, because it does not know what reliability threshold will be used to assess its performance. In response to this uncertainty, many OEMs felt obligated to offer services or replacement units not covered by warranty. In effect, OEMs found themselves offering airlines reduced prices on new equipment with no corresponding reduction in warranty coverage.

To get out of this unprofitable situation, many OEMs are replacing their price-plus-embedded-warranty contract structures with separate contracts for new equipment and for MRO services. Instead of treating MRO services as a cost of doing business, they now look at the after-sales market as a business opportunity.[74] They are linking their repair costs to the implicit prices of the warranties they provide to determine whether a warranty on a particular system is profitable. This makes good business sense for at least three reasons. First, the MRO business is larger than the business of aircraft production. Second, it is more profitable.[75] Third, for many OEMs it holds better

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[73]One reason why the airlines are taking this approach is that the reliability of aircraft parts and equipment, as measured by Mean Time Between Unexpected Removals (MTBURs) and Mean Time Between Failures (MTBFs), continues to improve dramatically.

[74]As Harry Stonecipher, President of Boeing and former CEO of McDonnell Douglas, commented in 1997: "Clearly there is creative ferment in the MRO world. . . . The old way of looking at MRO was as a *cost of doing business*; the new way is as a *promising business in its own right*. That is to say, a business that appeals to customers, a business that offers opportunities for growth and profit." (Italics in the text.)

[75]From December 1992 to December 1997, the average stock price for an index of 15 suppliers rose 28.7 percent each year, higher than the average for Boeing, at 22.8 percent, or United Technologies, at 10.8 percent (United Technologies is the holding

growth prospects than sales of new equipment. Indeed, for the 1998–2002 period, the forecast average annual growth for new aircraft demand and for DoD R&D and procurement is just 8 and 3 percent, respectively, compared with projected growth in MRO activities of 40 percent by 2005.[76]

An OEM that has become prominent in this business is GE Aircraft Engines. Its entry into MRO started in 1992 with the acquisition of British Airways' engine overhaul and maintenance operations, quickly followed by a number of acquisitions and joint ventures. By 1998, GE's share of the engine overhaul market not serviced internally by airlines themselves had grown from 20 to 50 percent. Aftermarket activities now account for 40 percent of GE Aircraft Engine's revenues and 75 percent of its operating profit. Not surprisingly, such success is attracting other OEMs to the MRO market. Recently, Boeing and Airbus have indicated an interest in entering the MRO market as well (Schneider, 1998).

Within specified utilization parameters, many MRO service contracts now cover all activities related to a given aircraft, including entire aircraft systems "bumper-to-bumper." Sometimes, the airline is simply charged a per-hour utilization fee. Contracts based on per-hour utilization fees are particularly popular for aircraft engine maintenance, for which condition monitoring data are easily generated and wear-modes identified. In "power-by-the-hour"–type engine maintenance contracts, for example, aircraft operators pay a fixed monthly fee based on the hours flown within the month multiplied by a specific dollar rate per engine flight-hour.[77]

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company for Pratt & Whitney). Firms included in the supplier stock index are BE Aerospace, BF Goodrich, Coltec, Ducommon, Curtiss Wright, Fairchild, HEICO, Hexcell, Moog, Precision Castparts, Sequa, SIFCO, Simula, Sundstrand, and Wyman Gordon. See Schneider (1998).

[76]New aircraft demand and DoD procurement numbers from Schneider (1998). MRO numbers based on a survey of MRO suppliers described in *AWST* (1997).

[77]See, for example, Rolls-Royce Allison (undated). "Power-by-the-hour" is also used to describe arrangements whereby airlines lease an engine from the OEM and the OEM is responsible for all maintenance. According to Schneider (1998), engine leasing is growing in popularity among airlines.

Airlines as well as OEMs perceive major advantages in these types of long-term fixed-price contracts for MRO services.[78] First, by establishing a fixed price for life-cycle MRO services, it removes any uncertainty about the future availability and price of spare parts and spare systems. Parts proliferation is not a problem because the OEM has responsibility for inventory control. Second, it creates an incentive for the OEM to improve the life-cycle reliability of the system. Improved system reliability reduces MRO service costs, which under fixed-price contracts translates directly into higher profits for the OEM.

In an effort to reduce their costs on MRO contracts, for example, OEMs have been tracking the number of so-called "No-Fault-Found" (NFF) removals—the removal of a component later found to be fully functional. Aviation data suggest that there are in excess of 400,000 such removals per year, representing 23 percent of all (1.76 million) component removals. With an average cost of $800 per removal—including labor, tracking, testing, etc.—NFF removals cost the industry approximately $300 million per year.[79] One of the best ways to limit such NFF removals is to staff line maintenance crews with expert technicians. These personnel are now often trained at or directly provided by OEMs.[80]

Even more important, throughout the life of a fixed-price MRO contract OEMs now have strong incentives to track actual system failures and weaknesses. Within the limits of FFF parameters, OEM system designers use information about items that fail repeatedly to identify areas for improvement. New technologies or designs are introduced to decrease production costs as well as increase reliability. Feedback from repair services provides a crucial element in the drive toward continuous product improvement.[81]

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[78]MRO contract lengths and the range of contract features offered can vary considerably. More research is needed in this area.

[79]Approximately a third of this amount is related to avionics components.

[80]Industry studies reveal that NFF can be reduced by 68 percent using expert diagnostics, representing annual savings of $200 million (Canaan Group, 1998).

[81]The incentive to upgrade an item is constrained by the desire to avoid changes that require the costly process of FAA recertification.

To facilitate this process of continuous improvement, however, OEMs have had to undergo a major restructuring of their operations. At many firms, what were two entirely separate departments, R&D and support engineering, are now being integrated. Financial accounts are being restructured to allow OEMs to track R&D, production, and after-sale costs for individual systems. This kind of restructuring has become possible only since R&D risk-sharing has given OEMs increased control over the R&D agenda. The ability to control technical tradeoffs is helping to make the switch to "bumper-to-bumper" support both feasible and financially enticing for OEMs.

The competitive pressures introduced by airline deregulation have led to far-reaching changes in the market for commercial aircraft MRO services. More and more, airlines are choosing to outsource their MRO activities to third-party airlines, independents, and especially OEMs, including both system and airframe integrators. OEMs, for whom MRO services were once simply a "cost of doing business," are becoming major players in the MRO field. The trend toward OEM provision of "bumper-to-bumper" life-cycle service contracts has given them a new focus on product reliability. As a result, OEMs are now integrating their after-sale activities with R&D and production, introducing new designs and technologies that hold the promise of increased cost-effectiveness.

For DoD, these after-sale market trends in the commercial world also hold the promise of increased weapon system reliability at lower cost. Outsourcing life-cycle support services to OEMs for a fixed price could help to ensure system supportability and maintainability over time. Although there are some real concerns about the support and maintenance of military aircraft (and weapon systems more generally) by civilians during wartime, experience suggests that these obstacles to increased reliance on commercial suppliers are not insurmountable.[82] The gains could be large—not only in terms of lower life-cycle support costs but as an integral part of the CMI strat-

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[82]According to Stonecipher (1997), during the Gulf War McDonnell Douglas had 1100 technicians supporting F-15s in Saudi Arabia. When the C-17 was deployed to Bosnia, support personnel from McDonnell Douglas were again deployed.

egy of increasing contractor configuration management and control of weapon system programs.[83]

CONCLUSION

We began this chapter by asking four questions about the full or partial adoption of a commercial-like approach to weapon system acquisition:

1. Can system cost be reduced without sacrificing performance?
2. Will qualified contractors be willing to absorb more of the market and technical risk associated with new aircraft development?
3. Can DoD promote and maintain adequate levels of price-based competition?
4. Can DoD ensure the supportability and maintainability of systems over time?

Based on an examination of the ways in which U.S. participants in the market for large transport aircraft have approached similar questions, our answer to each is a qualified "yes." On net, we believe that adopting a commercial-like acquisition strategy will prove beneficial to DoD. If military contractors adopt the "best" commercial practices used by their commercial counterparts, we expect to see a decline in the cost to DoD of developing, producing, and maintaining military aircraft. We caution, however, that cost declines may be accompanied by a diminution of the technical virtuosity of U.S. military aircraft if too much emphasis is placed on cost-control relative to performance requirements.

We found that binding cost constraints introduced by "must cost" have shifted the focus of airlines and aircraft manufacturers from performance to cost. This has not resulted in airliners with poor performance characteristics; in fact, along certain dimensions there have been notable improvements. Arguably, however, aircraft

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[83]There are serious and possibly unique difficulties involved with designing appropriate warranties for weapon systems, however, as discussed in Kuenne et al. (1988). Relevant RAND studies on how best to source and structure military logistics support services include Keating (1996) and Keating et al. (1996).

manufacturers have been less willing to introduce dramatic technological improvements. Instead, the focus of technical innovations has been to meet the joint goals of low operating costs and supersafe flight in increasingly crowded skies. If DoD adopts a true “must cost” approach, emphasizing cost over other considerations, then careful program management will be required to maintain technical innovation in the desired areas.

We also expect that DoD will be able to lower its financial support for new aircraft development without causing qualified contractors to leave the market. Contractors will respond to the challenge by choosing partners who are able to provide their own financial capital as well as technical capabilities. To facilitate this, DoD must be willing to give prime contractors and their risk-sharing partners increased responsibility for and flexibility in program management, working closely and cooperatively with them as part of IPTs. DoD may also be required to accept a narrowing of its supplier base, as prime integrators choose from among a smaller group of qualified suppliers with proven track records.

To maintain sufficient competition to prevent price-gouging, as well as to encourage greater risk-sharing by contractors, DoD should take three steps. First, DoD should continue to foster cooperation between the services in weapon system acquisition, not only to take advantage of sharply declining average unit production costs but also to encourage manufacturers to compete for military contracts. Second, with respect to standardization and interoperability, DoD should encourage the use of existing commercial specifications and standards wherever practical, but take advantage of growing commercial competency in modular integrated systems when the associated economies of scope and scale are large. For these types of systems, the pros and cons of life-cycle “bumper-to-bumper” support service contracts provided by OEMs are worth examining more carefully. Third, DoD must carefully consider the role of foreign firms in the development of sensitive technologies. In the commercial world, foreign firms not only provide important financial and technical resources to their U.S. partners but also provide the world’s airlines with a potent alternative to the dominance of U.S. firms. Competition from abroad deters U.S. manufacturers from resting on their laurels, encouraging them to find new ways to cut costs and pass the savings on to their airline customers. As a final consideration, military producers will know that if they exorbitantly exploit any changes in cost-control regulation, political pressure will certainly be brought to bear to reinstate the controls.