

Are Good Jobs Flying Away?  
U.S. Aircraft Engine Manufacturing and Sustainable Prosperity

by

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## Introduction

In a manner not unlike the other industries highlighted in this series of reports, aerospace, the “crown jewel” of post-war U.S. manufacturing, is experiencing a structural decline, seeing “good jobs” slipping away at an alarming rate. The 1990s have seen the U.S. aerospace industry undergoing a far-reaching process of consolidation; shedding thousands of highly-skilled, well-paid blue collar jobs in addition to white collar design and engineering jobs that only a few years ago seemed secure. In five short years, between 1989 and 1994, aerospace equipment manufacturers cut close to half a million jobs, a decline of 37% from their 1989 employment level of 1,331,000. [Barber and Scott, p.12] Much of this decline has to do with the slowing of military orders as the Cold War wanes. But declining employment in aerospace manufacture has occurred alongside a narrowing of the trade surplus, an increase in the foreign content of commercial aircraft and engines, and a greater role for foreign companies in product development and even basic research activities. These developments are all indications of a structural shift in the industry, one whereby production has become increasingly globalized over the last two decades.

These developments have been particularly significant in the area of aircraft engine manufacturing which saw employment peaking in 1988 with 141,400 U.S. employees. [1992 Census of Manufactures, p.37B-9] By 1995, employment in the industry had plummeted by almost half to 76,300. [1995 Annual Survey of Manufactures, p.1-24] The U.S. barely maintains a trade surplus in aircraft engines and engine parts, with exports of \$6.266 billion and imports of \$5.247 billion in 1993, despite the fact that the two largest firms in the industry, General Electric Aircraft Engines and Pratt and Whitney, which together command two-thirds of the world market, are U.S.-based. [Aerospace Industries Association (a), p.122-123] Probably the most telling indication of a structural shift in the industry is the fact that, since 1993, new orders have been on the increase (up 25% in 1994 and 10% in 1995, in real terms). [See Appendix 2] But during this period, the decline in employment continued unabated, with 27,000 jobs lost between 1993 and 1995 alone. [See Appendix 2]

How the U.S. aircraft engine industry went from being the world’s leader in the design, development, and manufacture of the most sophisticated equipment in transportation to its

current, diminished state is a story that involves many factors, but whose central character is uncertainty. Simply stated, building aircraft engines is risky business; development costs for a new engine program can run to \$1.5 billion (for firms whose revenues are in the \$6 billion range) and product cycles span not years, but decades. The fact that General Electric and Pratt and Whitney remain world leaders in sales proves that these firms have responded to this uncertainty well enough to not merely survive, but to lead the market. However, over the last two decades, what has also become clear is that these firms' investment and marketing strategies, however adept at managing risk for shareholders, have not had the effect of preserving the stock of good jobs in the U.S. A key reason for this is the reluctance of U.S. firms to make the kinds of investments necessary to extend learning to front-line production workers on the shop floor. While the existing literature on the industry has not focused on organizational integration as an important determinant of enterprise and national competitive advantage, it is clear that many aspects of the U.S.'s slipping competitive advantage in the industry cannot be explained without a consideration of organizational integration.

### **Industry overview**

The aircraft engine and aircraft engine parts industry is made up of firms engaged in the design, development and manufacture of engines for various types of aircraft. Aircraft engines can be of two types, turbine or piston engines. The latter make up a negligible fraction of engines produced, measured by value.<sup>1</sup> For the purposes of this report, we will focus on large turbofan engines produced for large civil transports or military aircraft.<sup>2</sup> According to the 1995 Annual Survey of Manufactures, the U.S. aircraft engines and engine parts industry, (classified by the

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<sup>1</sup> In 1993, aircraft powered by piston engines represented shipments of only \$76 million, or less than 0.2% of total aircraft shipments. [Aerospace Industries Association,(a), pp 32, 39, 40.]

<sup>2</sup> Other markets for turbine engines are general aviation (e.g. business jets) and helicopters. Together these segments accounted for only about 10% of aircraft shipments in 1993 with general aviation shipments of \$2.1 billion and civil helicopter shipments of \$113 million. By comparison, shipments of large civil transports totaled \$24.1 billion that same year. On the military side, the 1993 flyaway value of military helicopter acceptances amounted to \$1.5 billion compared to \$9.8 billion for all other aircraft (e.g. bombers, fighters, transports). [Aerospace Industries Association, (a), pp 32, 40]

Department of Commerce's Standard Industrial Classification system as SIC 3724) recorded shipments of \$17.5 billion. The industry employed 76,300 people in 1995, with a total payroll of \$3.6 billion. Aircraft engine and engine parts employment represented about one sixth of the 1995 total aerospace industry employment of 483,200. [1995 Annual Survey of Manufactures, p.1-24]

**Table 1. 1995 Statistics for Aerospace Equipment Industry**  
*1995 Census of Manufactures. U.S. Department of Commerce, Bureau of the Census.*

<b>INDUSTRY (SIC)</b>	<b>Employ-ees</b>	<b>Produc-tion Workers</b>	<b>Value added by manufacture (million \$)</b>	<b>Value of shipments (million \$)</b>
Aircraft (3721)	201,400	86,400	20,904.3	49,504.1
Engines and Engine Parts (3724)	76,300	41,900	9,061.3	17,519.4
Aircraft Parts & Equipment (3728)	116,300	64,000	11,903.5	16,841.3
Guided Missiles & Space Vehicles (3761)	60,800	20,000	7,770.2	14,315.2
Space Propulsion Units & Parts (3764)	19,600	6,700	1,943.5	2,953.6
Space Vehicle Equipment, N.E.C. (3769)	8,800	4,600	852.0	1,397.9
<b>Aerospace Totals</b>	<b>483,200</b>	<b>223,600</b>	<b>52,434.8</b>	<b>102,531.5</b>

While the number of firms in the industry is quite large, the bulk of industry employment is concentrated in large establishments. Of the 442 establishments recorded by the most recent Census of Manufactures, 301, or 68% of these establishments were small, employing fewer than 100 employees. Although large in number, these establishments accounted for only 7% of industry employment. [1992 Census of Manufactures, p. 37B-16] Most of these establishments represent smaller parts and components manufacturers. These many small firms supply the three, large, integrated firms that design, manufacture and sell complete jet engines for large commercial and military aircraft; Pratt & Whitney, owned by United Technologies (UTC), General Electric Aircraft Engines, both U.S.-based, and the British Rolls Royce plc (hereafter to be referred to as Pratt, GE and Rolls, respectively).

General Electric currently leads the market in new commercial orders, winning half of 1995 world orders for large engines. GE's 1995 revenues amounted to \$6.098 billion. Pratt's

1995 revenues were even greater than those of GE, however, amounting to \$6.170 billion.

This outcome would seem impossible in most industries. How could it be that despite *more* new commercial orders, GE's revenues could be *lower* than Pratt's? This peculiar comparison points to the significance of follow-on sales, especially sales of spare parts, in the engine business. In an industry where the product may last 20 to 30 years, time plays a significant role. Although GE may be gaining a greater share of *new* commercial orders, Pratt's historic dominance of the market through the mid 1980's means that it is still earning revenues as a result of orders that were filled as long ago as the early 1970's. In fact, in 1993, 45% of all engines installed on civil aircraft worldwide were Pratt and Whitney engines.<sup>3</sup> [Aerospace Industries Association (a), p.88] The unusually long product cycle in the engine business (and indeed in the aircraft industry at large) contributes significantly to the character of the competitive landscape of the industry, a point to which we will return.

### **The competitive landscape in engine manufacture**

Pratt, GE and Rolls compete vigorously for initial orders; their customers being either airframe manufacturers (for example, Boeing or Airbus), commercial airlines or governments and their armed forces. Demand for engines is highly cyclical, depending on the financial health of commercial airlines as well as on government expenditures, especially on defense. Manufacturers attempt to compete across a range of products, offering a "family" of engines that span from 16,000 lbs of thrust to more than 80,000 lbs. to fit aircraft carrying from as few as 100 to as many as 500 passengers.<sup>4</sup>

To the winners of intense sales competitions go the spoils of not only initial orders, but also future spare parts and possibly follow-on service and maintenance revenue. In the past, the gains from initial orders were particularly great, due to the prevalence of "single source" contracts. "Single sourcing" refers to the historical practice of new aircraft programs selecting only one engine for a given airplane. In other words, when an airline ordered a plane, the engines

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<sup>3</sup> See Appendix 3 for world civil market share data for the major engine manufacturers.

<sup>4</sup> See Appendix 1 for product specifications for major large commercial aircraft and engines.

were “part of the package”. Usually, the airframe manufacturer, along with an airline which committed to purchasing the aircraft early on in the development process, known as a “launch customer” decided which engine would power an aircraft. For example, all McDonnell-Douglas MD-80 and Boeing 727 aircraft are powered exclusively by Pratt’s JT8-D engine, all MD-90 aircraft are powered by the V2500 engine, and all Airbus A340's are powered by the CFM-56. Single sourcing provided “pricing power” to engine manufacturers, generating stability in revenues, allowing for development costs to be spread over a large base. [Smart, Browder and Dawley, p. 126] Now, however, single sourcing is the exception rather than the rule. For the majority of new aircraft, airlines have a choice of engines when they make a purchase. This means that engine manufacturers now engage in intense competition, not just at the time of the launch of a new aircraft program, but continually, each time an airline buys a plane.

Since engines typically represent 25% of an airplane’s price, a significant share, airlines, under intense price competition themselves, clearly prefer having a choice of engines, as manufacturers offer discounts and attractive financing arrangements to win orders [Feldman, p.56]. These discounts can be significant. For example, 1995 and 1996 saw all three engine makers selling engines for Boeing’s new 777 at discounts of up to 75%, charging prices that covered only half the cost of development and production. [Smart, Browder and Dawley, p.124] “Discounts” of this magnitude would suggest an impending hemorrhaging of profits, yet all three engine manufacturers have enjoyed increasing profits since 1994.

This seemingly paradoxical accounting can be explained by the importance of spare parts and follow-on sales in the industry. Spare parts and maintenance may amount to two to three times the original cost of the engine over an engine’s lifetime, creating a significant revenue stream for the manufacturer, long after the initial sale. [March, p.27] According to one trade publication, current pricing strategy in the engines market amounts to “win a sale no matter what and make it up in captive spares volume.” [Vincent, p.55] According to *Air Transport World*, Pratt currently “counts on customers’ buying 1 ½ to 2 times the initial purchase value of whole engines in spares.” [Vincent, p.56] Clearly, spare parts sales represent a significant source of revenue; for UTC, parent company of P&W, for example, sales of spares represent 40% of total corporate pretax earnings. For GE, parts and service generate a third of revenues. [Carley, p.A8]

However, analysts worry that this over-reliance on future spares revenue may pose problems down the road for firms. In the past, sales of spares were the way to finance new development projects. With firms relying on spares revenue to recoup losses incurred at the time of the initial sale, resources for new product development will be sparse.

Current pricing practices will likely increase the reliance of GE, Pratt and Rolls on other firms to share the financing of bringing new products to market, accelerating the trend of international collaboration in engine development. Moreover, it is conceivable that this dynamic could become self-reinforcing, evolving into a downward spiral for U.S. producers. That is, as greater shares of production are taken on by international partners, it can be expected that more of the high-margin spares business will be undertaken by international partners as well, meaning even fewer resources flowing to U.S. producers for future product development, creating an even greater need to collaborate with international partners in development with each successive generation of products. It may be the case that this dynamic has already been set in motion. The past two decades have seen the degree of reliance on international partners growing among GE, Pratt and Rolls in almost all phases of the business, from production to financing new product development, even product development itself. According to most industry analysts, a key element driving this reliance is risk. Trade magazine *Air Transport World* summed up the current position of engine manufacturers recently this way, “[According to former GE Aircraft Engines CEO, Brian Rowe], ‘If we spend \$1 billion over four years [to develop an engine], we’ll probably break even in 17 years’ on a product whose life may be 20 years. That’s a long time when GE Chairman Jack Welch is your boss.” [Vincent, p.56] According to this line of reasoning, the financial pressures manufacturers are under to produce rates of return acceptable to Wall Street dictate that they find some way to spread development costs and risks; their chosen path has been to look overseas. However, whether “risk-sharing” is the only, or even the most significant factor driving these international partnerships may be an open question.

### **Recent industry trends**

Due to the aforementioned costs associated with developing new engines and the reluctance of the “big three” to bear the uncertainty inherent in the industry individually, GE, Pratt

and Rolls have increasingly relied on collaboration with other firms to share development costs and risks. Through collaboration, these firms “compete across ranges by offering engines produced in partnership in those areas where they are relatively weak.” [Todd, p.132]

Collaboration is generally international in nature, pairing firms across both Atlantic and Pacific in partnerships taking a number of forms. There are risk-sharing agreements where “junior” partners commit to financing some share of the project in exchange for a defined work share as a subcontractor sometimes, though not always, participating in the development process. At a more involved level, there are joint ventures where partners form entirely new corporations with each partner holding an equity stake in the enterprise, sharing activities from development to manufacture to marketing and after-sales service.

The most enduring of these partnerships involves GE and the French firm SNECMA (Societe Nationale d’Etude et de Construction de Moteurs d’Aviation). GE - SNECMA cooperation dates back to 1969 when SNECMA played a key subcontracting role in producing GE’s CF6 engines for the first generation of Airbus, the A300. [Hayward, p.128] In its current form, this partnership takes the form of a joint venture called CFM International in which each partner holds a 50% share. CFM International manufactures the highly successful CFM-56 for mid-size jets such as the Boeing 737 and Airbus A320 and the wide body A340. The success of CFM International is reflected in the fact that its engines account for 10.9% of installed engines on civil transports; impressive market share when compared with Rolls’ 9.1% share and even GE’s 11.0% share. [Aerospace Industries Association (a), p.88] GE has continued and expanded its partnership with SNECMA most recently in developing the GE90, the giant 80,000 lb. thrust engine built to power Boeing’s new 777 super twinjet which entered service in 1995. Facing a \$1.5 billion price tag to develop the GE90, GE and SNECMA invited the Japanese firm Ishikawajima-Harima Heavy Industries (IHI) and the Italian firm Fiat Aviazione Societa per Azioni to collaborate in development. [Smart and Schiller, p.80]

Meanwhile Pratt is involved in a number of collaborative partnerships as well as maintaining membership in a joint venture called International Aero Engines (IAE) which manufactures the 25,000 to 30,000 lb. thrust V2500 engine and its derivatives which power narrow bodies like Airbus models A319, A320 and A321 as well as McDonnell Douglas’ MD90.



Firms that make up IAE include Pratt, Rolls, Fiat, Daimler Benz subsidiary Motoren-und-Turbinen-Union Munchen (MTU) and a consortium known as Japanese Aero Engine Corporation (JAEC). JAEC is, in turn, made up of Japanese “Heavies”, Kawasaki Heavy Industries (KHI), Mitsubishi Heavy Industries (MHI), and Ishikawajima-Harima Heavy Industries (IHI). While IAE is made up of many firms, its structure is basically an “alliance of two multifirm groups, centered respectively around Rolls Royce (partners with JAEC) and Pratt and Whitney (partners with MTU and Fiat).” [Mowery, p.88]

There is, to an extent, a sort of cross-firm, cross-national “division of labor” on these cooperative projects. The lead firm on a project (Pratt, GE or Rolls) designs and manufactures the “heart” of the engine, the high-pressure turbine and compressor. Fiat has come to specialize in gear boxes, while IHI has an expertise in long shafts which connect the low-pressure turbine and fan. [National Research Council, pp. 131-138] MTU, MHI and IHI tend to manufacture disks and blades for low-pressure turbines and low-pressure compressors. [National Research Council, pp. 131-139]

**Table 2. International Partnerships in Commercial Engine Development and Manufacture**

Partnership	Engine	Aircraft Application
International Aero Engines (IAE) Pratt & Whitney (33%), Rolls Royce (25%), Fiat (8%), MTU (11%), IHI (13.8%), KHI (5.8%), MHI (3.5%)	V2500	<i>Airbus A319, A320, and A321 as well as McDonnell Douglas MD90</i>
Pratt & Whitney, MHI (10%), KHI (1%)	PW4000	<i>Airbus A300 and A310, McDonnell Douglas MD11, and Boeing 747 and 767</i>
Pratt & Whitney, MTU (12.5%), MHI (5%), KHI (1%)	PW4084	<i>Boeing 777</i>
Pratt & Whitney, MTU (12%), MHI (2.8%)	PW JT8D- 200	<i>McDonnell Douglas MD80</i>
CFM International GE (50%) and SNECMA (50%)	CFM56	<i>powers the Airbus A319, A320, A321 and A340 as well as Boeing 737</i>
GE (59%), SNECMA (25%), IHI (9%), Fiat (7%)	GE-90	<i>powers the Boeing 777</i>

With the exception of the GE-SNECMA partnership, collaborative arrangements are generally project-specific, with firms that are fierce competitors in one product line cooperating in the development of other products. For example, Pratt’s PW2037 is a direct competitor to Rolls’

RB211-535 for the Boeing 757 (thrust range of 38,000 lbs.), yet through IAE these two firms collaborated in the development of the V2500 engine for the Airbus A320 (thrust range of 25,000 lbs.). Further illustrating the project-specific nature of cooperation was Fiat and IHI's recent collaboration with GE and SNECMA on development of the GE90 for the new Boeing 777, an engine which competes with the 84,000 lb.-thrust PW4084 built by Pratt, MHI and KHI. Although Fiat and IHI partner with Pratt, MHI and KHI through IAE, membership in IAE does not preclude cooperation with GE on other projects for these firms. Nor does Rolls' membership in IAE prevent it from launching its own engine for the 777, the RB211 Trent, independently.

As discussed above, participation in collaborative projects for the "big three", GE, Pratt and Rolls, is a way to offer a complete "family" of engines in the face of exceedingly high costs of development. For the smaller manufacturers, decisions to participate in risk-sharing partnerships or co-development may be made strictly on the prospects for sales, but usually involve a consideration of opportunities for learning. As will be discussed in more detail below, while partnering for the "big three" generally has to do with accessing markets, sharing financial risks and lowering costs, for the smaller manufacturers, partnering is a way to break into what might otherwise remain a global oligopoly, sacrificing short-term losses for access to specialized product and process technologies which, in the long term, creates significant opportunities for organizational learning both within the aerospace industry and across other sectors. Japanese firms are a case in point. For KHI, MHI and IHI, all members of JAEC, participating in a number of collaborations across a range of products has become a conscious strategy, with the result that "no new airframe in the twentieth century will be equipped with an engine that is not manufactured at least in part in Japan." [Samuels, p.257] The emergence of Japanese and European firms as key players in an industry that as recently as 25 years ago was dominated by U.S. manufacturers speaks to the determination of these firms, but also to the determination of the governments of their respective countries who played important roles in steering resources to aerospace, mitigating potentially destructive competitive tendencies and fostering a stable, domestic market, helping to nurture aerospace growth. Interestingly, these were exactly the same roles that the U.S. government played in fostering aerospace competitive advantage in the post-war era.

## History of the industry in the U.S.

The aerospace industry was the “crown jewel” of American industry in the Post-War era. Employing more workers than any other manufacturing industry save autos, U.S. aerospace enjoyed a technological advantage that no other nation was able to match. This advantage was fostered by decades of Cold War military expenditures and reinforced by a stable, regulated commercial market. Hefty defense contracts from the U.S. Department of Defense (DOD) as well as from foreign allies helped to finance research and development activities, which in many cases were carried over to commercial applications. For example, GE got its start in engine manufacture when it was selected by the U.S. military in September 1941 to manufacture the British “Whittle engine”. Though GE had been involved in gas turbine research dating back to 1903, under the direction of engineers Sanford Moss in Lynn, Massachusetts and Glenn Warren in Schenectady, New York, GE “teetered on the edge of the turbojet revolution throughout the 1930s” while engineers in Europe forged ahead designing the first jet engines. [Constant, p.221] While this early research was crucial in positioning GE for undertaking war-time projects, it wasn’t until the 1960s that GE broke into the commercial market. Again, though, military contracts served as the foundation for GE’s success when GE successfully transferred the concepts imbedded in the TF-39 high bypass turbofan engine to a commercial turbofan, the CF-6. The TF-39 was developed for the Air Force’s giant C-5 transport and the Department of Defense picked up \$495 million in development costs for the project. Likewise, CFM International’s successful CFM56 engine is designed around the core of the F101, also developed for the Air Force by GE. [March, p.76]

At the same time that the U.S. Department of Defense and NASA were supporting research and development activities, regulation of commercial airlines under the Civil Aeronautics Board (CAB) also had the effect of fostering technology improvements in aircraft and engine design and manufacture. CAB regulation of routes and fares meant that airlines were, for the most part, not competing on the basis of price, but rather on the basis of service. This had the effect of creating a “technology pull” from airlines and allowed airframe and engine manufacturers to pass on costs of development to airlines, who could then, pass increased costs along to

consumers in the form of CAB-approved fare increases<sup>5</sup>. The stable margins created for manufacturers as a result of direct and indirect government support played a crucial role in financing development activities in this risk-laden industry where the product may last for 25 years or more and where the costs of developing a new product run into the billions of dollars. The technological and market advantages of U.S. manufacturers combined to place the U.S. at the pinnacle of aerospace: in 1971 2,076 of the 2,136 jet aircraft in service on U.S. airlines were produced by American manufacturers. [Thornton, p.29] This landscape began to shift, however, during the mid-1970s.

### **The shifting landscape of engine manufacture**

Just as the end of the Korean War had slowed orders, the 1970's brought a Post-Vietnam military downsizing. Real federal expenditures on aerospace declined by half from 1968 to 1974 causing employment among engine manufacturers to plummet from its historic peak of 195,400 employees in 1967 to only 99,300 by 1976 [Aerospace Industries Association, 1994/95 p.21, 24 and 1977 Census of Manufactures, p.37B-5]. Alongside this decline in employment began a trend of geographic dispersion. Traditionally, the engine and engine parts industry in the U.S. had been concentrated in Southern New England (Massachusetts and Connecticut) and in the Midwest (Ohio), being centered around Pratt and Whitney's headquarters in Hartford, Connecticut and around GE Aircraft Engines alternating headquarters in Lynn, Massachusetts and Evendale, Ohio. Starting in the late 1950's, however, GE began moving toward parallel production, the practice of building multiple production facilities capable of handling the same work, with its establishment of a plant in Ludlow, Vermont. Later, in the mid-1970s GE established another Vermont plant in Rutland also adding plants in Madisonville, Kentucky, Durham and Wilmington, North Carolina, and Albuquerque, New Mexico. Pratt and Whitney, meanwhile pursued a similar course, establishing plants in Canada, West Virginia, and North Berwick, Maine. This strategy of parallel production was a way for GE and Pratt to ensure that work-stoppages due to strikes or other labor actions would not jeopardize on-time delivery of products. Disputes such as the 1965 IUE

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<sup>5</sup> For more on the role of Civil Aeronautics Board (CAB) regulation in fostering "technology-push" in commercial aircraft and engine manufacture, see March (1989).

strike in Lynn documented in David Noble's *Forces of Production* were indicative of the rocky nature of labor-management relations in the industry. GE was also the target of a major company-wide strike in 1969, when the 13 unions representing GE workers at 233 plants in 33 states walked out. [Bluestone et al., p.153] The strike was a long one, lasting 101 days. For its part, Pratt also felt the effects of a strong, unionized workforce when a 1979 strike at two important suppliers delayed delivery of F100 engines. Thus, parallel production also served as a means to reassert workplace control. In their major study of the engine industry, Bluestone et al. contend that parallel production served the dual purposes of "provid[ing] production capacity during company/union labor disputes, and severely weaken[ing] the union's ability to strike in the first place." [Bluestone et al., pp 82-83]

While U.S. firms were pursuing a downsizing of the industry and utilizing adaptive strategies such as parallel production to drive down costs, during this same period, the major European countries and Japan had recognized the strategic importance of aerospace, not merely in the traditional military sense, but also to industry overall in generating high-end product and process technologies. The good jobs associated with a world-class aerospace industry were an additional incentive in devoting resources to aerospace activities. The Allies wanted their share of the highly skilled, well-paid, and relatively secure employment that U.S. aerospace workers enjoyed, partly as a result of military and commercial sales outside of the U.S. In Europe, this pursuit of a domestic aerospace industry took the form of the successful Airbus Industrie consortium which had its beginnings in the early 1960s, joining firms from across Europe. The first Airbus, the commercial wide-body, twin-aisle A300, entered service in 1974, powered by the fuel-efficient high-bypass turbofan CF-6 (designed and developed by GE, but assembled by the French SNECMA). High fuel prices added to the design advantages of the A300 and, after a slow start, sparked demand for the Airbus, marking the first major European inroad into commercial aerospace. Meanwhile in Japan, MITI had been playing a significant role in targeting resources to develop a Japanese aerospace industry and aiding the process of technology diffusion across firms in the industry. Throughout the 1970s, Europe and Japan continued to nurture their respective aerospace industries and used NATO military procurements to leverage opportunities for access to U.S. aerospace technologies and to produce U.S. aircraft and engines under license.

Perhaps the most dramatic shift in the competitive landscape came in 1978 with the end of airline regulation in the U.S., marking an end to CAB-approved fares and the end of an era of equipment cost “pass-through”. Airlines now competed firmly on the basis of price and in the new environment of post-deregulation competition, airlines pushed airframers for competition in making purchases. Whereas in the past the purchase of a particular aircraft meant the purchase of one designated engine, airlines pushed manufacturers for choice of engines. While the disappearance of “single sourcing” was not a result of deregulation, per se (it in fact had begun to fade with the advent of the turbo-fan in the mid-1960's), “single sourcing” became even more of a rarity after deregulation and contributed even more to a climate of increased uncertainty for manufacturers. In response, U.S. firms, unwilling to make investments in organizational integration independently, began looking more and more to international partners to collaborate in production and to share the financial risks of development. European and Japanese producers, eager for learning opportunities, were happy to oblige.

### **Roots of international capacity in engine manufacture**

Certainly, the ability of international partners to collaborate with U.S. engine manufacturers was a necessary pre-condition to any globalization of production in the industry. Had European and Japanese firms been lacking in skills and/or physical capacity, U.S. firms would have had to come up with some other way of dealing with the uncertainty inherent in engine production. Clearly, this was not the case, however; in Europe and in Japan development of a internationally competitive domestic aerospace industry was a goal pursued for many decades. The manner in which this goal was targeted and the degree to which it was achieved varies, of course, according to the country in question. Two examples of successful targeting of aero-engine manufacture can be found in France and Japan, examples to which we now turn.

### **France**

The development of France as a player in the world turbo-engine market had its beginnings in military activities, activities that were closely tied with the U.S. armed services. Samuels credits Chateaurault, Europe’s largest F-86 and B-29 maintenance facility, with

providing the French with opportunities to build skills and learning by servicing U.S. military jets, [Samuels, p. 203] but the French, far from being the “new kids on the block” had a strong presence in aviation back to its earliest days. The industry, devastated like the rest of the country after the war, received substantial help from the U.S. in rebuilding its lost productive capacity. The French government played a strong role in technology development, with many of the major French aerospace firms state-owned. However, producing for a small domestic market in the context of a global market increasingly dominated by formidable competitors across the Atlantic, the French in the 1950's came to decide that their best competitive strategy would involve European cooperation. [Thornton, pp. 45-56]

Prior French-German cooperation on such military projects as the Breguet 1150 Atlantic ASW (Anti-Submarine Warfare) Patrol Aircraft and the Transall C-160 troop transport laid the ground for the most comprehensive and successful European cooperative aerospace venture, the Airbus. [Thornton, p.55] The unwavering commitment of the French to European collaboration on the Airbus project in the face of vacillation on the part of Rolls Royce was probably the single greatest factor in SNECMA's current success in the international aero-engine market. Rolls lobbied hard to supply the RB207 engine for the first Airbus, the A300, subsequently withdrawing from the program only a few years later, in 1968, under financial strains associated with problems in developing the RB211 for the Lockheed 1011. The British had made a strategic error in over-committing to both the RB207 and RB211 projects simultaneously, resulting in both projects being plagued by performance problems and cost overruns. [Thornton, p.78] The withdrawal of the only European manufacturer capable of designing, manufacturing, and servicing a large turbo-fan for the ambitious Airbus program left cooperation with a U.S. manufacturer as the only other alternative. The Airbus consortium decided on GE's CF-6 engine with SNECMA assigned a leading subcontracting role amounting to about 25% of the value of the engine with the German firm MTU taking a 10% share. [Hayward, p.130]

This relationship between GE and SNECMA developed from a subcontractor to co-development partner with the two firms joining as equal partners in the development of the CFM56. While “not entirely convinced that a 22,000 - 26,000 lb. [thrust] engine was a sound prospect, [GE] was attracted by the idea of sharing the costs [of developing such an engine] with

a publicly financed company.” [Hayward, p.131] In fact at the time of the agreement in 1971, GE had very little to lose by cooperating with SNECMA and very much to gain. Not only could GE access inexpensive capital and strengthen its relationship with an important sub-contractor, the CFM-56 designed around the military F101 engine would embody some of the most advanced technology available in a commercial power plant, representing a leap forward in engine performance and design. Moreover, the CFM-56 would enjoy a distinct advantage over U.S.-built engines among European customers (especially Airbus customers) who would prioritize high levels of European content in engine decisions. For its part, SNECMA stood to gain from access to cutting-edge jet technology and to expanding manufacturing activities. However, a scare came in 1972 for the principals in this story, when the U.S. government threw cold water on GE’s plans to transfer the F101’s “hot-core” technology abroad.<sup>6</sup> [Hayward, p.132] An agreement was subsequently negotiated between the U.S. government, GE and SNECMA limiting both the extent of technology transfer and SNECMA’s role in systems integration. Within a year the project was up and running once again and the rest, as they say, is history. The CFM-56 has been a tremendous success by either technical or commercial measures. As of 1993, 3,812 CFM-56’s were in service world-wide. The CFM-56 dominates the mid-size engine market: it is installed on 71% of Airbus A320’s, 100% of Airbus A340’s, 58% of Boeing 737’s and 34% of DC-8’s. [Aerospace Industries Association, p. 88-89]

More recently, though, SNECMA has experienced losses associated with its risk-sharing partnership with GE in the GE-90 program for Boeing’s 777. Cut-throat price competition for engines for the 777 led to deep discounts, forcing job cuts. [Sparaco, 1996, p.50] By late 1994, employment at SNECMA was down to about 11,500. However, in the face of these difficulties, SNECMA also tried to blunt the impact of cost-cutting, proposing a shortened work week and initiating efforts to reduce engine development costs by reducing lead times. Also, as a state-owned company, SNECMA can rely on capital injections from the French government and other sources of low-cost, long-term financing to carry on new development projects, such as the CFM-XX, a 40,000-43,000 thrust engine for “growth versions” of the Airbus A340. [Sparaco, 1995, p.

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<sup>6</sup> The “hot core” of an engine comprises the high-pressure turbine and compressor. It is the “heart of any jet engine, and is the most difficult element in an engine’s design.” [Hayward, p.132]



The success of the GE-SNECMA partnership illustrates the priority the French have placed on nurturing a globally competitive engine industry. Due to its small size, it is unlikely that SNECMA could independently undertake the design, development, and manufacture of a major new engine program, since to do so would require massive investments, not only in tooling and design and testing capabilities, but also in a worldwide network for marketing and product support. Still, for now it may be enough that the French have established themselves as critical links in the supply chain, maintaining a stock of good jobs in Europe when so many other industries see these good jobs slipping away.

### Japan<sup>7</sup>

The key players in engine manufacture in Japan are the Japanese Heavies: Ishikawajima-Harima Heavy Industries (IHI), Mitsubishi Heavy Industries (MHI), and Kawasaki Heavy Industries (KHI). Japan's history in aircraft production is a long one, but was interrupted in the key post-war years 1945 to 1952. U.S. military forces dismantled the industry, banning all activities related to aircraft, from manufacturing to repair to research activities. However, according to Samuels' account, the key firms never really exited the industry. Ishikawajima-Harima, for example, was actively engaged in gas turbine research during the years of the ban, "ostensibly for marine transport," research activities which positioned IHI to become the leader among Japanese firms in engine manufacture, a lead which has held to the present day. [Samuels, p.198-200]

Still, the ban meant seven lost years in manufacturing at a critical juncture, just as jet technology was fundamentally changing military and soon, commercial transports. In an effort to regain lost ground, Japan played an active role in repairing and servicing U.S. fleets engaged in the Korean, then Vietnam wars hoping to become "Asia's Chateaurault." [Samuels, p. 203]

As Japanese skills and capacity grew, so did opportunities for co-production, especially on

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<sup>7</sup> This section borrows from Samuels' thorough historical account of the Japanese aircraft industry, *"Rich Nation, Strong Army": National Security and the Technological Transformation of Japan*. Cornell University Press, Ithaca and London. 1994.

military projects. Throughout the 1950s and 1960s, Japanese companies produced a variety of fighters, trainers and military transports under license from the U.S. companies that had developed these products for the U.S. Department of Defense. Generally, firms were first sent “knock-down kits” to assemble, then as learning progressed, domestic content gradually increased. Japanese firms benefitted greatly from the substantial technology transfers associated with co-production as firms “received all product designs and specifications and all process specifications.” [Hall and Johnson, as quoted in Samuels, p.209] Japanese firms also got assistance with tooling and training and, in some cases, outright subsidies from the U.S. DOD. Over the course of the past three decades, this process of indigenization progressed impressively. Whereas the J-79 engine for the F-104 Starfighter was originally imported from the U.S. in 1960, by the end of the F-104 program in 1966, domestic content of the engine had risen to 59.9%. [Samuels, p. 217] And by 1990, the Pratt and Whitney F100 engine, manufactured for Japan’s F-15 fighters had Japanese content of 75% by dollar value, ten years after the first knock-down kits were delivered in 1980. However, in these programs, Japanese firms were excluded from certain activities, such as design and development, and shielded from sensitive components such as the high pressure turbine and combustion system. Access to these activities and components would be crucial to Japanese firms becoming players in the world engine market. Thus, at the same time that the industry was following a strategy of “autonomy through dependence”, many in Japan argued in favor of indigenous development to give aircraft and engine manufacturers practice in activities from which they were precluded in licensed production projects. Indigenous projects, both military and civil were attempted and in some cases, carried out, but these projects generally did not encompass indigenous engine development.

By the mid-1980s, the capacity and skills of Japanese producers had reached a level that posed a serious competitive threat to U.S. firms in supplying certain aircraft and engine components. A report by the General Accounting Office claimed that Japanese learning as a result of the F-15 program had, in some cases, served to “displace the original U.S. supplier and licensor.” [Samuels, p.231] Resistance to transferring technology to Japan came to a head politically with the “FS-X War” of the late 1980's. Japan felt ready to “graduate” from co-producer of U.S. military jets to developing the next generation FS-X (Fighter Support

Experimental), but under intense political pressure, the Japan Defense Agency decided on a modified version of General Dynamics' F-16 to be powered by the GE F110 engine. A series of negotiations ensued regarding the co-development process, circumscribing the extent of technology transfer from the U.S. to Japan, but also including provisions for "flow-back" of Japanese technologies that represented improvements to know-how originally transferred by the U.S. [NRC, p.124] However, these technology transfer and flow-back issues probably are not as significant for the engine as they are for the rest of the FS-X aircraft. The F110 engine designated for the FS-X is not "markedly different" from the engine used on the previous generation F-16 fighter. So, "the development phase is a relatively simple process." [NRC, p.135] At the same time, however, the FS-X program is significant in that it represents the first time that Japan "would receive U.S. assistance in design and development of an advanced fighter". Co-development is significant in that it involves the transfer of "not only manufacturing processes or 'know-how' but full design processes, or 'know-why,' as well." [Samuels, p.241]

This movement from supplier/co-producer to development partner has not been limited to military projects. In commercial projects, Japanese firms which started as suppliers, began to participate with the large engine makers during the late 70's as "risk sharing partners" in projects such as the PW4000 (with MHI's stake at 10% and KHI's stake at 1%) and JT8D-200 (MHI had 2.8% stake). In these projects, while the Japanese firms played no development role, they committed as equity partners in projects, taking responsibility for tooling and plant investment in exchange for defined work shares on a sole-source basis. U.S. firms pursued risk-sharing partnerships to spread the burden of up-front production costs as well as to secure relationships with reliable suppliers. Japanese firms participated in risk-sharing arrangements with the anticipation that such arrangements were just the next rung in the ladder towards eventual partnering in design and development.

Indeed, this type of partnering has progressed. Through the International Aero Engines (IAE) consortium, for example, the Japanese firms MHI, KHI and IHI developed and manufacture the fan and low pressure compressor for the V2500 engine, giving these firms valuable learning opportunities in areas where they previously had been inexperienced. The organization of MHI, KHI and IHI in a consortium of their own JAEC, within IAE, facilitates

work share distribution and technology diffusion among all three firms. A more recent example of Japanese-U.S. firm co-development is the GE90 engine for the new Boeing 777. On this project, IHI is responsible for designing and developing “several stages of turbine disks for the low pressure turbine, the blades in those disks and the long shaft that goes between the low pressure turbine and fan”. [National Research Council (NRC), p.131] GE is “pleased” with IHI’s performance to date and has benefitted from IHI’s fast prototyping of turbine blades. [NRC, p.49]

Japanese progress in aerospace manufacture has attracted much attention in academic and policy circles, perhaps curiously since the current competitive position of Japanese firms is quite lacking in certain key areas. “Across the board the Japanese companies are weak in software and lack sophistication in the analytical tools necessary to do world-class design.” [NRC, p. 143] These disadvantages are compounded by “relatively high unit manufacturing costs and overhead.” [NRC, p.143] However, observers are usually quick to point out Japanese “ambitions” to overcome these weaknesses, noting that Japanese firms are “...asking more often for access to analytical tools [e.g. software and systems integration methodology] in their international alliances.” [NRC, p.143] Moreover, Japanese firms, like firms in other countries, have become specialized in the manufacture of particular components. For example, MHI produces turbine and compressor disks and turbine blades while IHI specializes in the production of long shafts, manufacturing all such shafts for Pratt, Rolls and for GE’s newest engine, the GE90. [NRC, p.138] Japanese manufacturing practices are praised as “very effective” in ensuring the very close tolerances required in engine manufacture. [NRC, p.143]

Whether the potential competitive “threat” posed by Japanese firms is any more significant than potential competition from European producers, the loss of market share by U.S. firms to Japanese producers in a range of other high-tech industries looms large in the discussion. In the words of the National Research Council’s Committee on Japan, “...the committee believes that *leadership in global competition will increasingly go to firms emphasizing high-quality, low-cost manufacturing. This is precisely the area that the Japanese have made their top priority.*” [NRC, p.9] The “industrial targeting” strategy that has served Japanese manufacturing so well in areas ranging from automobiles to electronics has been steadily pursued by MITI in the aerospace

industry over the course of the last two decades. If Japanese aerospace firms are able to replicate the successes of their counterparts in other “targeted” industries, U.S. suppliers, and perhaps even U.S. integrators will have reason for concern over their competitive positions.

One telling indication that Japanese manufacturers are indeed committed to maintaining a presence in the industry for the long-haul is MITI’s sponsorship of the Japanese Supersonic/Hypersonic Propulsion Technology Program (JSPTP or HYPR). The eventual goal of the project is “the development of a scale prototype turbo-ramjet, Mach 5 methane-fueled engine”, the next generation supersonic transport. [NRC, p.140] The project is Japan’s first national R&D effort to include international partners; foreign partners Pratt, GE, Rolls, and SNECMA together share 25% of funding while the Japanese partners IHI, Kawasaki, and MHI receive 75%. The Japanese partners “take the lead in technology development and design” while GE and Pratt serve as “coaches,” reviewing design work and offering critique. That MITI is willing to essentially pay GE and Pratt for this service indicates that Japanese firms, though clearly still behind U.S. producers in key areas, are not content to remain so.<sup>8</sup>

### **Sustainable prosperity in the U.S. aircraft engine industry**

Given the success of countries like Japan and France in building domestic aerospace capability, what are the implications for employment in the industry in the U.S.? Recent developments suggest they are not positive. Following an unprecedented peacetime boom peaking in the late 1980’s, the waning Cold War began to shrink Pentagon excesses by the dawn of the new decade. Meanwhile, the 1990-91 Gulf War and recession slowed airline demand and air traffic. U.S. airframers currently find themselves facing unprecedented competition from Airbus, while foreign capacity in engine manufacture continues to expand. In this buyer’s market, manufacturers are making substantial concessions to obtain orders and squeezing their workforces in an attempt to obtain cost savings and increase “flexibility.” While invoking the rhetoric of the “new competition,” U.S. manufacturers have impressed upon their workforces and suppliers the

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<sup>8</sup> GE and Pratt are collaborating on their own on research on high-speed civil transport (HCST), funded by NASA. According to the NRC, this project “involves a much higher funding level than Japanese government support of HYPR. The U.S. engine makers are not transferring technology from this work to the Japanese.” [NRC, p.141]

importance of quality, on-time production. Womack and Jones, in their new book, *Lean Thinking*, highlight efforts at Pratt and Whitney to lower costs and improve production along “lean” principles. They describe Pratt’s success at reducing inventories, driving down lead times, and lowering costs by reorganizing production into “cells”, collapsing job classifications, and introducing multi-skilling, job rotation, and other forms of work reorganization. Unfortunately, Womack and Jones’s study focuses on the activities of top managers, championing their “steamroller” resolve to turn Pratt around, no matter how many people needed to be fired and how much work had to be outsourced. (As it turned out, employment at Pratt was slashed from 51,000 in 1991 to 29,000 by 1994. Several functions such as sheet metal forming, disk fabrication, and gear and gearbox manufacture were all contracted out.) Unfortunately, very little attention is paid in Womack and Jones’s study to issues of organizational integration. How much involvement is there by front-line production workers in the reorganization on the shop floor? What has happened with apprenticeships at Pratt? Are there other training initiatives being undertaken? Are there new capital expenditures? Of what nature? These questions are not addressed, though are crucial to assessing not only the likely long-term commitment of Pratt to U.S.-based production, but indeed the competitive position of the industry leader in this increasingly competitive industry. Thus, it appears that what lies behind trade publication reports cheering “innovative work reorganization” may in fact be a different story altogether. It is an open question as to whether U.S. firms have undergone a strategic reorientation toward investing in organizational learning or whether firms are just calling old-fashioned adaptive strategies by new names. Although on the surface, it seems that Pratt is making strides towards a “high-performance workplace” that could potentially have positive effects for its competitive position and, in turn, for its U.S. workers, the existing literature has not gone the extra step to scratch that surface.

#### **“Multi-processing” at GE**

One example that might lead us to believe that attempts at work reorganization among U.S. manufacturers may just be “industrial window dressing” can be found at GE Aircraft Engines. Whereas in the past, parallel production was established to minimize the effects of work-

stoppage, it recently has played an important role in forcing changes in work organization. [Interview with Jeff Crosby, President, IUE Local 201 at GE Aircraft Engines, Lynn] In 1991, GE abandoned its “highly-automated, high-volume factory-of-the-future concept” in favor of “kaizen”-style management practices. [Kandebo, p.56] As a part of this initiative, GE attempted to collapse several job classifications and broaden tasks workers would be expected to carry out at its Evendale plant in 1993. The workers refused GE’s attempts and in response the company shifted work to its other facilities in Lynn, Wilmington, Madisonville, Strother, Kansas, and Canada, and announced plans to open a mothballed plant near Durham, North Carolina. “In all, 40% of all part numbers made at Evendale were shifted to other sites”. [Kandebo, p.56] At the same time, GE cut 3,900 jobs in Evendale in a single year. [Kandebo (b), p.79] In the context of a cyclical downturn, these cuts were devastating. Employment at Evendale in 1988 was close to 20,000; by 1994 only 8,000 remained. [Kandebo, p.56]

GE subsequently turned to its workforce in Lynn making the same “multi-processing” demand which would have given management a free hand in assigning multiple operations simultaneously to any worker in the plant. Workers in Lynn rejected this demand out of hand and the saga of Evendale was again played out in Lynn. Work was shifted out of Lynn and held out to the devastated Evendale plant as the “reward” they would receive if they would now accept GE’s work reorganization demands. It worked; Evendale employees voted in early 1994 to accept the company’s demands. It was Lynn’s turn on the “hot seat.”<sup>9</sup> The union in Lynn has continued to resist proposals that would give management any unrestricted rights to reassign workers, preferring to negotiate changes on a case-by-case basis. This strategy has been working reasonably well for the union, but problems remain. The multi-skilling agreements contain no provisions for training and apprenticeship are long gone from GE. In fact, it is the union that has taken the lead locally in developing training programs that would maintain the region’s skill base in the face of the aging Lynn workforce. [Interview with Jeff Crosby, President, IUE, Local 201 at GE Aircraft Engines, Lynn] It is observations like these that suggest that there may be a

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<sup>9</sup> This whipsawing is made that much easier for GE, by the fact that its aircraft engine workforce is represented by three different unions: the International Union of Electrical Workers (IUE), the United Auto Workers (UAW), and the International Association of Machinists (IAM).

darker side to the shift to the “high-performance workplace.” They also suggest that GE, in spite of its long history of various “programs” (the “pilot program”, the quality control movement, the “Work-Out”, and now, “Sigma Six”), has remained reluctant to make the kind of long-term investments that organizational integration requires.

GE chief Jack Welch, discussing his current strategy to drive down costs and improve quality, recently remarked,

“You can’t behave in a rational manner. You’ve got to be out there on the lunatic fringe. You have to tell your people that quality is critical to survival, you have to demand everybody gets trained, you have to cheerlead, you have to have incentive bonuses, you have to say, ‘We must do this.’” [Carley, p.A1]

But Welch’s program stops far short of the requirements for real organizational learning. For example, the training he refers to applies only to “Quality Black Belts,” managers who “spend full time roaming GE plants and setting up quality-improvement projects.” [Carley, p. A8] Training of front-line workers apparently is not considered important in ensuring quality at GE. Likewise, “incentive bonuses” are reserved for management. The threat of job loss due to shifts of work is the only “incentive” held out for production workers. [Interview with Jeff Crosby, President, IUE, Local 201 at GE Aircraft Engines, Lynn]

Indeed the threat is a credible one: employment at GE has fallen dramatically from about 40,000 in 1988 to only about 22,000 by the end of 1994. [Kandebo, p.56] Moreover, GE’s job cuts have not been restricted to production workers. “The white-collar engineering staff, which peaked at 10,000 in 1991 was slashed to 4,000.” [Smart and Schiller, p.78]

### **Supplier Squeeze**

Suppliers to the major firms have also felt the squeeze: “Pratt wants its vendor list cut to 200, already down to 465 last year from 596 in 1990.” [Feldman, p.56] On its face, this could be a signal of a new era of closer ties between suppliers and primes, one in which long-term production relationships, rather than short-term cost considerations, determine who will build parts and components for the big three. Again, though, looking below the surface, it becomes clear that cost consideration are still foremost in the supplier-prime game. One GE supplier remarked “Over the last three to four years, we’ve noticed a significantly worsening relationship [with



GE],” citing GE demands for a 15% price reduction, “on top of 15%” the prior year. [Smart and Schiller, p.78] “Since 1992, GE has extracted huge concessions from suppliers, while trimming its list of vendors by nearly two-thirds, to 500.” [Smart and Schiller, p.78] However, the intense downsizing of the supplier base during the first half of the decade may be coming home to roost, now that orders are once again on the upswing. Both GE and Pratt managers acknowledge that “there is not enough capacity in the supply chain at this time.” [Velocci, p.63] Thus, it appears that organizational integration along the production chain remains a challenge to U.S. firms as well.

### **The Innovation Dynamic**

The effects of the seeming lack of organizational integration for the future of the industry appear gloomy. In the new “streamlined” environment, research and new product development cannot be sustained by firms alone, increasing the role for international partners to participate in development, who are ready, willing and able to participate. In a tacit acknowledgment of the improved competitive position of Japanese and European partners, U.S. firms increasingly hope to gain “flow-back” process technologies from collaboration. The 1990's are also seeing an emergence of other countries intent on playing in the world aerospace market. With the growth of the economies of the Newly Industrialized Countries and China, more and more aircraft orders are coming from the Pacific Rim and forecasts expect that the trend will continue into the 21st century. According to a GAO report, over the next twenty years, more than 50% of world air traffic will be to, from or within Asia. [GAO, p.2]

Like their European and Japanese counterparts two decades earlier, Asian buyers negotiate “offsets,” co-production and licensed production arrangements with the intent of nurturing their own, domestic aerospace industries. These “offset” deals are negotiated as part of an aircraft purchase agreement and specify that a certain portion of the aircraft will be produced locally and/or that local suppliers be given some fixed share of the work. According to one report, offsets have “become the rule, more than the exception” in military markets and are becoming increasingly common in the civil sector, despite the fact that they “in principle” violate a number of trade agreements. [Barber and Scott, p.29] Unions representing aerospace workers in the U.S.

decry offset deals as U.S. corporations “giving away the store.” “Instead of safeguarding technologies they (and the U.S. taxpayers) spent billions to develop, the aerospace giants are pouring these precious skills into Asia.” [IAM Journal, p.13] However, without a seat at the table when sales are negotiated, U.S. workers are powerless to prevent their jobs from becoming chips on the table.

Indeed, the current decade has seen the proliferation of a number of new international partnerships in engine manufacture. The most significant of these is Pratt and Whitney’s joint venture with the Chinese Chengdu Engine Company. This, the first aerospace joint venture in the PRC, was announced in early 1996 and produces engine parts for Pratt and Whitney. For its part, GE also is involved in cooperative ventures in China [GAO, p.10] Some believe that an “Asian Airbus” consortium is just a matter of time and South Korea has played a “leading role” in organizing such an effort that would include “China, Singapore, India and others.” [EPI, p.66]

Further west, aerospace firms in the Commonwealth of Independent States (CIS) and Eastern European countries may play a role in the global aerospace industry of the next century. Although observers note that engine manufacture was a weakness in the former Soviet Union, [EPI, p.56], that has not prevented Pratt from joining with Perm Motors to “co-produce engines for long-range airliners.” [Galuszka and Smart, p.40]

What effect on the competitive position on the industry in the U.S. these new international relationships will have remains to be seen. Looking backward, it is clear that in an industry like aircraft engine manufacture, there are many obstacles to becoming an integrated producer. Firms like IHI, SNECMA, and MTU have become critical players in the world aero-engine market, but lack a number of capabilities central to competing with the “big three.” It seems likely that over the short to medium term, where competitive effects will continue to be felt will be among the ranks of supplier firms. The past two decades have shown the potential for international competitors to make inroads into engine parts manufacture, with the results for the stock of high-quality jobs discouraging for U.S. workers. Employment is approaching historic lows and wages appear to have stagnated. [See Appendix 2.]

Over the longer haul, though, it may be anyone’s game. If Japanese and European producers are willing to commit to organizational investments, the terrain could very well shift

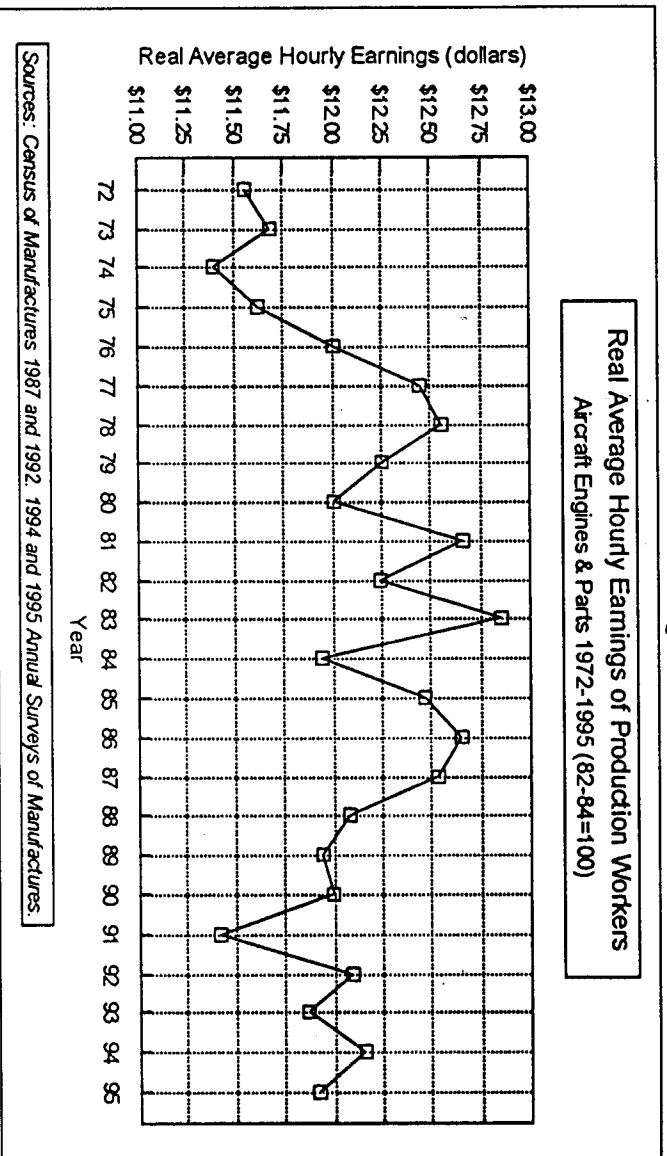
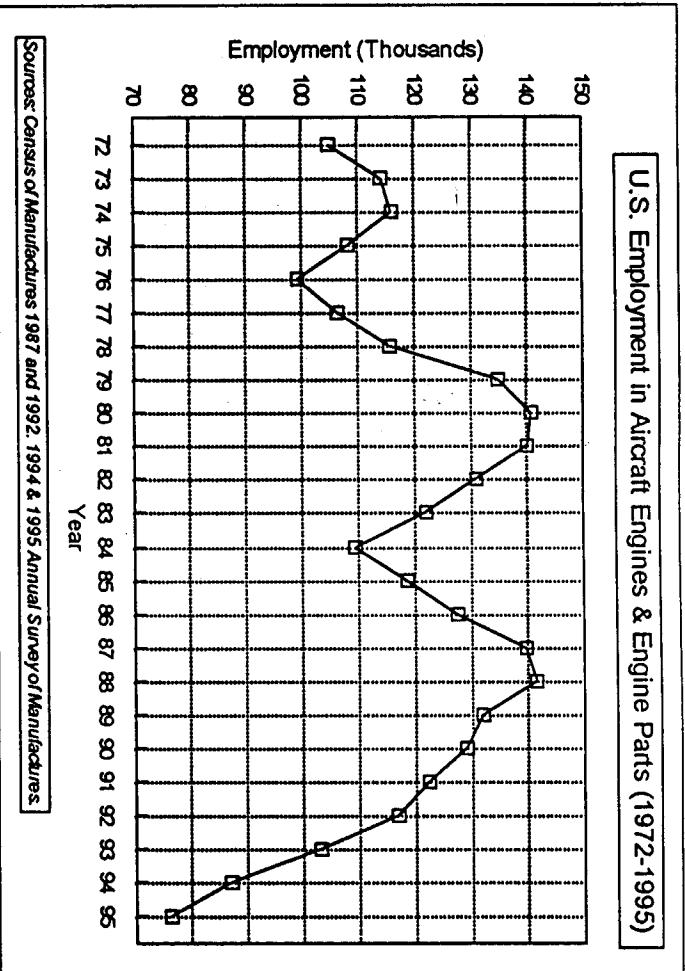
enough in the industry for a fourth integrator to emerge. Or, there may be consolidation in the industry along the lines of the recent Boeing-McDonnell Douglas merger, to make room for another competitor. Last year's announcement by GE and Pratt that they would collaborate on the development of an engine for the new expanded Boeing 747-500X and 600X super-wide bodies is probably an indication that neither firm wants a repeat of the kind of cutthroat competition they had to suffer in the scramble to supply engines for the 777. [PR Newswire, September 2, 1996] That competition wasn't devastating enough to either firm's bottom line for the GP7176 alliance to represent an early indication of something more, although this "unprecedented alliance" of the two largest engine manufacturers in the world is certainly an interesting development. It remains to be seen whether international partners will be brought on board for this project. Who will eventually perform the work involved in building the GP7176 may be indicative of the future direction of the industry. Will Pratt and GE regroup, invest in their workforces and make steps toward organizational integration? Or will the new century see the continued flight of high-quality jobs from U.S. manufacturing?

## Appendix 1 - Product Specifications of Large Commercial Aircraft

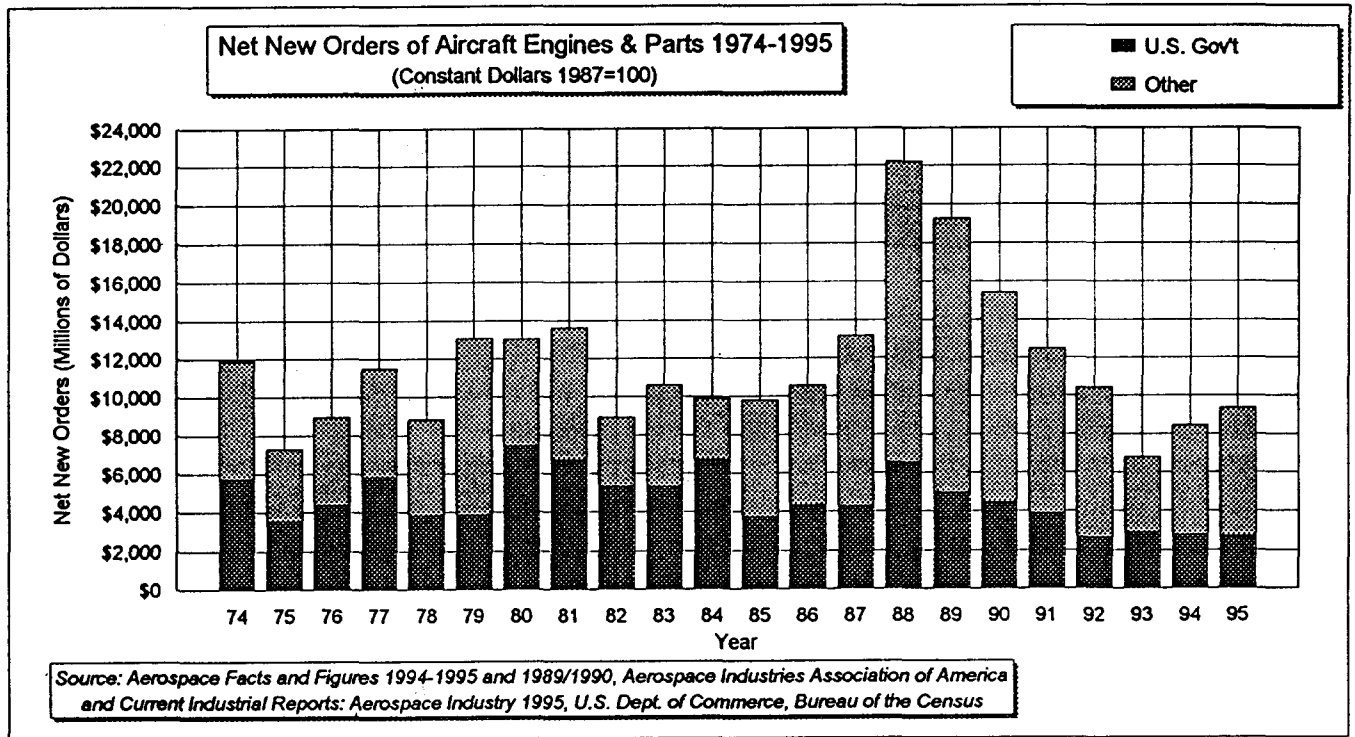
Aircraft	Passengers	Powerplant (Number installed and make)	Maximum Power @ Sea Level	Produced By
<b>Narrow Body Turbofans</b>				
Boeing 727	94-145	3 JT8D's	15,500-17,400	Pratt
Boeing 737	103-159	2 JT8D's 2 CFM 56's	15,500-16,000 20,000-23,500	Pratt GE/SNECMA
Boeing 757	186-220	2 PW2037's or PW2040's 2 RB211-535's	38,250 37,400-43,100	Pratt/MTU Rolls
McDonnell Douglas MD-80	130-155	2 JT8D's	19,250-21,700	Pratt/MTU
McDonnell Douglas MD-90	139-208	2 V2500's	22,000-28,000	IAE
AirbusA320	140-179	2 CFM56's 2 V2500's	25,000-26,500 25,000-26,500	GE/SNECMA IAE
AirbusA321	180-220	2 CFM56's 2 V2530's	30,000-31,000 30,000	GE/SNECMA IAE
<b>Wide Body Turbofans</b>				
Boeing 747	276-550	4 JT9D's 4 PW4056's 4 CF6's	45,600-53,000 50,000-64,000 46,500-57,900	Pratt Pratt GE
Boeing 767	174-290	2 JT9D's 2 CF6's 2 RB211's	48,000-50,000 48,000-60,800 50,000-63,000	Pratt GE Rolls
Boeing 777	300-375	2 PW4000's 2 GE90's 2 RB211 Trents	84,000 76,900-92,000 74,700-95,500	Pratt/MTU GE/SNECMA/IHI etc. Rolls
McDonnell Douglas DC-10	250-380	3 CF6's 3 JT9D's	51,000-54,000 53,000	GE Pratt
McDonnell DouglasMD-11	293-410	3 PW4360's 3 CF6's 3 Trent 685's	n/a 61,500 n/a	Pratt GE Rolls
AirbusA300	220-375	2 CF6's 2 JT9D's 2 PW 4000's	51,000-61,300 56,000 50,000-64,000	GE (some w/MTU) Pratt Pratt
AirbusA310	210-280	2 CF6's 2 PW 4000's	50,000-59,000 50,000-64,000	GE Pratt
Airbus A330	280-550	2 CF6's 2 PW 4000's 2 RB211 Trents	67,500-72,000 50,000-64,000 67,500-71,100	GE Pratt Rolls
Airbus A340	185-550	4 CFM56's	31,200-34,000	GE/SNECMA

Source: Aviation Week and Space Technology, January 13, 1997.

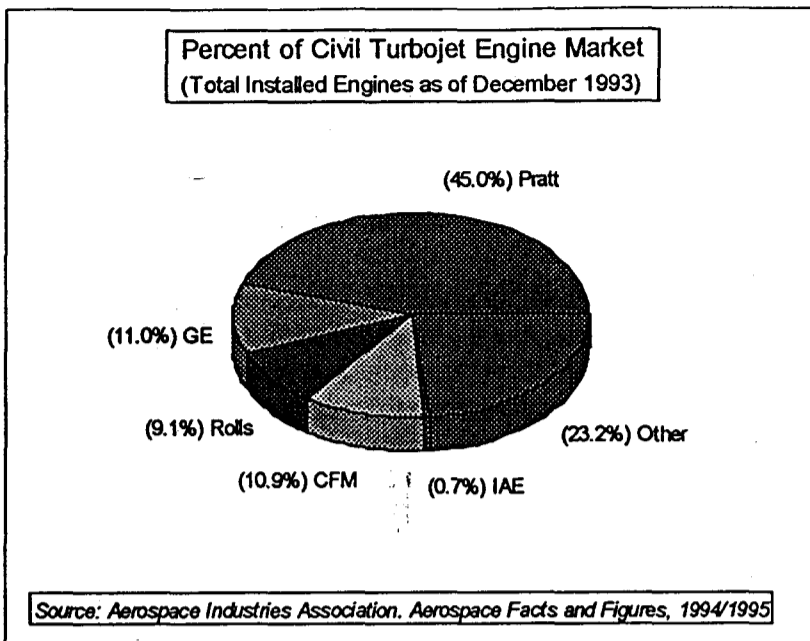
Appendix 2 - Employment, Wage and Orders Trends in the U.S. Aircraft Engine Industry



Net New Orders for U.S. Firms



### Appendix 3 - Shares of World Civil Turbojet Market



Aerospace Industries Association of America (a). *Aerospace Facts and Figures, 1994-1995*. Washington, D.C. 1994.

Aerospace Industries Association of America (b). *Aerospace Facts and Figures 1989-1990*. Washington, D.C. 1989.

*Aviation Week and Space Technology*. March 16, 1992. pp.88-111

Barber, Randy and Robert E. Scott. *Jobs on the Wing: Trading Away the Future of the U.S. Aerospace Industry*. Economic Policy Institute. 1995.

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