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Outsourcing US commercial aircraft technology and innovation: implications for the industry's long term design and build capability

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Abstract
This paper reviews the accelerating trend toward the formation of global inter-firm partnerships to design, develop, and manufacture new commercial aircraft. While the US has long enjoyed a strong comparative advantage in commercial aircraft production, this advantage is steadily weakening in light of growing international competition from the European Union, Brazil, and Canada. Several newly emerging markets (NEMs) are also beginning to challenge the US, including Russia, China, and India. The only remaining US producer of large passenger jets (Boeing) has opted for a systems integration mode of production, whereby manufacturing and design processes are distributed across an international network of risk-sharing partners. This business model has clear financial advantages for Boeing, but it also entails substantial levels of technology transfer from the prime contractor to the risk-sharing partners (the latter might eventually become competitors). We illustrate this point with regard to a variety of co-operative ventures between Boeing and several foreign companies. Our principal conclusion is that the financial imperatives driving this business model may soon compromise the ability of the US to maintain a significant presence on the manufacturing side of the commercial aircraft industry. The paper concludes with a brief discussion of the strategic implications of this scenario in terms of industrial employment, skills, and technological capability.

Introduction

The commercial aircraft industry has long served as a powerful symbol of US technological leadership, design excellence, and engineering capability. This industry has been the top US export sector for more than five decades (United States Department of Commerce, 2004), and many of the advanced technologies developed by this sector have been successfully adopted by other industries (e.g., automotive, electronics, metal fabricating). In recent years, however, the sole remaining US manufacturer of large passenger jets (Boeing) has opted for a systems integration mode of production, whereby key components and sub-assemblies are designed and manufactured by external suppliers (see Pritchard and MacPherson, 2004). While this represents a logical strategy from a financial standpoint, a potential downside is that foreign subcontractors and/or risk-sharing partners must receive direct infusions of technology or tacit knowledge from the systems integrator (otherwise the strategy would not work). This raises an important question that ought to be of interest to trade policy analysts and other scholars that are concerned with national industrial competitiveness. Specifically, to what extent does technology transfer to foreign companies represent a good idea in terms of long-run economic or industrial effects?

Set against this backdrop, our paper is organized as follows. Section 2 provides a research context for the discussion. This section reviews the evolution and development of industrial offset agreements in the US commercial aircraft industry. Next, Section 3 presents a summary of recent trade and employment trends in US commercial aircraft production. Section 3 introduces a number of strategic issues with regard to Boeing's 7E7 aircraft launch. Here, we make extensive use of data from personal interviews with industry representatives, public officials, and others with an active interest in the 7E7 program. Section 4 offers a prognosis for this segment of the US industrial base. The paper concludes with a brief discussion of the strategic issues that flow from Boeing's deployment of systems integration as a business model.

2. Research Context

The term 'industrial offset' refers to a form of compensatory trade where the exporter grants concessions to the importer. In the commercial aircraft industry, these concessions typically take the form of production-sharing agreements. [1] The first major industrial offsets in aircraft manufacturing occurred in the 1960s when Douglas subcontracted the fuselage assemblies for its DC-9 and DC-10 jetliners to Alenia in Italy. As a result of these transactions, Douglas secured substantial sales of aircraft to the flag carrier of Italy. One of Boeing's early offsets was with Japan in 1974, when Mitsubishi was given contracts to produce inboard flaps for the Boeing 747. Major sales of 747s to Japan followed. In most of these cases, the goal has been to secure a sale that would not have taken place in the absence of compensatory provisions. Douglas, which orchestrated the first batch of offsets as we know them today, no longer exists as an independent aircraft company. Boeing has become the nation's largest corporation in terms of offset-related commitments (Pritchard, 2001). In 1960, imports of aircraft and parts amounted to only 5 percent of aircraft exports by value. Today that figure is 45 percent. Foreign content for the 7E7 might run as high as 70 percent. The foreign content of a Boeing 727 in the 1960s was only 2 percent. For the 777 in the 1990s, foreign content was nearly 30 percent.

As part of the launch process for the 7E7, three Japanese companies are expected to create the manufacturing processes for final assembly of the wing. Boeing has never considered subcontracting wing production to external suppliers before. Given that Japan has incrementally acquired production competence for a wide range of airframe components via years of industrial offsets from Boeing (see Pritchard, 2001), the transfer of wing manufacturing and assembly expertise to Japanese companies effectively gives Japan 'total production competence' with regard to commercial airframes. Japan has already announced that it wants to produce commercial aircraft (Pritchard and MacPherson, 2004). In this regard, it is likely that Japan's first airliner will be an all-composite regional jet - a competitor to Canada's Bombardier and Brazil's Embraer. Some experts believe that the next generation of Boeing's 737 will be an all-composite airframe produced totally in Japan. Where does this leave the existing U.S. supplier base and the nation's engineering capability? The average U.S. aerospace worker is 48 years old (Sorscher, 2004). Boeing has laid off more than

[1] While Airbus also operates with industrial offset agreements, these agreements are typically for older Airbus products. Newer models are more often sold with indirect offsets (e.g. the provision of landing rights to major EU airports such as Heathrow and Gatwick).

50,000 workers over the past three years, so there are few young employees to pass along the technological and tribal knowledge for designing and manufacturing commercial aircraft.

3. US Commercial Aircraft Globalization: 30 years in the making

The commercial aircraft sector accounts for around 8 percent of the nation's manufactured exports ($53 billion in 2000), over 790,000 jobs, and close to 10 percent of U.S. industrial output (U.S. Department of Commerce 2004). Despite strong export performance over the last four decades, evidence is accumulating that this sector is not as healthy as it was in the 1960s or 70s. In 1960, for example, imports of aircraft and parts amounted to only 5 percent of exports by value, compared to 45 percent by 2000. This percentage is likely to increase dramatically over the next 10 years. There are two major reasons for this. First, order backlogs for older Boeing models (e.g., 747s, 767s) are low. This means that total domestic production activity will continue to decrease. A second and related reason is that the 7E7 may eventually be produced with as much as 70 percent foreign content. More simply, each 7E7 that is exported will have a much higher foreign content than previous Boeing models.

In terms of global market share for large commercial aircraft (LCAs), the U.S. moved from an almost total monopoly (95 percent) in 1960 to a much weaker position by 2001 (49 percent). Most of this trend can be explained by the rise of Airbus, which moved from zero market share in the early 1970s to a 51 percent position by 2001 (Smith, 2001). Faced with an increasingly competitive market, the U.S. commercial aircraft industry has responded via downscaling, joint ventures, mergers, and various types of international subcontracting arrangements (James, 2001). By now, there is only one major U.S. LCA manufacturer and only two high-volume domestic parts producers (contrast this with the 1970s, when there were three large producers and over ten major parts suppliers). Foreign content has increased dramatically over the past four decades. In the case of the Boeing 777, for example, there is no domestic production for the center wing box or the fuselage sections.

To an extent, the plummeting domestic content of U.S.-built aircraft reflects a cost-driven trend toward global sourcing (Mowery, 1988). Of the $23 billion import bill for 2000, over 50 percent consisted of airframe parts for Boeing's assembly facilities in the Seattle area (Puget Sound). Although this type of intra-industry trade (IIT) has been growing for some time, U.S. revealed comparative advantage (RCA) in aircraft production remains strong (Table 1). Whether or not the RCA index will remain above unity over the long-run is far from assured, if only because this index indirectly accounts for U.S. imports by scaling U.S. exports against world exports.

Table 1. US trade in commercial aircraft and parts (1970-2000)

Year	Exports (US$ millions)	Imports (US$ millions)	a. Imports/Exports	b. IIT	c. RCA
1970	2286	271	11.8	0.21	4.08
1980	13494	2662	19.7	0.33	8.71
1990	35770	10817	30.2	0.46	5.70
2000	52920	23772	44.9	0.62	3.70

a. imports as a % of exports

b. intra-industry trade index: IIT = 1 - [(x - m)/(x + m)]

where: x = exports; m = imports.

c. RCA = (US aircraft x/total US x)/(world aircraft x/total world x).

RCA = revealed comparative advantage.

Source: US Department of Commerce, 2001.

The growth of IIT can be traced to the nature of competition within the world's aerospace sector. While Airbus and Boeing compete mainly in terms of price, product quality, reputation, and delivery speed, the ability to offer and/or satisfy offset packages is also important. Direct offset agreements between airlines and aircraft producers are designed to transfer a slice of the manufacturing work to the buyer. Thus, for example, some Boeing 737s contain Chinese parts (tail assemblies) because Air China negotiated offset production as a condition of purchase. Clearly, the growth of offset agreements has cut the domestic supplier base for major aircraft companies such as Boeing. To an extent, then, part of the recent employment trajectory for the US aircraft industry can be traced to offset-induced imports (Table 2). For instance, many of the US airframe parts that were once supplied by US firms are now imported under offset agreements with companies from South Korea, Japan, China, and Russia. Significantly, several of the firms that were once major suppliers to Boeing are no longer in business (e.g. Fairchild).

Table 2. US employment in commercial aircraft production (1970-2000)

Year	a. Jobs (000s)	b. S&E Jobs (000s)	c. S&E %	d. S&E as % of All sectors
1970	1900	573	30.2	22.5
1980	1690	341	20.2	17.7
1990	1200	238	19.9	16.3
2000	798	120	15.1	6.2

a. Production plus non-production workers (total employment).

b. R&D scientists and engineers.

c. R&D scientists and engineers as a % of aerospace employment.

d. Aerospace R&D scientists and engineers as a % of total manufacturing employment.

Sources: US Department of Commerce (2001); Pritchard (2002).

A more alarming attribute of Table 2 is that employment levels for aerospace R&D scientists and engineers (S&Es) have been dropping quickly for a long time. Between 1970 and 2000, total aerospace S&E employment fell from 573,000 to 120,000 (a loss of over 450,000 skilled jobs). Over the same period, S&E employment as a proportion of total aerospace employment dropped from 30% to 15%. Thirty years ago, the U.S. aerospace sector held a 22% share of the nation's total S&E employment, compared to just over 6% today. When we factor in the fact that the aerospace workforce as a whole is aging, the steady drop in S&E employment suggests that the industry will soon face a major human capital shortage (Pritchard, 2002; Sorscher, 2004).

This interpretation was reinforced in a March 2004 interview with Owen Herrnstadt, Director of Trade and Globalization of International Aerospace Machinists (IAM), who noted that the average IAM member is now 48 years old. Post 9/11, tens of thousand of IAM members have been laid off and one-third of the remaining IAM members in the commercial sector will retire over the next 4 years. On March 12, 2004, John Douglass (the President and CEO of the Aerospace Industries Association) told a House Aerospace Caucus that the average age for a US aerospace engineer is 54. Douglass is seriously concerned about this, mainly because "only two percent of young engineering students enter aerospace" (Aerospace Industries Association, 2004).

A further cause for concern is that Boeing has been trailing Airbus for many years with regard to R&D spending and capital investment (see Figures 1 and 2).[2] In 2003, for example, Airbus allocated 9.5 percent of its total revenues toward R&D, compared to 3.5 percent for Boeing. In the same year, Boeing allocated only 0.97 percent of its total revenues to capital investment, compared to 9.1 percent for Airbus. While these percentages will no doubt increase as the A380 and 7E7 programs unfold, the fact that Boeing has underinvested for so long suggests that the 'catch-up' game in technological and engineering terms will be difficult to play. This decline dismantles our technological and manufacturing communities from within, eroding the network of relationships, expertise and authority, developed over decades (Sorscher, 2004).

Figure 1. Investment by Airbus

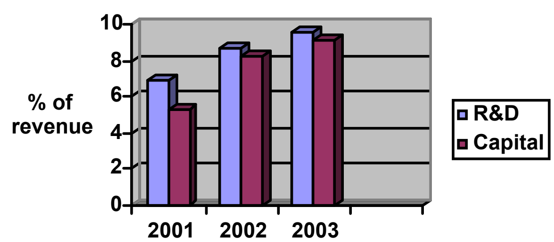
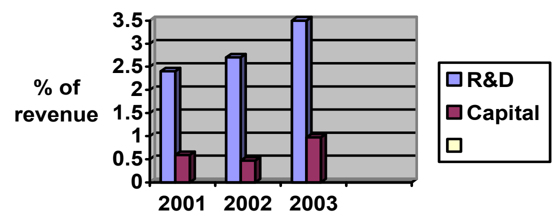


Figure 2. Investment by Boeing



Source: Annual Reports. Note: peruse the vertical scales before making interpretations.

4. Boeing 7e7: Trading technology and innovation for financial support.

The Japanese heavy firms Mitsubishi, Fuji and Kawasaki will build 35 percent of the 7e7 aircraft structure, which will include the design and manufacturing specifications in comparison to a build-to-print relationship on previous Boeing programs. Thomas Pickering, Boeing's senior vice president for international relations, recently stated that "Japan did less than 10 percent of the (Boeing) 767 and 20 percent of the 777" (Shimbun, 2004). From 1978 to 1983, the Japanese government covered about half of the costs of developing parts built by the Japanese companies for the Boeing 767 (Belson, 2004). In the 1990s, Japanese companies spent 104.5 billion yen ($942 million) to develop parts for the Boeing 777, aided by a 60 billion yen loan from the Japanese government (Belson, 2004). Today, these three Japanese firms will have full responsibility for tooling their factories for wing production. "This is the first time we have ever put the full wing…into the hands of a partner," said Thomas Pickering (Gibbs, 2004). He further stated, "We said (Boeing) let's spread the risk and spread the benefit…They get the advantages but they also carry the burden."

The national goal for Japan's Ministry of Economy, Trade and Industry (METI) and the industrial sector has been to revitalize Japan's aeronautics industry. The industry is now being aided by a METI-financed foundation, the International Aircraft Development Fund (IADF). This new foundation has offered the 3-company consortium (Japan's aircraft

[2] Note that the Boeing figures are for commercial aircraft only (military spending is excluded).

manufacturers) a $3 billion low interest loan to ensure Japan's participation in the 7E7 program (Sakai, 2004).

Boeing says it expects contracts with its tier-one suppliers to be finalized by the end of 2004 (Table 3). The first tier suppliers will select, contract and oversee the second and third tier suppliers in the early part of 2005. The 7e7 program will be the first time that a supplier will control the selection process of suppliers in a Boeing commercial aircraft program. This should cause alarm to the U.S. supplier base since the governments of Japan and Italy will be subsidizing the 7e7 program up to $3 billion (Pritchard and MacPherson, 2004). It should be expected that the aerospace infrastructure of these two nations will be developed with new national suppliers being chosen for receptivity for the government funding. In a recent interview with Bill Lewandowski, Vice President of the Supplier Council for the Aerospace Industries Association, he had two concerns, "the first being that upper tier U.S. suppliers (sigma three group) would probably be only offered to quote against Japanese and Italian second and third tier suppliers, and, secondly this U.S. group would have difficulty communicating with the overseas first tier suppliers since they aren't export ordinate". (Lewandowski, 2004).

Table 3. Outsourcing Trends for Boeing Airframes

Airframe	727	777	7e7
Wing	US	US	Japan
Center Wing Box	US	Japan	Japan
Front Fuselage	US	Japan	Japan/US
Aft Fuselage	US	Japan	Italy
Empennage	US	Foreign	Italy/US
Nose	US	US	US

Airbus has been introducing major technical advances over the past 25 years, dating back to the late 1970s when the company started test flying composite panels on their commercial aircraft models. Japan's technological leadership in composites gives it competitive advantages by supplying critical parts to the world's aircraft builders like Boeing and Airbus. Expertise in this area is one reason Boeing is going to contract 35 percent of the 7e7 airframe structure to Japan. In an interview with Paul Lagace, MIT Professor of Aeronautics & Astronautics and Engineering Systems, "the United States lags behind Japan, Spain and Russia in aircraft composite technology" (Lagace, 2004). Boeing's airframes have changed very little since the introduction of the 747. With Airbus introducing major technological advances over a relatively short corporate lifetime, Boeing has been forced to move into this all composite aircraft. In the past, when Boeing was the world's leader in commercial aircraft manufacturing, it rested on position in the industry and did not invest heavily in research and development for its commercial product line.

Boeing is looking to leapfrog Airbus on composite technologies for the 7e7 aircraft and the only "low technological risk and low financial exposure" would be to partner with the industry's composite leaders such as Toray. Boeing has recently awarded a 12-year contract worth $3 billion to the Japanese firm Toray for the carbon-fiber composite material to be used on the 7e7 aircraft (Gates, 2004 B).

But this dependency on Japan should not come as a major surprise. Recent developments reflect a continuation of the concerns that were discussed in a 1994 monograph "High-Stakes Aviation" by the National Research Council. We interviewed Charles Wessner, Director of Technology and Innovation, National Academy Sciences in March 2004. Wessner's principal concern is that the 7e7 wing technology and larger composite structures being sourced to Japan will ultimately curtail US innovation capability and compromise US security interests (Wessner, 2004). Perhaps ironically, some of the advanced composite technologies and related processes developed by Boeing (McDonnell Douglas Commercial) under 1989-1997 NASA R&D funding (the $354 million Composite Wing Development Program), as well as some $54 million in NASA funding for the Composite Fuselage (1989-1996) along with funding under the Advanced Subsonic Program (1993-1998), will be delivered to Japanese and Italian risk-sharing partners under the 7E7 program. It would seem that U.S. tax dollars that were originally spent to promote U.S. technology development will soon be indirectly employed to upgrade that manufacturing and materials handling capabilities of foreign companies.

The technology and process improvements required for the 7E7 go far beyond raw material requirements (composites). Boeing's risk sharing partners in Japan, Italy and the U.S. will be building composite structures that are stuffed with sub systems that are already certified, tested and ready for final assembly. There will be minimum work content for the less than 1,000 Boeing Everett workers on the 7e7 program. "One composite section will stovepipe over another, connected by two rows of fasteners. The holes will have already been drilled by computer-controlled machines during the manufacturing process, saving time on the factory floor" says Frank Statkus, Boeing's vice president of new technology, tools and processes for the 7e7 program (Wallace, 2004).

A statement from Frank Statkus, Vice President of new technology, tools and processes, illustrates the transfer of critical technological knowledge when he described the unprecedented cooperation between Boeing engineers and the risk sharing partner engineers from Alenia (Italy) and Kawasaki (Japan) for designing the composite fuselage sections (Gates, 2004b). Along with engineering work being done by foreign risk sharing partners, a further requirement for U.S. aerospace engineers for the 7e7 program is the introduction of new software tools (which are being financed by Washington State taxpayers). This technology gain allows a couple of engineers (foreign engineers will be trained at the new 7e7 training center which is being partly funded by U.S. federal unemployment funds) a few hours to design and build modifications that used to take 50 engineers two to three weeks (Mercier, 2004). This has caused the Society of Professional Engineering Employees in Aerospace to be alarmed and calls for investigation on these new practices (Gates, 2004a). In a March 2004 interview with Charles Bofferding, Executive Director of the Society of Professional Engineering Employees in Aerospace, he stated "aerospace engineers are not portable like construction workers, you can exhale out, but its difficult to transfer them to other aerospace companies (like the electronics industry in Silicon Valley) and it's more troublesome to bring them back to the aerospace industry… The U.S. is falling behind in engineering talent as whole, foreign-born scientists make very significant contributions to U.S. technological advancement…. U.S. industry, government and academia have grown highly dependant on foreign born science and technology" (Lieberman, 2004).

Boeing has announced that the 7E7 will have a 50% composite structure, but it is unclear whether this percentage is based upon weight, surface area, or cost. On a tradition Boeing aircraft launch, the program schedule would have key suppliers and critical path equipment contracted within the first 90 days, but the 7E7 will not have its first-tier risk-sharing partners contracted until the end of 2004. This 6-month delay in all likelihood reflects a lack of design definition for the structure and subsystems, along with incomplete agreement regarding design responsibility between Boeing and its launch partners (including engine suppliers, certification authorities, and first-tier risk-sharing suppliers). Boeing is at a critical juncture in light of its relative shortage of engineering talent, as witnessed by major layoff cycles since the 777 era, the ageing of its existing workforce, weak stocks of younger people with the skills to replace retirees, and the availability of early retirement options at age 55. Given that the average SPEEA member is 54 years old, the prognosis does not look good as far as the company's human capital stock is concerned.

From a technical perspective, the 7E7 launch has additional problems aside from those associated with engineering talent. After contracting first-tier suppliers, Boeing has an approximately 36-month window before the first scheduled 7E7 flight. Technical challenges include the weight of the aircraft, which may turn out to be overweight as a result of the switch from an initial aluminum design to a composite design (the material substitution often results in the composite part being heavier than the initial aluminum part). Coupled with the fact that this is a very complex exercise in international systems integration, the aggressive first flight target date may prove to be difficult to meet.

What is the future for commercial aircraft technology?

Regarding the retention of aircraft-related technological expertise inside the U.S., an interviewee from MIT (Paul Lagace) noted that: "you can't expect a private corporation to hold this responsibility, a national policy should be developed" (Lagace, 2004). A similar concern for long term technology and innovation (tribal knowledge) retention was voiced by Mark Tuttle, Professor of Mechanical Engineering at the University of Washington in a March 2004 interview (Tuttle, 2004). Jacques Tournut, director of the Aerospace Program at the Toulouse Business School, in a March 2004 interview, went on to question the wisdom of transferring the critical wing design and manufacturing technology for the 7e7 outside the company's control to a risk sharing partner (Tournut, 2004).

Mitsubishi Heavy Industries (MIH) certainly has a clear vision on where the new aircraft composite technology for the 7e7 can lead them in the future. Junichi Maezawa, Executive Director of MHI, said "7e7 is a cornerstone for Japan to become a stand-alone aircraft manufacturer in producing a 30 to 50 seater aircraft in a few years" (Shimbun, A 2004).

China has recently launched the ARJ-21 60-95 seat regional jet that features western produced flight hardware and engines. This is only the prelude to the Chinese becoming self-dependant for supplying the internal demand for future air traffic growth. The Chinese aviation industry has the goal of developing large aircraft as part of an ambitious science and technology program in the next two decades (The Straits Times, 2004). This initiative for producing their own "western certified" aircraft is designed to save billions of dollars in import costs for foreign aircraft. Boeing recently forecast that the Chinese market would require $144 billion worth of aircraft over the next 20 years. Why buy these airplanes from the U.S. if they can be built in China at a fraction of the cost?

Conclusions

Boeing's product line is rapidly aging, with 4 of the 6 commercial product lines projected to close in the next few years (717, 757, 767 and 747). This leaves only the 737 and 777 in production until the 7e7 comes on line. One has to question whether the 7e7 is too late in arriving to save the Boeing commercial product line. In the future, moreover, will Boeing and its risk-sharing partners be willing to invest enormous sums of money to keep developing aircraft models? This is illustrated by a statement of Sir Richard Evans, the outgoing chairman of BAE, who estimated Boeing would need to spend between $40 to 50 billion over the next 10- 15 years to "match" Airbus's product range (Odell, 2004). Richard Aboulafia says in his unique way "our problems don't come from a decade of jetliner product line underinvestment and a shareholder-focused strategy; they come from *those darn foreigners*" (Aboulafia, 2004). Washington State paid Deloitte & Touche $715,000 for advice on giving Boeing "giant tax breaks" of $3.2 billion (Holmes, 2004). While conducting research for this paper, the Project Blue Sky presentation by Deloitte and Touche to Washington State became publicly available. In reviewing the presentation, one would have to question if the tax breaks are being presented as production subsidies.

Boeing is proposing for the 7E7 to have a three-day final assembly cycle (accounting for about 2 percent of the aircraft's value). The company was awarded $3.2 billion in production assistance by Washington State for that activity. There will probably be more Japanese working on the 7E7 than Americans, which would make one wonder why U.S. taxpayers continue supporting Boeing's globalization effort via the foreign sales tax and U.S. Export-Import Bank loans for Boeing aircraft.

U.S. taxpayers reward Boeing shareholders with billions of dollars by elimination of taxes via Foreign Sales Corporations (ruled illegal by the World Trade Organization), and there is no accounting for domestic content in return. The Ex-Im Bank export promotion mandate for the U.S. was to create jobs. However, with the continued decrease of U.S. content and no believable reporting of job creation from Boeing, one could argue there is no longer any need for taxpayers to subsidize Boeing aircraft. And, with 7e7 first tier suppliers not to be contracted until late 2004, followed by second and third supplier selections in 2005, one has to wonder if the 7e7 "first time" system integration style program has the potential of slipping to the right because of not meeting its schedule for producing first article parts in 2006 to satisfy the first flight in 2007 and first delivery in 2008.

Finally, it is worth mentioning that Airbus and Boeing have radically different strategic visions when it comes to demand projections for international passenger flight. Airbus believes that large aircraft (e.g. A380) moving between major hubs offer the best prospects for commercial sales. Boeing, in contrast, believes that smaller aircraft moving passengers to final destinations (bypassing hubs) will pay better dividends. If Airbus turns out to be correct, than Boeing's 7E7 program will not be terribly successful. If Boeing turns out to be correct, then the 7E7 may eventually face stiff competition from new entrants to the LCA market such as Bombardier, Embraer, and, further down the road, emerging producers from Japan, Russia, India, and China (not to mention other Airbus models that still have extensive life-spans ahead of them). Regardless of which company is correct from a strategic assessment perspective, Boeing's systems integration model portends a steady reduction in U.S. content. Ultimately, this suggests that fewer jobs will be retained for U.S. commercial aircraft production.

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