CHAPTER 4

Costa Rica in the Aerospace Global Value Chain

Opportunities for Entry & Upgrading

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Table of Contents

List of Tables

List of Figures

List of Boxes

Acronyms

A&P	Airframe & Powerplant
BC	Baja California
ATTC	Aviation Technical Training Center
CINDE	Costa Rican Investment Promotion Agency
DOD	Department of Defense
EASA	European Aviation Safety Agency
EU	European Union
FAA	Federal Aviation Administration
FEMIA	La Federación Mexicana de la Industria Aeroespacial
GVC	Global Value Chain
HS	Harmonized System
IAQG	International Aerospace Quality Group
IT	Information Technology
LCA	Large commercial aircraft
MEP	Manufacturing Extension Program
MNC	Multinational Corporation
MRO	Maintenance, Repair and Overhaul
NASA	National Aeronautics and Space Administration
NIST	National Institute of Science and Technology
OASIS	Online Aerospace Supplier Information System
OEM	Original Equipment Manufacturer
R&D	Research and Development
SATI	Sistema de Agilización de Tramites para la Industria
SEDESU	Secretaría de Desarrollo Sustentable
SIAE	Singapore Institute of Aerospace Engineers
US	United States

1. Introduction

Since the aerospace industry began to globalize in the late 1990s, shifting numerous production functions from traditional aerospace strongholds in Europe and the United States (US) to other lower-cost locations, many developing countries have targeted the sector as an important opportunity for job creation and the transfer of sophisticated technologies. In 2010, the Costa Rican government began to explore potential entry into the global aerospace manufacturing sector, based on the initial success of local firms such as COOPESA and Tech Shop. The aerospace sector in the country is still in its infancy; nonetheless, employment and exports have slowly begun to grow. In 2010, Costa Rica's Ministry of Science and Technology established a national research and development (R&D) council to help channel efforts to develop the aerospace sector in the country (Algarañaz et al., 2011) and the national investment attraction agency, CINDE, is already attempting to recruit new aerospace firms (Field Research, 2012).

The global aerospace sector, however, is a challenging industry to enter. Developing countries that have been able to make in-roads have done so as the result of: 1) technology transfer as aircraft manufacturers pursue market-seeking strategies; 2) strong local government spending in defense; and 3) labor cost arbitrage, among other explanations. Costa Rica's comparatively small labor force and lack of internal market demand put the country at a disadvantage. Yet, specialized advanced manufacturing capabilities and an important focus on quality, customer service and rapid turnaround may give the country an edge over other competitors in niche areas such as maintenance and repair operations (MRO), component manufacturing and software services for the sector. While Costa Rica has experienced some initial success, the growth of this nascent industry to date appears to have been the result of isolated initiatives. Sustainable and gainful entry and participation in the global industry will require the country to develop a comprehensive strategy. This strategy must take into account the global dynamics of this industry and identify key areas where Costa Rica, as a late entrant into the sector, can leverage its strengths in order to compete with lower cost countries.

This report contributes to the formulation of this strategy by using the global value chain (GVC) framework to understand the complexity of the sector and the numerous subsystems of which it is composed. The GVC analysis is particularly useful to inform policy makers as it examines the full range of activities that firms and workers around the globe perform to bring a product from conception to production and end use. It examines the labor inputs, technologies, standards, regulation, products, processes and markets in specific segments and international locations, thus providing a holistic view of the industry both from the top down and the bottom up (Gereffi & Fernandez-Stark, 2011). In doing so, the analysis allows policy makers to assess where local resources may be invested to gainfully participate in global value chains.

This report has four main sections. First, there is an overview of the aerospace GVC and a discussion of the key segments of the chain. This section presents the governance structure, upgrading and workforce development aspects of this industry. While a global overview of the GVC is required to fully appreciate the mechanisms that drive the industry, emphasis is placed on those parts of the value chain that are most relevant for a small developing country in general, and Costa Rica in particular. This is followed by an analysis of the experiences of Querétaro, Mexico and Singapore as they established aerospace clusters in order to identify potential lessons for Costa Rica. Section 4 provides an analysis of Costa Rica's actual contributions to the global aerospace sector and the country's position in the GVC. Finally, section five discusses the potential upgrading trajectories available to allow Costa Rica to improve its participation in the industry, taking into account the country's unique economic and institutional context.

2. The Aerospace Global Value Chain

The aerospace industry is among the largest producers of high-technology goods in the global economy, driving innovation in diverse fields such as transportation, communication and defense. Though the industry is often associated with the productive apparatus behind national security programs ("aerospace and defense" describes this broader categorization), this report will focus principally on the civilian aerospace industry, and particularly on those sections of the industry whose final products include large commercial aircraft (LCA), regional jets, business jets and general aviation aircraft. This segment of the global aerospace industry alone accounted for US$130 billion in revenues in 2010 (Yang et al., 2011).[1]

Though it remains rooted in the advanced economies of North America and Europe, the aerospace industry has reorganized dramatically since the 1980s and 1990s, becoming increasingly global and consolidated at each stage of production. Large aircraft manufacturers, including Airbus, Boeing and Bombardier, outsourced non-core capabilities, and began placing increased demands on a reduced number of direct suppliers to maximize cost efficiencies, share risk and minimize supplier management challenges (Niosi & Zhegu, 2010; Christen Rose-Anderssen et al., 2008). A series of mergers and acquisitions (M&As) has subsequently reduced the number of major players in the industry even further. Competition, nonetheless, remains strong across the sector, and pressure on final buyers—major airlines and cargo carriers—to reduce costs in the face of rising fuel prices has been pushed down the chain, increasing the cost-sensitivity of suppliers. This has created opportunities for new, lower-cost countries to enter the sector. Due to job creation and the potential for the transfer of sophisticated technologies, several developing economies, including Mexico, Singapore and Poland, have developed policies to attract aerospace manufacturers and service providers as they pursue these offshoring strategies to improve economic efficiencies, and access both capital and talent.

This section highlights the global value chain for the sector, discusses geographic distribution of demand and supply, examines the leading firms in the sector and the manner in which the

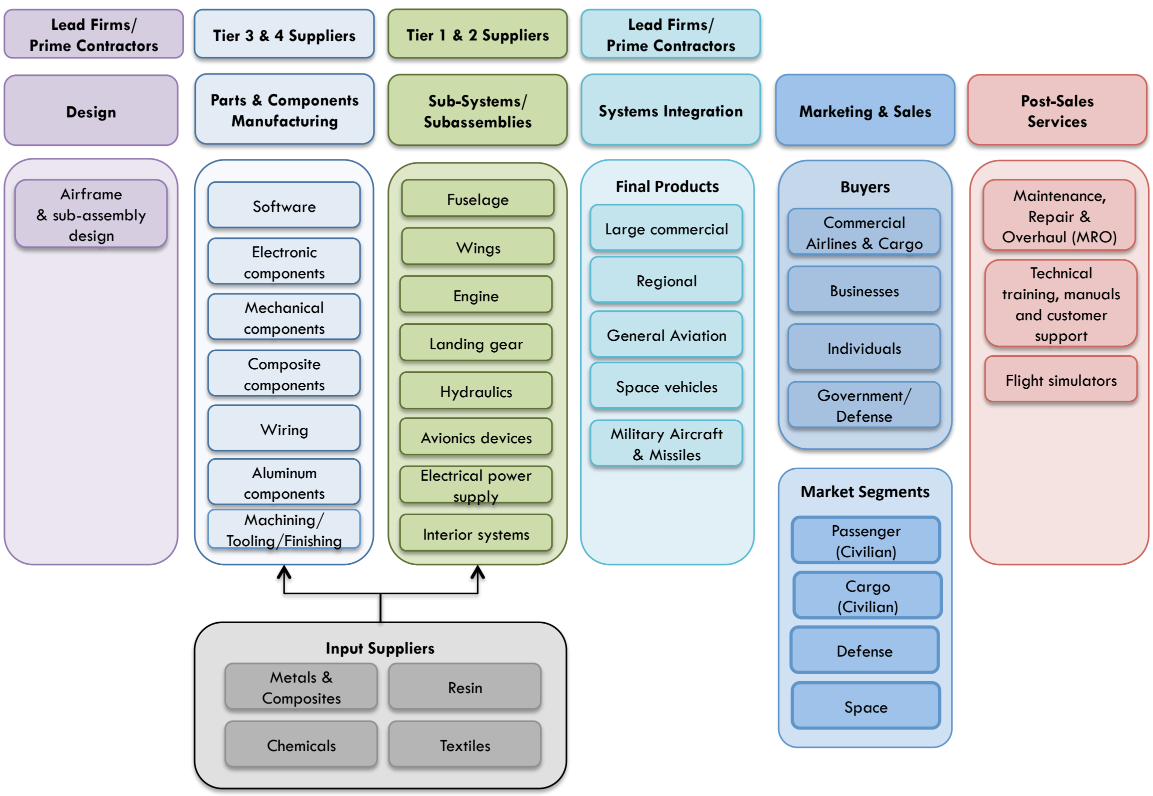
[1] Many companies participating in civilian aerospace global value chains also serve the defense industry. The broader aerospace and defense industry accounted for $648 billion in revenues in 2010 (PWC 2012).

chain is governed through public and private standards and provides an overview of differing human capital needs. By analyzing the global dynamics of the industry, these discussions can help to guide the development of a strategic plan for industry entry.

2.1. Mapping the Aerospace Global Value Chain

This section describes the principal stages of the aerospace value chain, including design, components manufacturing, subassembly and systems integration. Post-sales services have also become an increasingly important part of the industry. Figure 1 offers a visual representation of the GVC for aircraft manufacturing.

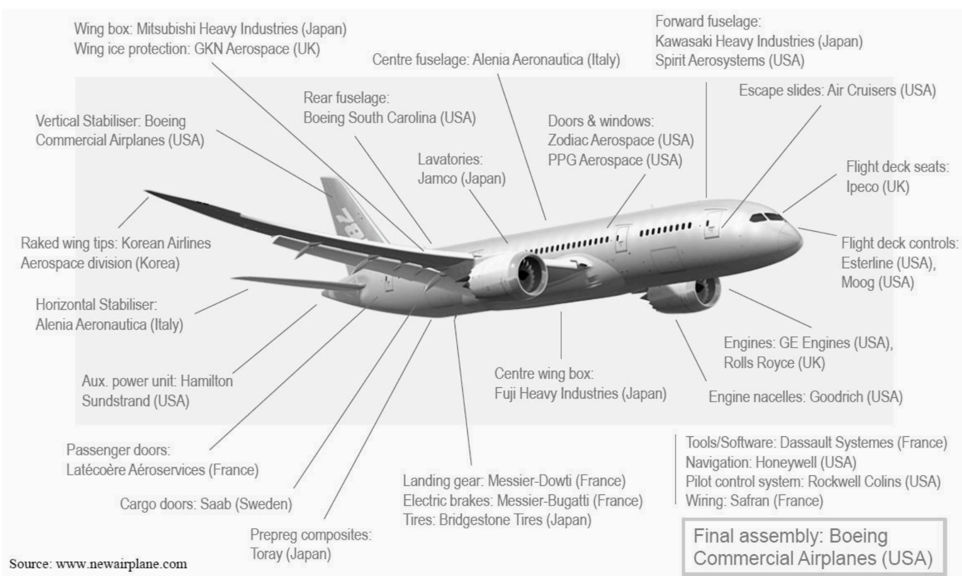
Figure 1. Aerospace Global Value Chain



Source: Authors.

Design: The R&D and product design costs required to develop a product line in the aerospace industry are formidable. Product development generally lasts from five to ten years, and it is estimated that it takes 10 to 18 years for an aircraft to become profitable (Niosi & Zhegu, 2010). In order to distribute the development costs of new aircraft, final aircraft manufacturers have moved towards a systems integration model. In this model, the manufacturing and some R&D of most subsystems and components is outsourced to a handful of "risk-sharing partners," that is, first-tier original equipment manufacturers (OEMs) who also share in profit and loss (Niosi & Zhegu, 2010; Niosi & Zhegu, 2005). One of the most significant risk-sharing operations to date has been the design and development of the Boeing Dreamliner 787, which was undertaken with over 40 risk partners, each responsible for the design, development, manufacture and delivery of their part of the aircraft. Risk-sharing partnerships were open to high-technology aerospace suppliers that were financially strong enough to invest in new practices, technologies and products (Christen Rose-Anderssen et al., 2009); approximately 60% of development costs were transferred from Boeing to these partners. In addition to risk sharing, governments in both the US and Europe contribute significantly to R&D financing through mechanisms such as launch aid programs and royalty-based financing (U.S. Department of Commerce, 2005).[2] Access to this low-interest government finance allows systems integrators and first-tier firms to maintain credit ratings to raise capital from other investors. Figure 2 illustrates how the production of the Boeing 787 was divided amongst its partners in practice.

Figure 2. Risk-sharing Partners of the Boeing 787 Dreamliner



Source: www.newairplane.com.

[2] In 2001, governmental financial support covered 41% of R&D expenditures in the European aircraft industry, while the US government financed 48% of R&D investments in their national aircraft industry (Gifas, 2004), ((National Science Foundation, 2006; cited in (Niosi & Zhegu, 2010)). Government support of the aerospace industry has been at the root of trade friction between the US and European countries for some time. A 1992 agreement between these countries was supposed to limit government subsidies of the sector. However, financing has continued and the agreement finally became null and void in the 2000s.

Box 1. Supply Chain Relationships in the Aerospace Manufacturing Sector

This section provides a brief description of the various suppliers in the global aerospace industry and the relationship between them. The tiered supply structure has become increasingly differentiated following changes to the aerospace supply chain in the 1990s, as all actors in the chain have sought to improve their competitiveness. Table 1 provides an overview of the different tiers, a description of the role each performs within the value chain and examples of the products each yields. In addition, the final column provides an example of the estimated profit margins each of the suppliers in the value chain can expect to make. Expected profit margins decline through the tiers, with tier three and four suppliers receiving the lowest margins.

Table 1. Organization of the Aerospace Production

Type of company	Description	Examples of products	Estimated profit margins (e.g. Airbus A380)
Prime contractor[3]	Responsible for the design, assembly and systems-integration for the final aircraft.	Completed aircraft	20%
Tier one supplier	Provide major subsystems, such as avionics, propulsion and some pieces of the airframe structure. These suppliers may act as risk partners for particular aircraft.	Propulsion system (engines), aviation system, wing, undercarriage	18%
Tier two supplier	Supply minor subsystems, airframe sections, turbines and avionics devices to the prime contractor and first-tier suppliers.	Computer systems, avionics devices, wing flaps, gear boxes	15%
Tier three supplier	Provide product- or industry-specific components for subsystems to the prime contractor or other suppliers.	Circuit boards, hydraulic pumps, motors, controls	11%
Tier four supplier	Tier four suppliers provide relatively low value-added commodity parts.	Pistons, o-rings, rivets	Not available

The relationship between the prime contractors and the tier one suppliers has become increasingly collaborative as the primes have moved towards risk-sharing business models. Tier one firms must now have the capabilities to identify and manage their own supply chains of lower-tier firms, as well as to manage financial investments in R&D systems. Some design and build capabilities are transferred to tier two suppliers, along with quality and price requirements, but lower-tier firms are mostly responsible for lower-value components used in subassemblies, and provide components based on set specifications. Intellectual property is protected internally through a trade secrets approach in the supply chain rather than through patent protection. One result of the risk-sharing model has been a reduction in the total number of suppliers with whom the prime contractor directly transacts. For example, as Embraer moved from the ERJ-145 line to the ERJ-170/190 project, it increased the number of risk-sharing partners from four to 16 and reduced the number of suppliers from 450 to 40. High management costs have also led producers in each tier to reduce their number of suppliers, putting increased pressure on tier two, three and four suppliers to consolidate and increase their capabilities. This dynamic creates higher barriers to entry in the chain.

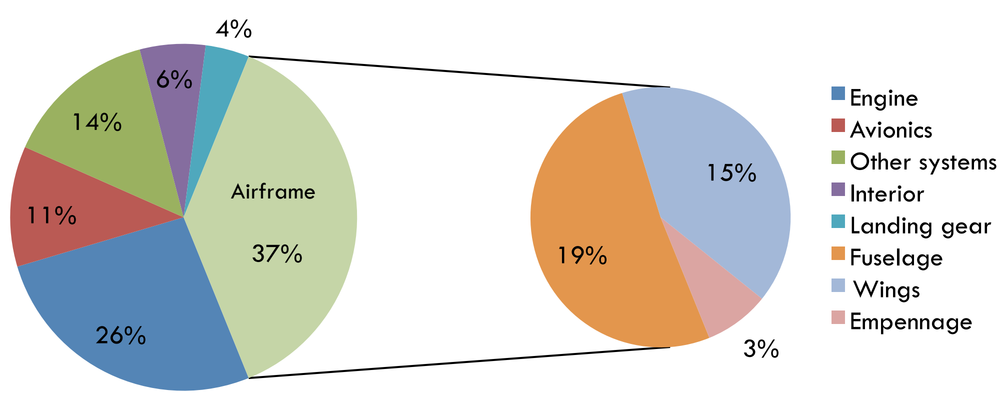
Source: Clearwater 2011; Dorna et al., 2004; Ehret and Cooke, 2010; Johansen et al., 2005; Kraemer-Mbula, 2008; Marques and Oliveira, 2006 and Smith and Tranfield, 2005, Nsioi & Zhou, 2005.

[3] It is important to highlight that the shifting relationships between aircraft systems integrators and their major sub-assembly suppliers has led to some confusion in the nomenclature of firms within the supply chain. It is not uncommon to see firms such as Rolls Royce or Honeywell referred to both as prime contractors and Tier 1 suppliers. For the purposes of this study, systems integrators are referred to as prime contractors to differentiate them from sub-assembly firms (tier one).

Parts and Components Manufacturing: This segment of the chain includes the specific and generic inputs required to form the subassemblies of the aircraft. Such components range from circuit boards and sensors to composite parts for the empennage (tail of the craft) to specialized screws used in tray tables. This segment of the value chain is dominated by firms which manufacture product- or industry-specific components such as rotors, antennas and motors, and firms which manufacture more generic components included un-machined castings and whose portfolio of clients often includes non-aerospace customers. Firms operating in the component segments may also manufacture components for other industries such as the automotive and industrial sectors.

Sub-assemblies or Sub-systems: Subassemblies are the modules that the aircraft manufacturer assembles into the final product. These subassemblies include airframes, propulsion engines, fuel systems, hydraulics, landing gears, avionics (flight, navigation and communication systems, discussed in Box 2), electrical power supply, and interior fittings amongst others. The relative value of subassemblies is shown in Figure 3. While the airframe is the most expensive, it should be noted that this "component" is made up of several modules (the wings, the center wing box, the front fuselage, the aft fuselage, the empennage and the nose), whose production is shared across multiple firms spread across several countries.[4] Firms operating at this stage of the value chain include those that produce final assemblies, such as the largest three engine manufacturers: GE Aviation, Pratt & Whitney and Rolls Royce (U.S. Department of Commerce, 2010).

Figure 3. Value of Subsystems as a Percentage of the Total Aircraft Value



Source: Wipro, 2009.

[4] For example, production of aircraft subassemblies for the Boeing 787 program are located in Japan, Italy and the US, and, through offsets, China has attracted some subassembly manufacturing activities from Airbus, Boeing and Embraer (Osse, 2012; Pritchard & MacPherson, 2004).

Box 2. Avionics Systems and Embedded Software

Avionics systems account for approximately 11% of the total value of an aircraft. These systems include both the hardware and software that control flight functions, navigation guidance control, communications and systems operations and monitoring. Global avionics spending is expected to increase from US$5 billion in 2011 to US$8.9 billion in 2020. The growth of the avionics market is being pushed by fleet modernization programs, including the purchase of new planes and retrofits of older craft, and pressure to increase fuel efficiency. Furthermore, changes in Air Traffic Management (ATM) standards in Europe (the Single European Sky ATM Research Program (SESAR)), the US (NextGen) and other major markets require additional avionics upgrades of the existing fleets to be completed by 2025. There are four key segments of avionics: communications, navigation, surveillance and integrated modular avionics (IMA). Navigation is the largest market segment, followed by communications. IMA, which focuses on maximizing functionality while minimizing power consumption, will remain the smallest market segment. The communications and navigations segments are less price-sensitive than surveillance, while IMA has the lowest price sensitivity. Avionics segments are also divided between mission- and safety-critical systems—such as guidance navigation control, power systems, landing gear and fire protection systems—and those that are not, such as in-flight entertainment.

Embedded avionics software is a core element in integrating the variety of hardware systems employed in aircraft and those on the ground in ATM systems. Key stages in the avionics software segment are design and development, verification and validation, development of tools, support and reserve engineering and maintenance. Software engineering is regulated in the US by DO-178C Quality Management Systems. DO-254 regulates hardware for avionics systems, while DO-278/EUROCAE ED-109 regulate non-airborne systems. Regulations require that verification and validation be performed by a different set of programmers than those that designed the system. Avionics systems developers thus typically maintain design and development in-house and outsource verification and validation. Verification ensures that the software requirements are implemented correctly. The software must be tested and analyzed to ensure that it not only performs as required, but that it also does not include any unintended operations. Additional tests are performed as the software is integrated with the hardware and validated at the system level. In mission-critical systems, in which failure is unacceptable, verification can account for a larger portion of the project than design and development. The growth of this embedded software market is expected to be exponential in coming years, with new projects estimating an average of 30% increase in the lines of code. Embedded software in the Boeing 787, for example, has more than eight million lines of code, four times that of the Boeing 777.

Price, size, functionality and compatibility with other systems are among the most important factors considered by buyers when selecting their avionics systems vendors. Honeywell, Rockwell Collins and Thales are the three largest system supplier buyers in the sector, with a combined 58% market share, although Honeywell has steadily been losing its lead position. Thales has grown considerably since becoming a core supplier for Airbus's new projects. Honeywell has strong relationships with Boeing, and Rockwell Collins with Bombardier. Other avionics systems integrators include GE Aviation, Goodrich (UTC) and Sagem DS. Leading embedded software providers that work with these integrators include Esterline, Wind River Systems Inc, and Green Hills Software. Embedded software firms tend to be smaller and serve multiple end markets, with annual revenues of between US$25 million and US$155 million.

Source: Abraham & Friedman, 2012, Cubas, 2012, Frost & Sullivan, 2012, Hoovers, 2012, McKenna, 2008.

Systems Integration: Systems integration refers to the process of connecting the various systems and subsystems that constitute the aircraft into a "complete system." For example, controllers in the propulsion system must be able to monitor and respond to changes registered in the avionics system. Final aircraft manufacturers have been moving towards a business model based around systems integration since the 1980s (Niosi & Zhegu, 2010;

Christen Rose-Anderssen et al., 2008). As risk-sharing suppliers begin assuming R&D and design roles, firms providing propulsion (engines) and avionics systems also play a role in systems integration, for example, ensuring that the various avionics subsystems properly communicate with one another. The term "OEM" is often used in the literature to refer to systems integrators.

Final Products & End Market Segments: Final products in the aerospace manufacturing market include large commercial aircraft (LCA), regional jets and general aviation aircraft (business jets, turboprops, helicopters, etc.), spacecraft and military aircraft such as fighter jets, attack helicopters and missiles. There are four principal end market segments in the industry: the passenger segment, which includes buyers ranging from airlines such as British Airways and American Airlines to businesses and medical rescue operations to individuals; cargo operations, including firms such as DHL, Fedex and UPS; the defense segment (national governments); and the space segment. This report focuses principally on the commercial and cargo segments—that is, the civil aviation segment. However, most firms in this segment also design and manufacturer aircraft for the military segment and it is difficult to discuss the development of one segment without the other.

Post-sales Services: Post-production services include maintenance, repair and overhaul (MRO), technical training and customer support and the supply of flight simulators. As global aircraft fleets expand, post-sales services are becoming increasingly important revenue generators. Product-specific training is required for pilots, crews and maintenance workers on ever more sophisticated aircraft systems, while the number of planes requiring ongoing maintenance and repairs has increased significantly. Box 3 provides a detailed analysis of the MRO segment and its emerging opportunities.

Box 3. The Maintenance, Repair and Overhaul (MRO) Market

Aircraft maintenance is carried out after specific times and/or usage and is a substantial part of total aircraft cost. It has thus become an important segment of the aerospace market. Global commercial MRO spending was valued at US$46 billion in 2011 and is expected to grow to US$65 billion by 2020 (Ali, 2011; Clearwater, 2011). Airlines, third-party providers and OEMs all compete in this lucrative segment. Large airlines such as Air France, Iberia and Lufthansa are key leaders, leveraging in-house competencies for profit generation by offering their services to other airlines, while many smaller and low-cost airlines have preferred to outsource this capital-intensive function to third-party providers to keep costs at a minimum. In the past, third-party providers often operated under license agreements with OEMs to maintain and repair components and subassemblies. However, in the 1990s, OEMs entered the segment as part of a shift towards a full-service business model. Driven initially by engine OEMs using strategies such as limited access to technical manuals, parts and tooling, thus making services certifications more difficult to obtain, OEMs have increased their participation in this aftermarket. OEMs offer their clients important value propositions including predictable costs, a single source for all maintenance and expertise that airlines or third-party operators cannot easily maintain on their own.

The single most important driver of the MRO segment is air transportation, with regional fleet size and projected growth providing strong indicators for demand. Geographic consideration for a firm's global footprint is crucial. MROs need to have major facilities in key traffic flow areas, as it is expensive to fly planes long distances for maintenance requiring just a few man-hours. At the same time, nonetheless, leveraging low-cost locations, skilled labor and quality performance for non-geographically sensitive work such as component MRO and more intensive maintenance work, is also important for sustaining competitiveness in the long term. As a result of balancing these needs for geographic sensitivity and utilizing low-cost locations, today many MRO firms have established global networks servicing multiple different clients.

Aircraft maintenance checks can be classified as heavy maintenance, engine overhaul, components overhaul, line maintenance, avionics or retrofit (see Table 2), with engines maintenance and repairs accounting for the largest share of MRO spending. MRO firms may be specialized in one area, such as engines or avionics, or offer an integrated service. Co-locating with other MRO firms with complementary expertise can also provide competitive advantage. For example, Singapore has become a leading provider of integrated MRO services in the Asia-Pacific region, thanks to the presence of OEM and third-party MRO providers in avionics, engines and airframe maintenance as well as a components manufacturing sector. Engines will continue to account for the majority of MRO revenue, followed by components. In the face of rising fuel costs and new regulations, there has been strong emphasis placed on improving engine technologies for fuel efficiency such as fuel burn reduction washes and R&D in hybrid engine technology.

Table 2. MRO Service Activities

Type of MRO	Description of Activity	Geographic Sensitivity	Firms
Heavy maintenance	This usually involves the disassembly of major components of the aircraft for detailed inspection and repairs.	Global/ Regional low-cost, specialized locations	AAR Corporation SR Technics ST Aerospace
Engine overhaul	This ranges from routine service checks to the complete repair of the engines.	Global, low-cost, specialized locations	Lufthansa Technique Rolls Royce GE Aviation
Components overhaul	This usually involves the overhaul of all other parts not categorized under the heavy-maintenance category. These range from landing gear to fuselage overhauls.	Global, low-cost, specialized locations	Hawker Pacific Aerospace APPH Ameco
Line maintenance	This function involves the routine maintenance of the aircraft as well as frequent inspection of the aircraft to ensure its safe in-service use and minor repairs as advised or required by OEM periodic publications.	Local, limited man-hours, in airport hubs	Scandinavian Aircraft Maintenance SIA Engineering
Avionics	MRO organizations in this category specialize mainly in the overhaul of the aircraft avionics and associated components.	Global, low-cost, specialized locations	Honeywell Selex Galileo Global
Retro-fits and conversions	This sector is responsible for the major and minor design retro-fits and the conversion of passenger aircrafts to freighter aircrafts.	Global, low-cost, specialized locations	Aeronautical Engineers Airbus Haeco

MRO revenue from Latin America is expected to reach US$3.7 billion by 2021. In the region, large airlines generally have favored in-house MRO operations; for example, Aerolineas Argentinas (Argentina), Avianca (Colombia) and TAM (Brazil) all have large MRO operations. Furthermore, consolidation of the regional airline industry as a result of bankruptcies of airlines such as Mexicana (Mexico) and Pluna (Uruguay), and mergers and acquisitions in the region, such as that between LAN (Chile) and TAM, have reduced the demand for regional third-party MROs. LAN's regional fleet will now be serviced in Brazil. With shrinking regional demand for outsourced services, third-party suppliers have had to make significant investments in infrastructure, certification and training in order to serve the large fleets (often over 200 planes) of US based airlines. In Central America, Aeroman (El Salvador) has emerged in the past 10 years as an important third-party operator, with capacity to serve 11 planes simultaneously in state-of-the-art facilities.

Source: Ali, 2011, Ayeni, et al., 2011, Boeing 2012, de Lavigne, 2009, Field Research, 2012, McBride, 2012, Spafford, Aso et al., 2012, Spafford, Hoyland, et al., 2012.

2.2. Leading Countries

Global Demand

Global demand for commercial aircraft is driven primarily by major airlines expanding their fleet or replacing aging aircraft, and they account for over 75% of market share (IBISWorld, 2012). Although the industry was affected by the global economic crisis between 2008 and 2009, overall demand has recovered considerably with large aircraft manufacturers reporting strong profits in 2011 (Pwc, 2012). Boeing estimates that 20,000 aircraft will be replaced and 15,000 new planes will be added to the global fleet by 2030 (Boeing, 2012). The US and European markets are the most mature markets (65% share), with important growth derived from the renewal of fleets with more fuel efficient planes (Pwc, 2012), while strong economic growth in developing regions including Asia, Eastern Europe and South America is resulting in rapid expansion of their local airlines.

Over the next 10 years, more than 70% of Boeing's large civil aircraft will likely be delivered to customers outside of the US (Ali, 2011; U.S. Department of Commerce, 2010). For example, in 2012, one Asian airline announced an order for 230 aircraft from Boeing, the largest single order in aviation history (Pwc, 2012). Furthermore, both Airbus and Boeing recognize that China is the world's fastest growing market for commercial aircraft, and estimate that China will need around 3,000 new aircraft by 2025 (MacPherson, 2009). India's civil aviation market is also predicted to expand significantly over the next twenty years. Domestic passenger traffic there is expected to grow at 12.5% per year as the country's large and growing middle class spends more money on air travel (U.S. Department of Commerce, 2010). By comparison, the Americas fleet is projected to grow by just 1,000 planes in the next 10 years, with Latin America accounting for 625 of those planes.

Global Supply

The manufacture of aircraft is concentrated in a small number of countries home to major aircraft manufacturers: Brazil (e.g. Embraer), Canada (e.g., Bombardier), France, Germany (e.g., Airbus), and the US (e.g., Boeing). Exports in 2008 indicate that European sales (France and Germany) accounted for approximately 45.1% of all aircraft exports, while the US exports accounted for a lower market share of 39.2% (see Table 3).[5] Together with Canada and Brazil, these four exporters have maintained over 92% of global exports from 2004–2011.[6]

[5] 30% of US aircraft sales are absorbed by the domestic market and are not exported (Yang et al., 2011).

[6] Over the 2004-2011 timeframe the main exporters of helicopters included the EU-15 (Italy, France, and Germany), the United States and Canada (UNComtrade, 2012).

Table 3. Top Five Exporters of Airplanes by Value, 2004–2011

Airplanes	**Value (US$ Millions)**					**Share (%)**				
Exporter	**2004**	**2006**	**2008**	**2010***	**2011***	**2004**	**2006**	**2008**	**2010**	**2011**
World*	**74,936**	**101,347**	**118,168**	**129,200**	**140,755**					
EU-15	36,017	42,942	53,342	64,704	70,048	48.1	42.4	45.1	50.1	49.8
USA*	24,679	43,639	46,364	51,048	56,372	32.9	43.1	39.2	39.5	40.0
Canada	5,036	5,974	5,762	6,168	5,816	6.7	5.9	4.9	4.8	4.1
Brazil	3,269	3,241	5,495	3,996	3,932	4.4	3.2	4.7	3.1	2.8
Argentina	--	--	--	--	868	--	--	--	--	0.6
Switzerland	--	1,388	1,965	601	--	--	1.4	1.7	0.5	--
Russia	2,111	--	--	--	--	2.8	--	--	--	--
Top Five	**71,111**	**97,184**	**112,929**	**126,517**	**137,036**	**94.9**	**95.9**	**95.6**	**97.9**	**97.4**
				Main EU-15 Exporters		**Share of EU-15 Exports (%)**				
France	16,667	21,906	28,610	38,534	41,136	46.3	51.0	53.6	59.6	58.7
Germany	12,472	18,217	21,321	22,408	27,144	34.6	42.4	40.0	34.6	38.8

Source: UN Comtrade, 2012. Airplanes are represented by HS96 codes 880220, 880230, 880240.

* US data for 2010 and 2011 is from USITC and represents the share of HS 880000 of 2008 data (Airplanes represented 64.4% and helicopters 2.5%). The world value is also based on the USITC values. Reported US values for airplanes in 2010 and 2011 respectively were US$883.8 and US$1,161.6; helicopters were US$897.7 and US$577.5 respectively.

** Spain and Austria have not reported for 2011.

While Table 3 shows that systems integration continues to take place in these countries, over the past two decades, major aircraft assemblers and providers of key systems such as avionics and propulsion, headquartered in traditional aircraft manufacturing countries, have been offshoring production of both minor components and major subassemblies in order to take advantage of low-cost labor and gain access to locally available technology (Goldstein, 2002; Niosi & Zhegu, 2010).[7] By shifting production to lower-cost locations, these prime contractors can save as much as 30% on labor costs (Clearwater, 2011). Subsystem assemblers can realize similar cost savings, and as major suppliers open facilities in new locations, they are quickly joined by parts and component suppliers (which may be locally or foreign-owned) who are drawn to opportunities for follow-sourcing. Indeed, several studies have identified the presence of a lead firm as a key "anchor" in the establishment of a local aerospace sector (Niosi & Zhegu, 2005; Romero, 2010). This is due to both the investments of the lead firm in human capital development for the sector and the pull effect for suppliers. In some cases, OEMs have also been forced to procure from particular locations in order to gain access to specialized local technologies, such as Boeing's procurement of wings made of composite materials from Japan (McGuire, 2007; Pritchard & MacPherson, 2007).

In addition to seeking out low-cost labor and specific technology, the use of offset agreements has contributed significantly to the globalization of the aerospace industry. Through these agreements, final aircraft producers agreed to source components or subassemblies, or to set up assembly plants (often via joint venture) in particular countries, in

[7] Pritchard and MacPherson (2007) state that Airbus even informed its first-tier suppliers that outsourcing to Asia was a requirement, and that failure to comply would entail significant penalties.

exchange for gaining access to that country's market (*market-seeking production strategies*). The use of offsets as a criteria for production locations, however, has been declared bad business practice by the World Trade Organization (WTO) and may no longer be included as a criteria for the procurement process. Rose-Anderssen et al. (2011) find that while they no longer have a positive or significant effect on today's chains, these practices did contribute to global distribution patterns of supply chains in the past. Other studies suggest that offset practices continue to be used (Deloitte Manufacturing Group, 2012). Thus, while the industry remains concentrated in a small number of lead countries, several other nations have entered the aerospace GVC, including China, India, Indonesia, Japan, Poland, Mexico, Russia, Singapore, South Africa and South Korea.

Table 4 highlights the leading exporting countries for each of the following value chain segments: airframe subassemblies (e.g. wings, fuselage components, empennage, etc.), propulsion systems (and components), landing gear (undercarriages), navigational instruments (which form part of the avionics system), and other aircraft engines such as those required to power on-board electrical operations. The highest value export category is airframes, in which exports are dominated by the US and the EU-15 (Germany, France, Italy, & Spain), with Singapore and Japan making up smaller, but consistent, shares over the last eight years. The next largest category includes the main engines used for propulsion. The UK is an important contributor in the production and final assembly of various subassembly systems (Cooke & Ehret, 2009), in particular the propulsion systems; however, no final systems integration takes place in the country. Other subassemblies include landing gear (USA, EU-15 and Canada), navigation equipment (EU-15 and USA) and other smaller aircraft engines (Singapore, USA and EU-15).

Table 4. Top Five Exporters of Aerospace Subassemblies by Value (US$ Billions) and Shares (%), 2008

Exporter	Airframe Assemblies		Main Engines (Propulsion)		Landing Gear		Navigation Equipment		Aircraft Engines		Totals	
	Value	**Share**	**Value**	**Share**	**Value**	**Share**	**Value**	**Share**	**Value**	**Share**	**Value**	**Share**
World	55.0		24.1		4.1		2.9		2.0		88.1	
EU-15	19.2	34.9	10.5	43.5	1.2	28.4	1.1	39.8	0.2	9.7	32.2	36.5
USA	19.6	35.6	7.4	30.9	1.8	43.2	1.3	45.0	0.3	12.6	30.4	34.5
Canada	1.5	2.7	2.6	10.8	0.7	18.2	0.1	4.5			5.0	5.6
Singapore	3.1	5.6	--	--	--	--	0.1	1.9	0.9	46.6	4.1	4.6
Japan	2.3	4.1	--	--	--	--	--	--	--	--	2.3	2.6
HonKong	--	--	1.2	4.9	0.1	2.3	--	--	--	--	1.3	1.4
Russia	--	--	0.7	3.0		--	--	--	--	--	0.7	0.8
South Africa	--	--	--	--	--	--	--	--	0.1	5.4	0.1	0.1
India	--	--	--	--		--	--	--	0.1	4.1	0.1	0.1
China	--	--	--	--	0.1	1.3	--	--	--	--	0.1	0.1
Mexico	--	--	--	--	--	--	0.04	1.5	--	--	0.04	0.05
Totals	**45.6**	**82.9**	**22.4**	**93.0**	**3.8**	**93.3**	**2.7**	**92.7**	**1.6**	**78.4**	**76.1**	**86.4**

Source: UN Comtrade, 2012; (--) indicates country/region was not in the top five in 2008.

2.3. Lead Firms

In addition to the offshoring described above, the aerospace sector has undergone major restructuring with the introduction of outsourcing business models (Cooke & Ehret, 2009). The most significant change was the emergence of risk-sharing partnerships as a means to fund the design of a new craft, while spreading the enormous financial risk between the aircraft manufacturer and a handful of risk-sharing partners responsible for both R&D and manufacturing of subassemblies. Rather than independently manage the project's full supply chain, these systems integrators now act largely as facilitators rather than direct purchasers (Cooke & Ehret, 2009). Aircraft manufacturers have favored this model because it allows them to share the risk associated with any given product line with other firms. At the same time, risk sharing has entailed substantial technology transfer from the final manufacturers to their risk-sharing partners and to component suppliers. Intellectual property is protected through trade secrets in the supply chain (Niosi & Zhegu, 2005). There are currently only two remaining prime manufacturers of large commercial jets (Boeing and Airbus) and two manufacturers of regional jets (Bombardier and Embraer).

The first-tier OEM market has consolidated substantially as a result of this strategy, as OEM partners have been required to develop significant capabilities, scale and financial resources. Today, there are three American and three European firms that manufacture commercial jet engines,[8] and eight American and six European firms that supply other major subassemblies and components.[9] Likewise, airframe and avionics segments are also dominated by large OEM firms such as Triumph Aerostructures Vought Aircraft Division and Honeywell. These firms independently manage their tier two and tier 3 component suppliers (Pritchard & MacPherson, 2007).

Table 5 details the leading firms in both systems integration and in tier one subassemblies that frequently participate as risk-sharing partners.

Table 5. Lead Firms in the Aerospace Industry, by Revenue (2010)

Company	Headquarters	2010 Revenues (US$ millions)	Role in Aerospace GVCs
Systems Integrators			
Boeing	USA	64,306	Final craft (commercial jets)
Airbus (EADS)	France	60,599	Final craft (commercial jets)
Bombardier	Canada	9,357	Final craft (regional jets)
Embraer	Brazil	5,364	Final craft (regional jets)

[8] The American firms are GE Aircraft Engines, United Technologies Corp. (parent of Pratt & Whitney) and the Engine Alliance (itself a joint venture between GE and Pratt & Whitney). The European firms are Rolls-Royce Group PLC, Snecma Group and International Aero Engines (a large multinational consortium) (Niosi and Zhegu 2010).

[9] American suppliers are the Triumph Group (parent of Vought Industries), Eaton Corporation, Goodrich Corporation, Harris Corporation, Honeywell International, Inc., Parker Hannifin Corporation, Rockwell Collins, Inc., and United Technologies (parent of Hamilton Sundstrand). The European suppliers are BAE Systems PLC, Finmeccania SPA, MTU Aero Engines (owned by the US-based private equity firm Kholberg Kravis Roberts & Company), Smiths Group PLC, Thales and Volvo Aero (Niosi and Zhegu 201).

Tier One Subassembly Developers			
BAE Systems PLC	UK	34,428	Avionics and other commercial operations
Pratt & Whitney	USA	25,227*	Aircraft engines
Hamilton Sunstrand	USA	25,227*	Engine, flight and environmental controls
Finmeccania SPA	Italy	24,762	Avionics and fuselage components
GE Aircraft Engines	USA	17,619	Aircraft engines
Thales	France	17,364	Avionics, computer software and hardware
Rolls-Royce Group PLC	UK	16,794	Aircraft engines
Snecma Group	France	13,847	Aircraft engines and aircraft equipment
Honeywell International, Inc.	USA	10,683	Turbofan and turboprop engines, flight safety systems
Goodrich Corporation	USA	6,967	Airframe, engine systems, electronic systems, landing systems
Harris Corporation	USA	5,206	Communications equipment, small aircraft
Rockwell Collins, Inc.	USA	4,631	Aviation communications

Source: Identification of lead firms from Niosi and Zhegu (2010); 2010 revenues from PWC 2012.

Note: Goodrich Corporation has been acquired by United Technologies Corporation and together with Hamilton Sundstrand now make-up UTC Aerospace.

2.4. Standards

Due to the potentially fatal consequences of production errors in the aircraft manufacturing industry, quality standards have been implemented broadly across the sector, from standards for aircraft design through specific standards that apply to different materials used in the production of aircraft. Aviation authorities in respective countries, such as the US Federal Aviation Agency (FAA) and the European Aviation Safety Agency (EASA), determine these standards (De Florio, 2006). In an effort to harmonize standards, in the 1990s authorities of aerospace companies in the US, Europe and Asia organized the International Aerospace Quality Group (IAQG) with the intention of minimizing the complexity of integrating international standards for aerospace components, subsystems and system (Vasconcellos et al., 2007). In addition, OEM and tier one manufacturers have their own private quality standards, such as Boeing's DI 9000 Advanced Quality System for Suppliers, and carry out audits of their suppliers.

Table 6 highlights the key quality standards required by leading regulatory agencies around the world. Manufacturers at all levels of the GVC, from components to systems integrators, must comply with these public and private standards in order to remain approved suppliers. Important financial commitments are often required to achieve adequate safety and quality levels that can serve as barriers to entry for smaller manufacturers in the absence of access to finance.

Table 6. Quality Standards in the Aerospace Manufacturing Global Value Chain

Standard	Country	VC Segment	Description
SAE AS9100	Americas	Manufacturers	AS9100 takes the ISO 9001 requirements and supplements them with additional quality system requirements, which are established by the aerospace industry in order to satisfy DOD, NASA and FAA quality requirements. The intent of AS9100 is to establish a single quality management system for use within the aerospace industry. AS9100 is a product of an international effort to establish a single quality management system for use within the aerospace industry, and is recognized by all major aerospace OEMs. While the AS9100 standard is recognized worldwide, participating countries can use their own numbering conventions.
EN9100	Europe	Manufacturers	
JIS19100	Asia	Manufacturers	
DO-178B, DO-178C, DO-254/ Eurocae ED-80	United States	Avionics Developers	DO-178B/C is primarily concerned with development processes. The targeted DO-178B/C certification level is either A, B, C, D or E. Correspondingly, these DO-178B/C levels describe the consequences of a potential failure of the software: catastrophic, hazardous-severe, major, minor or no-effect. The RTCA DO-254/Eurocae ED-80 document provides guidance for design assurance of airborne electronic hardware from conception through initial certification and subsequent post-certification product improvements to ensure continued airworthiness.
AS 9120	Americas	Distributors	This standard addresses chain of custody, traceability, control and availability of records. AS9120 is applicable for organizations that resell, distribute and warehouse parts found in aircraft and other aerospace components. The standard is not applicable to value-added distributors due to customer-product changes nor is it intended for organizations that rework or repair products.
AS9110	Americas	MROs	The AS9110 aerospace standard is based on AS9100, but adds specific requirements that are critical for the maintenance of commercial, private and military aircrafts. This standard defines the quality system requirements based on AS9100 and includes additional criteria for MRO facilities serving the aircraft industry. In 2012, there were 109 certified firms.
NBR 15100	Brazil	Manufacturers	Applies to materials, components, equipment, project, production, evaluations, maintenance of aircrafts, subsystems, aerospace infrastructure and space vehicles. This standard was ratified by IAQG, establishing favorable conditions for the insertion of Brazilian aerospace production in the international chain.
FAA 145 certified repair stations	US/International	MROS	The FAA Type 145 repair certificate authorizes facilities to perform maintenance and airframe/engine repairs on specific aircraft. The FAA uses the Type 145 certification process to determine if a repair station has the equipment, personnel, manufacturers' maintenance instructions and inspection systems to ensure aircraft repairs are completed to US aviation standards.
OASIS database	International Aerospace Quality Group	All	The OASIS database is a product of the International Aerospace Quality Group (IAQG). OASIS houses supplier and audit assessment data for all companies who hold an accredited certification in any of the AQMS series of Standards (i.e. - AS9100, AS9110 and AS9120). OASIS is publicly used to identify the companies in compliance with AS9100, EN9100 and JISQ9100 standards as well as other international quality specifications. The long-term benefits of using the OASIS data system include a reduction in the number of different audits required of aerospace industry suppliers, resulting in cost efficiencies.

Source: Authors, based on De Florio, 2006, FAA, 2012, SAE International, 2012.

2.5. Human Capital and Workforce Development

Competencies and capabilities are central to competitive success of firms in different tiers of the aerospace industry (Cooke & Ehret, 2009; Hickie, 2006) and should be a core part of industrial policy, spearheading sector growth in developed and developing countries alike. Quality and safety assurances for the industry depend on well-trained personnel, and the attraction, development and retention of human capital significantly influences opportunities to grow in the sector (LARA, 2001). Due to risk-sharing agreements, tier one firms depend on a significant engineering workforce to support the need for design and development capabilities (Pritchard & MacPherson, 2007), and as these suppliers increasingly transfer design and development functions for components to their tier two and tier three networks, knowledge and skills become essential even at lower levels of the value chain.

Overall, the industry employs many skilled workers—in particular engineers, technicians and skilled production workers (Lloyd, 1999). At manufacturing companies, employers prefer individuals with robust advanced manufacturing skills and experience such as welding, drafting and assembly, to certifications that are typically not necessary for entry-level assembly positions.[10] The traditional manufacturing skill most valued by companies is the ability to accurately read complicated design specifications (RTI, 2009). Certification requirements are greater at MRO companies because their contracts with air carriers often stipulate that workers carrying out MRO work hold specific certifications.

Table 7 shows the profile of employees in the North Carolina (NC) aviation sector. The NC aviation cluster is focused mostly on components manufacturing and MRO operations (RTI, 2009), although firms such as GE Engines are also present. As can be seen, technicians and assemblers make up 78% of the workforce, and the minimum level of education is high school completion. Similar findings are noted in the Baja California cluster in Mexico, with a focus on components manufacturing, where even in the least specialized segments of the labor force, the regulatory demands of the industry required employees with a minimum of high school education. In Mexico, among components manufacturing firms, researchers found that aeronautic engineers were not necessary to carry out their operations; rather, emphasis was placed on hiring highly specialized machining specialists (Carillo & Hualde, 2007). However, several firms did indicate that the availability of aeronautical engineers would likely facilitate upgrading into other products and processes.

[10] These certifications are mainly used to advance to more senior positions (RTI, 2009).

Table 7. Employee Profile Breakdown, North Carolina Aviation Sector, 2009

Broad Employee Profile	Positions	Share of Workforce	Principal Formal Education Attainment & Training Requirements	Experience
Engineers	Software Systems Aerospace Electrical Industrial Mechanical Materials	20%	Mostly associate and bachelor degrees. Some masters & doctoral degrees.	Firms require two to four years of experience from either aerospace or another advanced manufacturing facility.
Technicians	Drafters & designers Electrical Electronic Machinists (Metalworking & plastic molding) Mechanics Quality & process Tool and die makers	52%	Associate degrees or trade school training. Apprenticeships and specialized on-the-job training. FAA certification in some positions: Airframe mechanic, avionics repair specialist and power plant mechanic.	
Assemblers	Assemblers Fabricators First line supervisors	26%	Mostly high school graduates. Apprenticeship and on the job training.	Firms may occasionally waive experience requirements.

Source: Based on (RTI, 2009) & MIT LARA Study.

Note: Where firms were responsible for procurement of raw materials and for maintaining low costs, professionals with business administration skills were required.

2.6. Upgrading Trajectories

Due to the highly consolidated nature of the aerospace sector and a rapidly evolving outsourcing environment (Ehret & Cooke, 2010), upgrading trajectories have not followed predictable paths. This section draws on examples of upgrading at both the firm and geographic level (outlined in Table 8) to highlight the different factors that have contributed to upgrading in the past.

Table 8. Upgrading Examples in the Aerospace GVC

Upgrading Trajectory	Example
Entry of small- and medium-sized enterprises (SMEs) via supplying a national systems integrator in Brazil	In 1994, Embraer moved towards a business model that focused on systems integration, funding the development of its new ERJ-145 line using risk-sharing partnerships with major international suppliers and devolving a substantial portion of its components manufacturing operations.[11] Several laid-off engineers and production workers opened new SMEs to provide Embraer and its upper-tier suppliers with parts and engineering services. Serving these upper-tier suppliers helped some of these SMEs to develop sufficient capabilities to become global suppliers. This upgrading was facilitated by several factors: first, the layoffs at Embraer resulted in the diffusion of knowledge to SMEs through labor mobility; second, proximity to the Embraer and OEM plants provided easier access for Brazilian SMEs in tier 2 & 3 functions; and third, loans from Brazil's National Economic and Social Development Bank (BNDES) and the presence of venture capital helped firms such as Garuna to develop the production scale and technological investment capacity to serve a larger number of buyers and to do so with improved technical capabilities (Cafaggi, 2012).
Functional upgrading in China and Japan	Learning by doing and specific technology transfer through offset agreements and other international production licensing models, and the need to access specific input technologies were essential to capability upgrading of both Chinese and Japanese firms. In China, both systems integrators (Airbus, Boeing and McDonnell) and prime contractors (Voight) transferred important technologies to Chinese manufacturers in order to gain access to the Chinese airline market (Pritchard & MacPherson, 2007). China is now positioning itself to enter the regional jet market as a systems integrator, along with a local supply chain for components (U.S. Department of Commerce, 2010). Japan, on the other hand, benefitted from its first mover advantage in composite materials. New aircraft today, including the Airbus A380 and Boeing's Dreamliner 787, rely on this composite technology to improve performance. Japanese firms are now the major airframe subsystem suppliers for the 767, 777 and 787, undertaking the detailed design work and production of most of the fuselage and main wing (McGuire, 2007). The financing of composite materials programs for Japanese firms was provided by the Development Bank of Japan to the Japan Aerospace Development Corporation (made up of Mitsubishi, Fuji and Kawasaki) on a royalties-based scheme. This strategy of funneling government money into the aerospace industry is similar to "launch aid" provided by European governments to Airbus (McGuire, 2007).
Process upgrading of tier two, three and four suppliers	Globally, tier three firms have expanded through M&As to increase their scale, range of capabilities and global networks. Just as systems integrators have shared risk with their tier one suppliers, tier one suppliers have done so with their tier two suppliers and so on (Cafaggi, 2012). Tier three and four firms have thus been consolidating, as these firms previously often did not have the sufficient scale to support the global components manufacturing. This process upgrading has required significant investments in new machinery and training. In some cases, venture capital financing allowed tier three firms to acquire capabilities in order to functionally upgrade to become tier two suppliers (D. J. Smith & Tranfield, 2005).
Diversification of target subassemblies	Carillo & Hualde (2011) note that despite Baja California's (BC) long trajectory in the sector, supportive government policies, the presence of lead firms such as

[11] Embraer itself has achieved product upgrading since its founding, moving from the production of turboprops to regional jets (40-50 seats) to large regional jets of over 100 passengers. They now compete with Boeing and Airbus in this segment, as well as successfully expanding into the business jet segment and capturing 14% of the global market share (U.S. Department of Commerce, 2010).

in Mexico	Honeywell and Gulfstream, experienced personnel, availability of low cost labor and close proximity to the end market, the region continues to produce in tier three and four segments of the value chain and has not been able to functionally upgrade.[12] Rather, there is a strong indication that lead firms have leveraged BC's close proximity to the US to access low-cost component manufacturing and assembly labor for in-house, non-critical, non-core functions (Romero, 2010). Indeed, Carillo & Hualde (2007) note that on average firms had been operating in BC for 13 years, and that limited investments had been made in improving equipment or operations. However, BC has diversified its products for a number of different subassembly segments (Romero, 2010). In 2011, the BC cluster included 53 manufacturing facilities for firms including Rockwell Collins, Lockheed Martin, Honeywell and Bourns, Inc., each of which fabricates a different product or product family.
Downgrading to enter new market segment	Prior to its participation in the Airbus A380, Swedish aircraft producer Saab exclusively manufactured complete aircraft for the military. As a system integrator and manufacturer, the firm already had significant capabilities when it was considering entering the commercial market segment. The firm previously depended significantly on government support, and deemed that without this support, entering the highly consolidated commercial market as a systems integrator would be too risky. Thus the firm opted to downgrade to subassemblies in order to enter the segment, and by becoming one of a number of subassemblers on the Airbus project, Saab was able to maintain its profit margin while lowering its risk. This was a change of corporate strategy that represented a major transformation for the entire Saab organization (Johansen et al., 2005). The South African aerospace sector, also initially oriented towards the military segment as a full aircraft assembler during the apartheid era, changed strategies to focus on becoming a lower-tier component supplier following cuts in defense spending and a shift in political orientation in 1994 (Goldstein, 2002; Kraemer-Mbula, 2008). Entry into the commercial aviation segment has also benefited from offset agreements looking to capture the growing southern African air travel business (Kraemer-Mbula, 2008).
Product upgrading	In 2006, Bombardier changed the wings of its C-Series regional jet from metal to composite materials. As it was not in a position to launch the new series alone, Bombardier requested government support from the Canadian and UK governments. The UK government required that the firm "move up the technological ladder" in order to qualify for financial assistance (Pritchard & MacPherson, 2007).

Several key themes can be identified from these examples regarding upgrading support:

- First, access to finance is essential for upgrading due to the need to develop or obtain new technological competencies. In these examples, financing was mostly provided by government investment agencies (Japan & composites, Britain & Bombardier and Brazilian SMEs). Goldstein (2002) argues that government motivation for investment in the aerospace sector is partly based in national security objectives, and partly due to the benefits of first-mover advantage. It also helps to support technology transfer. Government financing is often made available through "repayable launch aid" awards. These awards are essentially low- or no-interest loans with generous repayment terms, which include no repayment until a new plane is commercialized

[12] Firms based in Mexico also cater to the military market, with 63% of production dedicated to combined civil and military aviation projects (Carillo & Hualde, 2011).

and in some cases, if the project fails, no repayment is required. While in June 2010, the WTO ruled against Airbus's receipt of launch aid for the A380 program, noting that this undermined fair competition for Boeing (WTO, 2010), this practice continues to occur and is not considered illegal.

- Second, risk management is an important factor in firm decision making regarding upgrading or downgrading. For example, Saab's decision to downgrade was clearly based on a risk management strategy, as was the need for the consolidation and process upgrading of tier three and tier four firms.
- Third, knowledge development (Japan, SMEs in Brazil) and technological transfers (China) provided essential competencies for functional upgrading. Offset agreements and international licensing models played an important role in technology transfer (South Africa, China and Japan). This was a result of lead firms actively seeking access to technology as well as large markets.
- Fourth, geographic proximity was important for the expansion of low-cost components manufacturing in Mexico and Brazil.[13]
- Fifth, scale and reliability is important; the consolidation of tier three and tier four firms suggests that the entry of smaller, local firms is becoming less possible and industry growth in developing countries will increasingly depend on local production facilities of global components manufacturers, with domestic firms serving support functions.
- Sixth, intellectual property protection did not emerge as an important factor in these cases. This may be due to the risk-sharing partnerships combined with a tendency towards trade secrecy as opposed to patent protection in the sector, and the structure of systems integration. Firms at each stage of the value chain are increasingly responsible for their own R&D for new aircraft programs, and are thus more likely to make an effort to protect this internally, regardless of their location.

3. Lessons from Value Chain Entry and Upgrading Experiences of Singapore and Queretaro, Mexico

This section examines the entry and upgrading of two aerospace clusters, located in Singapore and Queretaro, Mexico. These two cases were chosen for analysis due to their similar characteristics to Costa Rica. These two clusters are located in areas with small populations (Singapore, 5.2 million in 2012, and Queretaro, 1.8 million in 2011). Prior to the development of specific government policies to develop these clusters, neither location participated in the aerospace industry in any meaningful way. Both locations were developed strictly as export-oriented clusters and in the absence of a national policy to develop a full systems integration operation. In other words, the development of these sectors was not based

[13] While the presence of prime contractors may have a clustering effect (Niosi & Zhegu, 2010), Lublinksi (2003) finds that proximity is of low importance to knowledge spillovers in the sector.

on national strategies to design, develop and manufacture an entire airplane as has been the case in other countries that have entered the value chain, such as Brazil, China, Indonesia and South Africa.

These two cases, however, present slightly different strategies for growth: Singapore's initial foray into the industry was based on important investments in the state-owned company ST Aerospace, while Queretaro's development was based on the establishment of a large Bombardier manufacturing plant. Local procurement in Singapore by the air force and Bombardier's interest in the Mexican market for business jets were supporting factors in driving industry growth. A brief overview of the evolution of the industry in each of these locations is provided, followed by a comparative analysis of key initiatives take to drive industry growth.

3.1. Singapore[14]

Singapore became involved in aerospace parts manufacturing and aircraft servicing in the 1970s following the government's designation of the aerospace industry as a priority area for development. While primarily supportive of the military sector, in the 1980s an influx of multinational firms brought work to the commercial sector as well. Two key events in 1981 helped to drive rapid growth in the industry: the opening of Changi International Airport, which expanded Singapore's capacity as an international servicing agent; and the signing of a bilateral aviation agreement with the United States, which opened the way for international certification of locally manufactured parts and components.

In the late 1990s, Singapore began to specialize in different segments of the value chain: it emerged as a regional leader in MROs, and government-owned ST Aerospace paved the way for Singapore to become one of the world leaders in aircraft maintenance. The country also began focusing on engine and propulsion systems. By 2011, the sector exported US$6.5 billion and employed 19,000 people. Two significant firms that expanded their operations were Hamilton Sundstrand and Rolls Royce. In 2012, Rolls Royce accounted for 15% of the country's aerospace exports. Within the last few years, the country has made significant in-roads into R&D, with Rolls Royce, EADS (Airbus) and Thales all opening important aerospace R&D centers in the country.

The development of the aerospace sector in Singapore has been based on a multi-faceted strategy led by the Economic Development Board (EDB), including investment promotion through infrastructure development, targeted tax incentives, preferential trade agreements (PTAs), a strong drive to develop human capital for the sector at both the technical and professional levels, and an emphasis on supporting the development of domestic Singapore firms. Singapore also hosted the first annual aerospace show at the Changi airport in 1981;

[14] Information for this section was drawn from the following sources: (Ali, 2011; de Lavigne, 2009; EDB & SPRING, 2009; Institution of Engineers, 2012; Sim et al., 2003; Singapore Workforce Development Agency, 2012; SPRING, 2012; U.S. Commercial Service, 2010; US International Trade Commission, 1998; Yuen, 2009).

this show went on to become one of the most important and influential trade shows in the aerospace sector. In 2006, the government also began the refurbishing of Seletar airport as a dedicated aerospace park, extending its runway to 1.8 kilometers. The US$50 million investment by the government extended the runway, added energy infrastructure to support new manufacturing demands for power, and financed the construction of state-of-the-art facilities for R&D and design. General efforts to improve the business environment, targeted tax holidays and other incentives for firms with specific technologies, a number of PTAs, and the establishment of the Association of Aerospace Industries helped to further support growth in the 2000s.

The government added to existing human capital development programs such as the Overseas Training Program, which had been launched in 1971 to train Singapore engineers abroad with foreign firms, with specific aerospace initiatives. These included the Air Transport Training College (ATTC), established in 1999 as the Professional Development Centre of the Singapore Institute of Aerospace Engineers (SIAE). The ATTC offered the first undergraduate degree in aircraft engineering, and in 2006 created the precision machining workforce qualification certification through the Singapore Workforce Development Agency, accompanied by a US$65 million commitment for technical education in precision machining. Local human capital was supplemented by immigration; rapid processing of work visas (two weeks) and an increasingly cosmopolitan city helped to attract highly skilled staff. By 2012, the country was graduating 1,000 aerospace technicians and professionals annually.

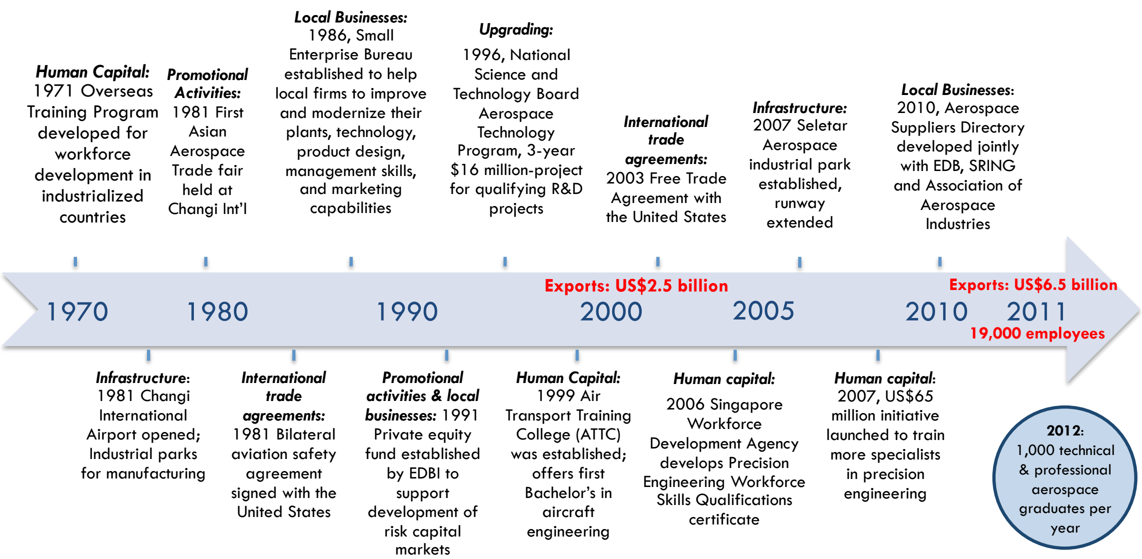
Between 1982 and 2012, numerous initiatives were taken by the EDB and SPRING, the agency under the Ministry of Trade and Industry charged with local enterprise development, to support the growth of local firms and their linkages with FDI in the country. In 1982, the Small Industry Technical Assistance Scheme provided grants to defray part of the cost of engaging short-term consultants and increase or establish in-service training for employees. In 1986, the Small Enterprise Bureau was set up with a specific focus on helping SMEs to improve and modernize their plants and technology, product design, management skills, and marketing capabilities. In 1991, Economic Development Board Investment (EDBI) was established; among other initiatives, EDBI created a private equity fund to help attract venture capital. In 1996, SPRING was created to support local enterprise development. SPRING continues to be an active agency in industry development. Initiatives include SME competitiveness funding options. One example is the Micro Loan Program, where businesses with less than 10 employees can apply for loans of up to US$41,000 to fund operations. Another is the Start-up Enterprise Development Scheme, where innovative Singapore-based start-ups below three years old can get a matching dollar from SPRING for every dollar an investor puts into the start-up business, up to US$820,000.[15] One of the most recent initiatives to support increased participation of local firms in the aerospace sector has been the publically available Guide to Singapore Aerospace Suppliers. This guide for potential investors provides information regarding the different stages of the value chain in which local

[15] For a comprehensive guide of the programs offered to support local enterprise in 2012, (SPRING, 2012)

firms operate, certifications, capabilities, information about the history of local firms and contact details.

Figure 4 highlights the key policy measures implemented to support the continued evolution of the aerospace sector in Singapore.

Figure 4. Singapore's Aerospace Evolution, Key Policy Measures



Source: Authors.

3.2. Queretaro, Mexico[16]

Queretaro's growth has been even more dramatic than Singapore's. Work in the aerospace sector began in the late 1990s, when GE established a large engineering operation in the state. This operation served both GE Aviation and GE Energy, with approximately 600 engineers working on design of tubes and brackets for the external parts of engines. However, it was the arrival of Bombardier in 2006 that marks the true entry of the state into the global value chain. The French group Safran and Spanish airframe manufacturer Aernnova quickly followed suit, establishing operations in 2007. Under the leadership of the Secretariat for Sustainable Development (SEDESU), Querétaro's aerospace cluster has since become one of the four leading locations in Mexico. By 2012, there were over 30 foreign firms operating in the state, with projected employment of over 6,000, approximately 20% of

[16] Information for this section is based on these sources: (Ayala, 2009; Casalet et al., 2011; Case, 2012; Johnson, 2012; Secretaría de Economía, 2012; Sorbie, 2009; The Business Year, 2012).

the country's aerospace workforce. Mexico's exports in the sector had reached US$4.5 billion by 2011, up from US$1.3 billion in 2004.

Like Singapore, major improvements to the state's airport infrastructure with the construction of the new Queretaro International Airport in 2004 were vital to kick starting its entrance into the aerospace value chain. This new airport infrastructure, a US$11.5 million industrial park, together with a host of initiatives in 2007, combined to attract a number of leading aerospace firms to the state. These included two important national initiatives: the 2007 national bilateral aviation safety agreement with the US; and the abolishment of all tariffs on imported components for the aerospace sector. 2007 also saw the establishment of the Mexican aerospace industry association, FEMIA (Federación Mexicana de la Industria Aeroespacial), to support the sector’s interests at a national level. FEMIA has since been instrumental in the formation of a national aerospace strategy, “Plan de Vuelo.” A key component of this strategy has been to establish ways in which the different aerospace clusters across the country can work together to develop alternatives for the entire value chain, such as highlighting niche areas for development in different clusters.

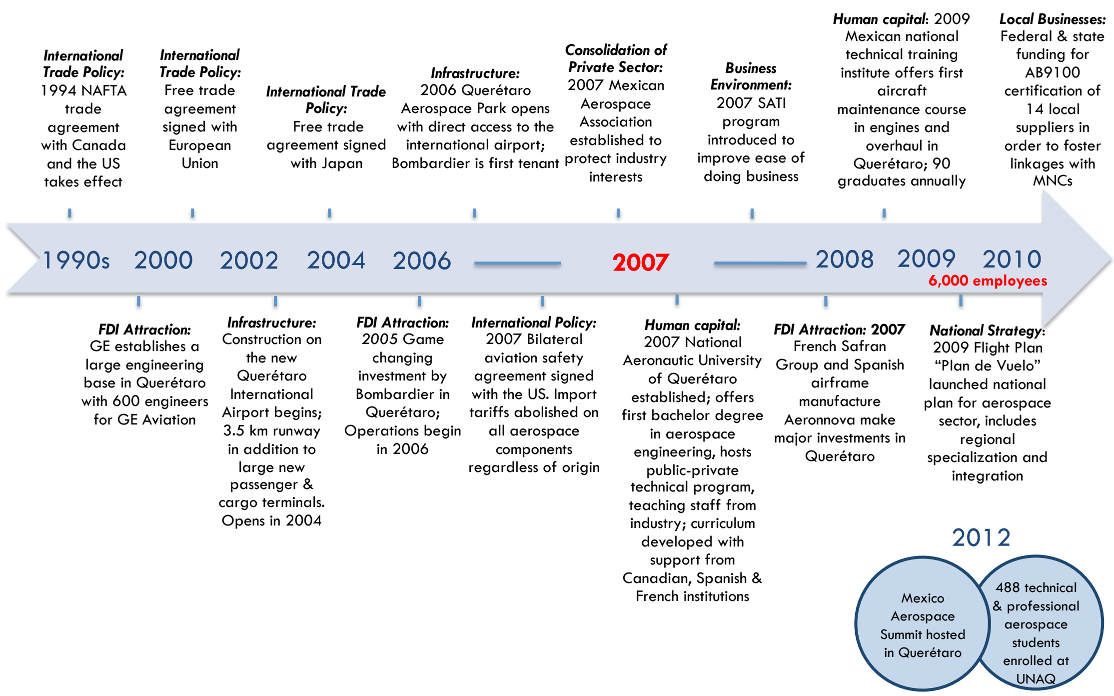
Growth at the state level was supported by a clear commitment to the development of the industry by the state government, among the most important of which was the creation of the National Aeronautics University of Queretaro (UNAQ) in 2007, which housed several technical programs developed in public-private initiatives and created the first aerospace engineering program in the country. State investments in UNAQ amounted to US$21 million by 2009. In addition to training teaching staff in both Canada and Spain, UNAQ draws teachers from aerospace firms working in the region. By 2012, there were 488 technical and professional students at UNAQ. UNAQ’s contributions to human capital development in the state added to an already strong engineering training base. In 2009, engineering graduates accounted for 41% of undergraduate degrees, while 65% of master’s degree programs available in the state were in engineering fields.

The introduction of the Queretaro SATI program (Programa de simplificación administrativa empresarial) made important strides in improving the business environment in the state by reducing the time and procedures required to set up a new business. Opening a new business takes just 48 hours, while building permits can now be obtained in 5–10 days, compared to an average of 9 and 69 days in the rest of Mexico.

Multiple factors have combined to make Queretaro an attractive aerospace location within Mexico: an improved business environment; growing availability of qualified personnel thanks to human capital investments and the state’s significant experience in automotive manufacturing; selective tax incentives; the development of a dedicated aerospace industrial park next to the airport; and its strategic location on the Pan-American highway between Mexico City and the US border. Since 2007, further initiatives that have helped to foster growth include the establishment of an aircraft maintenance program in Queretaro by the National Mexican Technical Training Institute, which graduates 90 technicians annually. This has supported the ongoing development of the state’s MRO capacity, and helped capture large investments, including the 2012 Delta-Aeromexico deal to establish a US$50 million MRO facility in the state with seven production lines to serve both airlines.

As also occurred in Singapore, SEDESU has taken several steps to ensure that local firms are not excluded from the global value chain as large FDI projects come online. These include the establishment of a fund to increase the competitiveness of local SMEs, which offers loans with preferential interest rates and conditions of up to approximately US$75,000 for firms that could not access finance through the traditional banking system. The federal government also financed ISO 9000 certification, specialized consulting and business coaching through this fund. State financing supported the certification of 14 local suppliers in AS9100B standards required to become suppliers to the aerospace sector. Two-thirds of the funding was provided by the federal and state governments, while the firms had to cover the final third of the cost. Finally, nine incubators in the state were leveraged to support the development of new technology-based firms. These incubators provided firms with advising, legal training, patent registration, business plan development and linkages with higher education institutions and research centers. Figure 5 highlights key measures taken to drive the development of the aerospace cluster in Queretaro, Mexico.

Figure 5. Queretaro's Aerospace Evolution, Key Policy Measures



Source: Authors.

4. Costa Rica and the Aerospace Global Value Chain

The aerospace sector in Costa Rica is still a nascent industry and it is comprised largely of a small number of foreign contract manufacturers, software developers and local MRO firms. A 2011 Procomer report estimated that there are approximately 110 firms participating in the sector, with over 4,000 employees in 2010 (Algarañaz et al., 2011);[17] however, counting only those aerospace firms in manufacturing and support services, brings this number down to 29 firms. Just under half of the firms are of Costa Rican origin, while all other firms are financed by US capital.

4.1. The Development of the Costa Rican Aerospace Sector

The majority of firms working in the sector were set up prior to 2000; these firms were dedicated to other industry sectors at the time of their establishment in Costa Rica and continue to serve multiple end-markets. Table 9 provides an overview of the 12 firms that have established operations since 2000.

Table 9. Entrants to the Costa Rica Aerospace Sector, 2000–2012

Firm	Value Chain Segment	Origin	Year Established in Costa Rica
Teradyne de Costa Rica SA	Components - Electronics	United States	2000
West Star	Components - Aluminum/Metallic	United States	2000
L3 Communications	Components - Electronics	United States	2001
Irazú Electronics	Components - Electronics	United States	2001
Mechania Engineering	Design & Engineering	Costa Rica	2002
Helicorp	Aftermarket -MRO	United States	2004
Ad Astra Rocket	Design & Engineering	Costa Rica	2005
Avionyx	Components - Software	United States	2005
Agilis Engineering	Design & Engineering	United States	2006
Sensor Group	Components - Electronics	United States	2006
Ridge Run	Components - Software	United States	2006
AEC Aerospace	Aftermarket - Technical manuals	United States	2010

Source: Authors.

Key Trends & Highlights:

MRO service firms are the most mature in the sector. MRO firms provided over 1,000 jobs in 2011. Locally owned COOPESA, established in 1963, is the leading MRO operation

[17] This report includes firms that we would not consider to be part of the global value chain, including two charter services and an air-cargo operation.

in the country, and accounts for the majority of Costa Rica's exports in the aerospace sector. It is an FAA 145 certified operation, and in 2011, was the largest single employer in the aerospace sector (PROCOMER, 2012). However, over the past few years, as a result of the consolidation of Latin American airlines and the economic crisis in the US, MRO firms in the country have been required to reevaluate their market strategy. A key challenge is to attract new customers from the US market, yet most do not have the required infrastructure or scale to do so (Field Research, 2012).

Recent entrants focused on higher value services. The majority of the companies that established operations in Costa Rica between 2005 and 2012 are focused on higher-value service activities within the aeronautic value chain. These firms are focusing on software and design & engineering that require skilled labor with university level education. This is also correlated with the higher paying jobs that these skilled employees receive for their work on the development of intangible inputs for the aeronautic industry. Average monthly wages were over US$1,750 by 2011 for firms in design and software development, compared to US$870 in electronics components firms. This suggests that, despite its limited participation in the aerospace sector to date, Costa Rica may potentially focus its efforts on entering into the value chain at a higher level.

Encouraging SME entry to support a local OEM firm. One example of companies providing sophisticated services to the aeronautic industry is Ad Astra Rocket, the most well-known aerospace firm in the country. This company is working on the design of a plasma engine for space travel and it has focused on developing relationships with local universities and suppliers. In particular, these local contacts include five precision machining firms, Fortech, AKA Precision, R&R Precision, Olympic Precision and FEMA, in addition to Mechania Engineering, a "design and engineering" firm which entered the aerospace sector as part of an alliance (CORAAL) to support the growth of Ad Astra. Ad Astra firm was founded by Costa Rican astronaut Franklin Chang, who is an important promoter of the industry (Algarañaz et al., 2011).

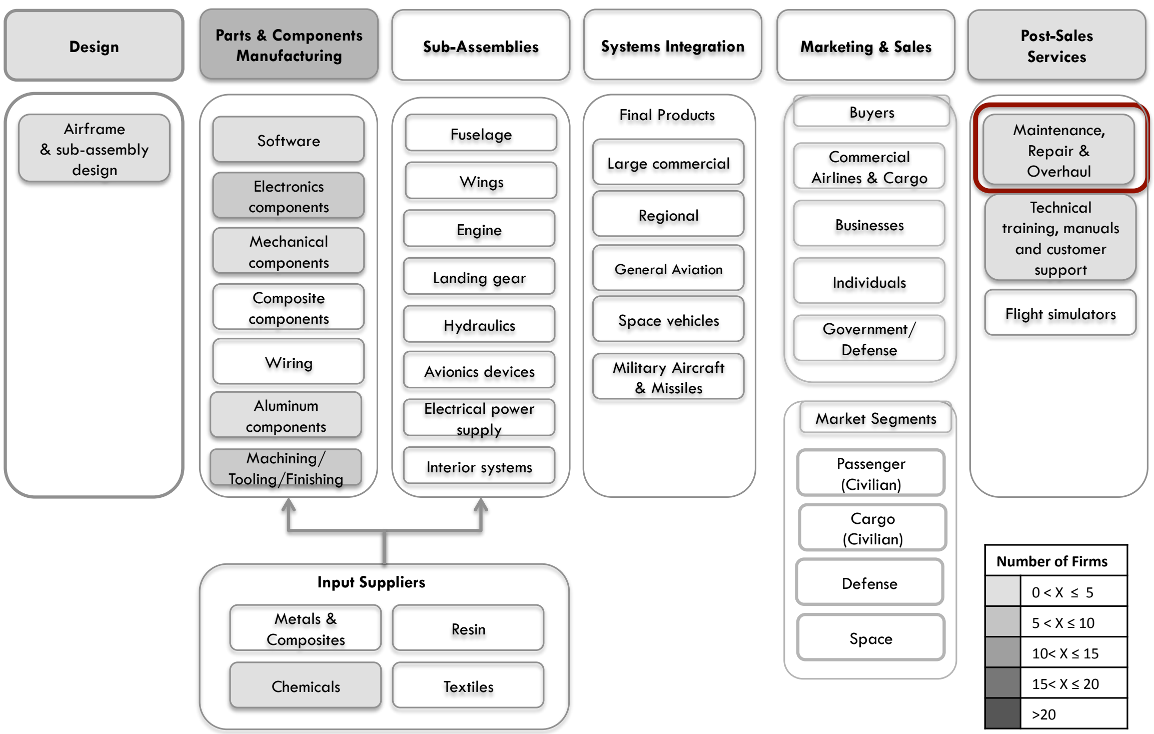
Contract manufacturers are focusing on high-mix, low-volume products with an emphasis on quality. Tier three and tier four contract manufacturers interviewed in this sector reiterated that although Costa Rican labor costs were higher than other low-cost locations such as India and China, the differentiating factor that they could offer was quality, with a high-mix, low-volume production model. Component manufacturers stress that the quality of their products is superior to those in lower-cost countries, and they are able to produce much smaller quantities that are not attractive to large-scale suppliers. Generally, these firms also serve a wide range of other markets including the automotive, consumer electronics and medical devices sectors. It is estimated that just 5% to 15% of contract manufacturing output is destined for the aerospace market (Algarañaz et al., 2011).

In general, local firms have yet to become significant aerospace exporters. Since 1990, six of the 20 firms establishing operations in the aerospace sector were Costa Rican. Three of these firms are focused on electronic components manufacturing (two of these firms were originally financed by US capital). Almost half of all Costa Rican firms perform precision machining services for the segment. These firms are among the oldest in Costa Rica's aerospace sector, having been established between 1979 and 1996. While an industry association has been established and initiatives taken by the government to channel aerospace development efforts, meaningful linkages between these firms have yet to be established (Algarañaz et al., 2011).

4.2. Costa Rica's Current Participation in the Aerospace Global Value Chain

Figure 6 illustrates the stages of the value chain in which aerospace firms are participating in Costa Rica.

Figure 6. Costa Rica's Participation in the Aerospace GVC



Source: Authors.

The aerospace-related activities currently performed in Costa Rica include components manufacturing, MRO operations and some software development in avionics and engine design. These activities are primarily destined for the commercial aerospace sector (Field Research, 2012). Table 10 details exports by product category from 2000 through 2010. One MRO firm accounted for nearly all exports during this period. As products that are shipped to Costa Rica for repair are also included in imports and exports, the weak trade data indicates that limited exports of specific aerospace products took place in the country over this time.

Table 10. Costa Rica Exports, by Product Category 2000–2010

Product Categories	HS Code	Export Value ($USD Millions)					
		2000	2002	2004	2006	2008	2010
Final Aircraft	8802	0.0	0.2	0.0	0.6	1.0	0.0
Aircraft Engines	840710	0.5	18.5	2.8	10.4	60.9	0.1
Aircraft Engine Parts	840910	0.0	0.3	0.1	0.2	0.5	0.0
Landing Gear & Parts	880320	0.0	0.0	0.0	0.4	0.2	0.0
Airframe Assemblies	8803	19.8	12.9	11.5	17.2	26.1	0.5
Navigations Systems	9014	0.0	0.4	0.1	0.0	0.0	0.0
Other	88	0.9	0.7	0.5	1.6	0.9	0.6
Engines (Main)	84111-18	0.0	0.0	0.1	0.0	0.0	0.0
Engines (Main) Parts	84119	0.0	0.0	0.0	0.0	0.3	0.0
Total		**21.2**	**33.0**	**15.1**	**30.4**	**89.9**	**1.2**

Source: Procomer, 2012. Note: The reduction of exports between 2008 and 2010 can largely be accounted for by the absence of export data for one key exporter.

The 29 firms in Costa Rica's aerospace sector can be divided into the following categories:

- There are nine firms that are entirely (or mostly) focused on the aerospace sector.[18] The most significant category is related to MRO, and includes: Coopesa, Helicorp and Sansaa, as well as one other firm related to technical training materials (AEC). The second group includes five firms in the areas of design, engineering and software: Astra, Agilis, Mechanica, Avionyx and Ridge Run.
- There are 10 firms that can be classified as 'general machine shops' that perform manufacturing-related activities such as molding, stamping and finishing. These firms supply the aerospace industry as well as other end markets, such as medical devices and automotive companies. These firms are: AKA Precisión, Diez Orlich (DO), FEMA, Fortech, H&S Metalmecánica, Micro Technologies, Olympic Precision, R&R Precision SA, Tech Shop and West Star.
- The final group includes nine electrotechnical component manufacturers. These firms, like the machine shops, produce components for a variety of end markets; however, between 10% and 50% of their outputs are for final products in the aerospace market. These firms include: C&K, Camtronics, Irazú Electronics, L3, Multimix, Sensor Group, Teradyne, Trimpot and Tico.[19]

4.3. Human Capital

Firms identified as exclusively focused on the aerospace sector employed approximately 2,000–3,000 people in 2011 (PROCOMER, 2012). Human capital in the sector differs according to the stage of the value chain in which a supplier operates. Firms in Costa Rica offering engineering and software services typically have a small number of employees (<50)

[18] See Appendix Table 17 for percentage of output destined for the aerospace sector.

[19] Tico is an exception in this category as all of their output is currently for the aerospace sector.

with a minimum of a bachelor's degree in engineering and informatics or information technology.[20] Contract manufacturers typically hire high school graduates or individuals with technical training (Algarañaz et al., 2011). Firms in the sector tend to draw engineering talent principally from Universidad de Costa Rica and Instituto Tecnológico de Costa Rica, and technical staff from high schools and Instituto Nacional de Aprendizaje (INA). MRO firms mostly provide training in-house; on the job training is an important aspect of staff development for firms in all stages of the value chain.

4.1. Challenges for Future Expansion and Upgrading

Costa Rica must overcome several important challenges to position the country as a potential participant in the competitive global aerospace sector.

A relatively small labor force combined with competition from other established export-oriented economic sectors has begun to tighten the labor market in the Central Valley. The medical devices and offshore services sectors in Costa Rica have grown considerably over the past ten years, employing approximately 12,500 and 33,000 people respectively in 2011. These firms are principally located in the same free trade zones (FTZs) as several aerospace companies and compete directly for much of the same labor. Engineering staff, in particular, is in very high demand; medical devices manufacturing draws heavily on mechanical, electrical and industrial engineers, while the IT segment of the offshore services sector is aggressively recruiting electronics and computer engineers. These other sectors are dominated by high paying MNCs with global footprints and strong training programs, and that provide employees with long-term job stability. The aerospace firms in the country are smaller and the uncertainty they faced during the global downturn in 2008 made it difficult to retain their staff. In addition, the overlap between these competing sectors and the aerospace sector drives up the cost of doing business in Costa Rica, not only in components manufacturing, but also in software development, MRO service work and design and engineering.

Given the increased cost sensitivity of the aerospace value chain, labor cost increases could undermine the country's competitiveness in the long term. Furthermore, as there has been no prior demand for personnel for the aerospace sector, there are no specific courses offered in aeronautical engineering, avionics or other programs important for the industry. Engineers with embedded software development skills required for the avionics segment are also in short supply in the country (Fernandez-Stark & Bamber, 2012). Given the specialized nature of MRO services, Coopesa trains all of its own staff; this limits the available labor pool for attracting other MRO firms to the country. Identifying key areas for development, and their subsequent human capital needs and commitment to establishing programs for to educate and train the corresponding workforce, will be necessary to attract global aerospace firms.

Limited access to finance and technological expertise constrains entry of local firms. The lack of access to finance and knowledge regarding the industry are important barriers to

[20] Design, engineering and software firms together accounted for approximately 100 jobs in the sector.

entry. As risk-sharing strategies become even more prominent in the sector, and tier one and tier two providers demand additional capabilities from their supply chains, substantial investments are required to become a qualified supplier. Capital markets in the region are limited in their ability to support the growth of domestic firms in the sector (Field Research, 2012), as is financial support from the government (Algarañaz et al., 2011). Without programs to encourage technology transfer and direct financial resources for the industry, the sector will be dependent on foreign firms to drive growth and upgrading. These firms often keep the highest value segments close to their HQs and core markets, which could restrict the country's upgrading potential in the long term, as seen in Mexico's BC operations. This is also a key challenge for the MRO operations. Coopesa operates in an outdated facility with limited capacity to attract new clients. Its cooperative status, designated by law, limits the company's potential to raise new capital for the infrastructure investments required to attract US clients.[21]

Outdated airport infrastructure is holding back the MRO business. The country has four international airports, two in San Jose, one in Liberia and one in Limon; the principal airport's main runway allows for operations of large, wide-body aircraft, including Boeing 747 and the Airbus A330-340 series, and is the second busiest in Central America, receiving approximately four million visitors annually. Expansion requirements for the San Jose airport however, require the relocation of the existing MRO operations to alternative airports (Field Research, 2012). Yet no flights can land or take off from the secondary San Jose airport at night. In addition to airport infrastructure, the infrastructure of MRO firms needs to be updated. The 2008/9 economic crisis and large mergers have reduced the number of potential clients from Latin America, which previously accounted for the major share of business. Costa Rican MRO firms increasingly need to compete for the US customer base. US airlines have high quality requirements for facilities, and demand increased capacity. Important infrastructure investments would be required to overcome these challenges and increase the competitiveness of Costa Rican-based firms.

No lead firms have committed to establish operations in Costa Rica. Although Ad Astra has the potential to become an important contributor to the space industry in the future, it is still a very small and highly specialized firm that requires a small number of suppliers to date to support it. Furthermore, the country has little previous experience in the sector. In other aerospace clusters, such as that of Queretaro, the presence of a large OEM has helped to drive local demand and follow sourcing to develop this sector. Yet, Costa Rica's endowments do not make it a leading destination for offshoring for OEMs as described below.

Internal market size, absence of defense spending and limited cost-competitive labor constrain potential competitiveness. Costa Rica's position as a small country without a military places the country in a unique situation in the aerospace sector. Other developing countries have leveraged their own systems integrator (Brazil), internal market size (China),

[21] Costa Rican labor costs are already higher than other MRO operations in Latin America and thus Costa Rica is no longer very competitive in that market.

defense spending (South Africa),[22] low cost labor (Mexico) and strategic location (Singapore MROs, Mexico) to enter the value chain. Costa Rica does not have many of these advantages; furthermore, as discussed in Box 4, there are restrictions on the manufacture, design and development of instruments, components and equipment that are destined for the defense sector.[23] Thus, despite government efforts such as the establishment of the National Council on Research and Development by the Ministry of Science and Technology in 2010 to help channel efforts to develop the aerospace sector in the country (Algarañaz et al., 2011), and CINDE's support by recruiting FDI from aerospace firms, Costa Rica is at a distinct disadvantage compared to developing country peers in the sector, and the country will need to develop an innovative industry growth strategy in order to enter the sector.

Box 4. Costa Rica, the Military and Aerospace Manufacturing

Costa Rica is unique country in that it is constitutionally prohibited from having a standing army. This provision, which was adopted in 1948, has had important consequences for the country, not least of which is allowing for significant additional resources to be channeled to the education sector. However, this constitutional position has led to some uncertainty regarding products that may or may not be produced within Costa Rica. There is a general perception that the manufacture of components, assemblies or subassemblies that may be used in the defense sector is illegal. This misconception has perhaps discouraged firms from establishing operations in the country in the past. Below, the specific limitations with respect to the manufacture or provision of products and services with potential for military use are outlined:

(1) There are no legal provisions in the Constitution of Costa Rica that forbid the manufacture of products for the use in military systems. There is only a Constitutional ban on the existence of an army.

(2) Guideline No. 10 of the Executive Branch issued in October 2006 states that FTZ status shall not be awarded to companies engaged in the manufacture or marketing of any type of weapons, permitted or prohibited, or in the manufacturing or sale of ammunitions, components, assemblies and subassemblies intended for use uniquely in the military sector. According to Costa Rica's constitution, guidelines have less authority than the constitution itself, domestic laws and executive decrees.

(3) The most recent amendments to the FTZ Regime Law (Art. 7) and its Regulations (Art. 10) establish limitations to FTZ benefits for firms engaged in the production of weapons and ammunitions containing uranium.

Source: (Monge, 2012)

[22] Even for lower value aircraft components, the role of government in driving the development of the sector by purchasing equipment for their armed forces should not be underestimated (Braddorn & Hartley, 2007).

[23] Furthermore, as noted earlier, most aerospace MNCs operate in both the civilian and military segments of the market and firms may thus be reluctant to operate in the country as a result of these restrictions.

5. Potential Upgrading Trajectories

1) Subassembly categories: In trying to build the cluster, focus on one or a small number of product categories rather than aiming to attract a broad range of producers. Build critical mass in that segment to gain credibility. Costa Rica needs to build depth in the industry by focusing on expertise, rather than breadth for manufacturing. Unlike Queretaro, Costa Rica has a lower portion of engineers and technicians experienced in advanced manufacturing, such as that required by an automotive sector that exports to the sophisticated US market. Furthermore, the total labor pool is limited in its growth potential. Labor costs are thus likely to be higher and rise more quickly than Queretaro, which can benefit from domestic immigration. Selecting a high-margin product category that is less sensitive to changing costs and that is consistent with other industry policies can help to support more sustained growth. For example, potential subassemblies include engines, industrial machinery and energy generation, tires and landing gear and oxygen systems. The emphasis on the development of fuel efficiency and clean energy globally, which will be an important aerospace growth area in the future, resounds with Costa Rica's national development plans to foster environmentally friendly business practices. Select subassemblies that have diverse end market segments. This helps to mitigate risk for suppliers in the sector. Oxygen systems, for example, can leverage the country's existing experience in the medical device plastics extrusion operations.

2) Entry into components manufacturing: Focus on niche, high-mix, low-volume parts that can leverage Costa Rica's flexible, quality production model developed in components manufacturing for the electronics industry. Due to less competitive labor costs, Costa Rica is not a competitive producer of high volume parts. However, this model provides opportunities for smaller firms seeking the advantages of offshoring from the US, but which cannot afford to invest in the scale required to make manufacturing in Asia, for example, profitable. Smaller firms also typically have more limited access to global supply networks and are more willing to work with local providers. Tier three and four operations with links across other industries including the medical devices sector and the electronics sector are potentially in the best position to diversify risk.

3) Entry into MRO services: Costa Rica already has two FAA certified companies in the country providing MRO services. These certifications are valuable assets as the FAA has not awarded new certifications outside of the United States since 2008, and it is unclear when this ban may be lifted.[24] However, Costa Rica must focus on entering

[24] While ostensibly the ban on issuing new FAA foreign repair stations is the result of security and safety concerns, it appears to be involved in a political battle between the aviation industry and labor unions. Industry advocates underscore that the ban prevents US firms from being able to leverage lower cost

the US market. Most major Latin American airlines have developed internal capacity to service their large fleets. Cheaper Latin American locations for MRO services undermine Costa Rica's potential competitiveness to enter the regional market, and indeed one major MRO in the country has seen a complete shift in their client base from a LAC-centric one to a US-based operation over the past three years, despite the economic crisis in the US. Serving US operations requires adequate infrastructure, as fleet size is significantly larger and a minimum of four production lines must be dedicated to each customer with a fleet size of approximately 200 planes (Field Research, 2012). Success for Costa Rica in the parts provision for the MRO business requires providing quality products faster than the original equipment providers, and at a lower price and better quality than low-cost providers, including Mexico. Like components manufacturing, MRO should focus on high-mix, low-volume production for niche products. Also, due to its location, the country should limit its efforts to attract line maintenance work to regional air traffic operations where it can leverage its strategic position, while focusing on developing a reputation in a niche MRO area.

4) <u>Entry into embedded software service operations</u>: Costa Rica's emerging IT talent and the establishment of a small number of software providers in the country could be leveraged to attract other specialized software providers to enter the sector. As aircraft move from analog to digital systems and become increasingly sophisticated, embedded software systems that integrate hardware with the plane's operating systems are becoming increasing important (see Box 2). This niche segment is beginning to be offshored in search of lower-cost talent. Costa Rica's strong reputation as an offshoring destination and the presence of large MNCs such as IBM in this segment can help to attract new firms. However, human capital is already relatively scarce in this sector and efforts would be required to improve its availability.

emerging markets, while labor unions are anxious that allowing new certificates to be issued will result in the loss of American jobs (Lombardo, 2012).

6. Appendix

Table A. 1. Aerospace Product Categories

Product Category	HS Code Aggregation	HS 2007 Codes Six-Digits
Helicopters	88021	880211: Helicopters of an unladen weight not >2000kg 880212: Helicopters of an unladen weight >2000kg
Airplanes	88022	Airplanes and other aircraft, of an unladen weight: 880220: not exceeding 2,000 kg 880230: >2000 kg but not >15000kg 880240: >15000kg
Landing Gear	88032	880320: Under-carriages & parts thereof , of goods of 88.01/88.02
Airframe Assemblies	88033	880330: Parts of airplanes/helicopters, other than propellers, rotors, under-carriages & parts thereof
Navigation Instruments	90142	901420: Instruments & appliances for aeronautical/space navigation (excl. compasses)
Engines & Parts (Propulsion)	8411 or 84111-84118 (engines) and 84119 (parts)	841111: Turbo-jets of a thrust not exceeding 25 kN 841112: Turbo-jets of a thrust exceeding 25 kN 841121: Turbo-propellers of a power not exceeding 1,100 kW 841122: Turbo-propellers of a power exceeding 1,100 kW 841181: Other gas turbines of a power not exceeding 5,000 kW 841182: Other gas turbines of a power exceeding 5,000 kW 841191: Parts of the turbo-jets/turbo-propellers of 8411.11-8411.22 841199: Parts of the other gas turbines of 8411.81 & 8411.82
Engines & Parts (Other on-board engines)	84071 (engines) 84091 (parts)	840710: Spark-ignition reciprocating/rotary internal combustion piston engines for aircraft 840910: Parts suit. for use solely/principally with the aircraft engines of 84.07
Other 88	8801 88026 88031 88039 8804 8805	880100: Balloons and dirigibles; gliders, hang gliders and other non-powered aircraft. 880260: Spacecraft (incl. satellites) & suborbital & spacecraft launch vehicles 880310: Propellers & rotors & parts thereof , of goods of 88.01/88.02 880390: Parts of goods of 88.01/88.02, nes in 88.03 880400: Parachutes (incl. dirigible parachutes & paragliders) & rotochutes; parts thereof & accessories thereto 880510: Aircraft launching gear & parts thereof; deck-arrestor/similar gear & parts thereof 880521: Ground flying trainers and parts: Air combat simulators and parts thereof 880529: Ground flying trainers and parts: Ground flying trainers other than air combat simulators, & parts thereof

Source: Authors illustration of the industry; definitions from UN Comtrade, 2012.

Table A. 2. Top Five Exporters of Aircraft Assemblies & Landing Gear by Value, 2004–2011

Aircraft Assemblies	Value ($US Millions)					Share (%)				
Exporter	**2004**	**2006**	**2008**	**2010***	**2011***	**2004**	**2006**	**2008**	**2010**	**2011**
World*	33,334.8	43,091.7	55,006.8	57,228.3	61,409.7					
USA*	13,393.7	18,169.6	19,584.4	21,562.9	23,811.6	40.2	42.2	35.6	37.7	38.8
EU-15	12,704.3	14,942.3	19,197.0	17,764.0	17,345.3	38.1	34.7	34.9	31.0	28.2
Singapore	991.5	1,802.8	3,083.1	4,225.8	4,962.9	3.0	4.2	5.6	7.4	8.1
Japan	1,115.9	1,965.6	2,254.7	2,492.4	3,144.8	3.3	4.6	4.1	4.4	5.1
India	--	--	--	--	1,838.2	--	--	--	--	3.0
Canada	966.9	1,208.8	1,488.6	1,496.3	--	2.9	2.8	2.7	2.6	--
Top Five	**29,172.3**	**38,089.1**	**45,607.9**	**47,541.5**	**51,102.8**	**87.5**	**88.4**	**82.9**	**83.1**	**83.2**
Main EU-15 Exporters						**Share of EU-15 Exports (%)**				
Germany	4,381.5	5,386.9	6,704.6	6,431.9	8,329.5	34.5	36.1	34.9	36.2	48.0
France	3,540.8	4,370.2	5,005.6	4,466.1	4,956.1	27.9	29.2	26.1	25.1	28.6
Italy	1,068.5	1,326.0	2,310.2	2,148.1	2,404.4	8.4	8.9	12.0	12.1	13.9
Spain	1,471.4	1,550.0	1,901.7	1,900.2	--	11.6	10.4	9.9	10.7	--
Landing Gear	**Value ($US Millions)**					**Share (%)**				
Exporter	**2004**	**2006**	**2008**	**2010***	**2011***	**2004**	**2006**	**2008**	**2010**	**2011**
World*	2,221.0	3,124.6	4,112.8	4,361.8	5,308.7					
USA*	1,069.6	1,350.4	1,776.8	1,956.3	2,160.3	48.2	43.2	43.2	44.8	40.7
EU-15	538.5	728.1	1,166.9	916.0	1,249.5	24.2	23.3	28.4	21.0	23.5
Canada	337.9	515.2	747.8	864.2	939.9	15.2	16.5	18.2	19.8	17.7
China	--	--	53.2	--	318.3	--	--	1.3	--	6.0
Mexico	--	--	--	147.5	156.8	--	--	--	3.4	3.0
Hong Kong	88.3	98.8	93.4	93.8	--	4.0	3.2	2.3	2.1	--
Zimbabwe	--	134.1	--	--	--	--	4.3	--	--	--
Rep. of Korea	48.8	--	--	--	--	2.2	--	--	--	--
Top Five	**2,083.2**	**2,826.7**	**3,838.0**	**3,977.6**	**4,824.8**	**93.8**	**90.5**	**93.3**	**91.2**	**90.9**
Main EU-15 Exporters						**Share of EU-15 Exports (%)**				
France	351.3	476.7	894.5	649.7	936.7	65.2	65.5	76.7	70.9	75.0
Germany	105.1	146.5	136.3	174.8	276.6	19.5	20.1	11.7	19.1	22.1

Source: UNComtrade, 2012.

Note *: Starting in 2009, the United States began exporting the majority of their exports as HS 880000. In this table, the US data for 2010 and 2011 is from USITC and represents the share of HS 880000 of 2008 data (Airplanes represented 27.2% and helicopters 2.5%).

Table A. 3. Top Five Exporters of Other Subassemblies by Value, 2004–2011

Main Engines (Propulsion)	Value ($US Millions)					Share (%)				
Exporter	**2004**	**2006**	**2008**	**2010**	**2011**	**2004**	**2006**	**2008**	**2010**	**2011**
World	20,252.8	25,234.1	24,069.0	22,512.4	24,192.6					
EU-15	12,194.3	14,718.5	10,467.1	16,330.4	17,354.3	60.2	58.3	43.5	72.5	71.7
Canada	1,410.0	1,743.6	2,595.2	1,748.2	1,840.6	7.0	6.9	10.8	7.8	7.6
Hong Kong	831.3	808.7	1,174.8	999.2	1,288.8	4.1	3.2	4.9	4.4	5.3
Russia	377.4	716.0	711.5	783.9	709.7	1.9	2.8	3.0	3.5	2.9
China	--	--	--	0.0	474.9	--	--	--	0.0	2.0
Ukraine	--	--	--	412.9	--	--	--	--	1.8	--
USA	4,673.2	5,398.6	7,443.9	--	--	23.1	21.4	30.9	--	--
Top Five	**19,486.3**	**23,385.3**	**22,392.6**	**20,274.6**	**21,668.3**	**96.2**	**92.7**	**93.0**	**90.1**	**89.6**
Main EU-15 Exporters						**Share of EU-15 (%)**				
UK	5,497.7	6,495.7	4,628.3	6,527.0	7,225.0	45.1	44.1	44.2	40.0	41.6
France	1,557.8	1,713.4	1,594.8	4,352.6	4,970.8	12.8	11.6	15.2	26.7	28.6
Germany	4,129.9	5,098.6	2,454.4	4,067.1	4,240.0	33.9	34.6	23.4	24.9	24.4
Other Engines	**Value ($US Millions)**					**Share (%)**				
Exporter	**2004**	**2006**	**2008**	**2010**	**2011**	**2004**	**2006**	**2008**	**2010**	**2011**
World	1,288.4	1,326.2	2,034.4	1,289.5	1,269.9					
Singapore	37.2	354.3	948.8	418.1	416.7	2.9	26.7	46.6	32.4	32.8
EU-15	265.6	176.6	196.9	247.8	164.8	20.6	13.3	9.7	19.2	13.0
India	--	--	84.1	83.7	133.1	--	--	4.1	6.5	10.5
USA	284.8	281.0	256.8	93.4	95.5	22.1	21.2	12.6	7.2	7.5
Mexico	--	--	--	--	75.9	--	--	--	--	6.0
Saudi Arabia	--	--	--	76.7	--	--	--	--	5.9	--
South Africa	--	--	109.3	--	--	--	--	5.4	--	--
Thailand	512.2	238.1	--	--	--	39.8	18.0	--	--	--
Australia	--	48.8	--	--	--	--	3.7	--	--	--
Cyprus	37.7	--	--	--	--	2.9	--	--	--	--
Top Five	**1,137.6**	**1,098.7**	**1,596.0**	**919.6**	**886.0**	**88.3**	**82.8**	**78.4**	**71.3**	**69.8**
Navigation Equipment	**Value ($US Millions)**					**Share (%)**				
Exporter	**2004**	**2006**	**2008**	**2010**	**2011**	**2004**	**2006**	**2008**	**2010**	**2011**
World	2,736.7	2,629.8	2,875.4	1,950.0	2,381.3					
EU-15	1,494.9	1,322.4	1,144.8	1,376.0	1,767.2	54.6	50.3	39.8	70.6	74.2
Canada	41.0	76.0	128.7	136.5	151.4	1.5	2.9	4.5	7.0	6.4
USA	991.8	1,005.6	1,292.5	137.0	139.6	36.2	38.2	45.0	7.0	5.9
Singapore	--	25.2	55.0	79.3	65.0	--	1.0	1.9	4.1	2.7
Russia	--	--	--	38.3	40.9	--	--	--	2.0	1.7
Mexico	87.6	45.6	43.6	--	--	3.2	1.7	1.5	--	--
South Africa	18.3	--	--	--	--	0.7	--	--	--	--
Top Five	**2,633.5**	**2,474.8**	**2,664.6**	**1,767.1**	**2,164.2**	**96.2**	**94.1**	**92.7**	**90.6**	**90.9**
Main EU-15 Exporters						**Share of EU-15 (%)**				
Germany	171.1	325.8	203.3	430.6	547.0	11.4	24.6	17.8	31.3	31.0
Italy	35.8	49.6	76.3	153.4	427.0	2.4	3.8	6.7	11.1	24.2
UK	834.2	417.1	329.6	332.7	420.3	55.8	31.5	28.8	24.2	23.8
France	273.6	458.6	366.1	294.0	341.8	18.3	34.7	32.0	21.4	19.3

Source: UNComtrade, 2012

Table A. 4. Exchange Rate, Colones to US Dollar

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Colones to US$1	376.4	418.7	458.1	496.7	517.3	496.5	558.4	553.5	503.1	504.7

Source: www.xe.com 21/08/2012

Note: Based on December 31 of each year.

Table A. 5. Firms Operating in the Aerospace Manufacturing GVC in Costa Rica

	Firm Name	Investment Origin	VC Segment	Year Est.	Est. Share of Sales to Aerospace
1	Ad Astra Rocket	Costa Rica	Design & Engineering	2005	100%
2	AEC Aerospace	United States	Aftermarket - Technical Manuals	2010	100%
3	Agilis Engineering	United States	Design & Engineering	2006	50%
4	AKA Precisión	Costa Rica	Components - Finishing/Machining	1991	
5	Avionyx	United States	Components - Software	2004	100%
6	C & K CoActive S.A.	United States	Components - Electrical	1988	33%
7	Camtronics	United States	Components - Electronics/Plastic	1992	
8	Coopesa	Costa Rica	Aftermarket -MRO	1963	100%
9	Diez Orlich (DO)	United States	Components - Finishing/Machining	n/a	33%
10	Etipres	Costa Rica	Labeling	1985	
11	FEMA	Costa Rica	Components - Metal Finishing/Machining	1983	
12	FORTECH	Costa Rica	Components - Metal Finishing/Machining	1994	
13	H&S Metalmecánica	Costa Rica	Components – Metal Finishing/Machining	n/a	
14	Helicorp	United States	Aftermarket - MRO - Helicopter Assemblies	2004	100%
15	Irazú Electronics	United States	Components - Electronics	2001	40%
16	L3 Communications	United States	Components - Electronics	2001	60%
17	Mechania Engineering	Costa Rica	Design & Engineering	2002	
18	Micro Technologies	United States	Components - Electromechanical	1999	10%
19	Multimix Microtechnology S.R.L.	United States	Components - Electrical	1999	
20	Olympic Precision	United States	Components - Finishing/Machining	1996	20%
21	R&R Precision SA	Costa Rica	Components - Metal Machining/Finishing	1979	10%
22	Ridge Run	United States	Components - Software	2006	
23	Sansaa Aircraft parts CR	United States	Aftermarket - MRO - Wheels, hydraulics, landing gear	n/a	100%
24	Sensor Group Costa Rica	United States	Components - Electronics	2006	33%
25	Tech Shop	Costa Rica	Aftermarket - MRO - Metal	1981	100%
26	Teradyne de Costa Rica	United States	Aftermarket - MRO - Electronics	2000	
27	Tico Electronics	United States/ Costa Rica	Components - Electrical	1995	100%
28	Trimpot Electronicas, Ltda	United States	Components - Electrical	1979	10%
29	West Star (Estrella de Precisión Tecnológica SA)	United States	Subassemblies - Metal Airframe Assemblies	2000	50%

Source: Authors.

Table A. 6. Stakeholder Interviews

Organization	Individual(s) Interviewed
Non-Firm Actors Interviewed	
AZOFRAS	Alvaro Valverde, Executive Director
CINDE	Irving Soto, Director, Investment Promotion Douglas Sanchez, Deputy Director, Investment Promotion Carolina Umaña, Investment Promotion Manager, Advanced Manufacturing Sandro Zolezzi, Director of Research
Costa Rica – Provee	Rolando Dobles, Export Linkages Director
INCAE	Arturo Condo, President
Instituto Nacional de Aprendizaje	Ileana Leandro Gómez, Gestora Tecnologica Luis Alejandro Arias Ruiz, Jefe Nucleo Eléctrico
Ministerio de Comercio Exterior (Comex)	Francisco Monge
Ministerio de Educación Pública	Dirección de Educación Técnica y Capacidades Emprendedoras Fernando Bogantes Cruz, Director
Procomer FTZ Regimen	Laura Chaves, Analista de Informes Anuales Andrea Cespedes, Advisors Coordinator Andres Villalta, Coordinador de Regímenes
Procomer	Francisco Gamboa, Trade Intelligence Director

7. Bibliography

Abraham, Jay and Jon Friedman. (2012, July/August). Building Confidence in the Quality and Reliability of Critical Software. *CrossTalk*.

Aeroman. (2012). Company History. Retrieved November, 2012, from www.aeroman.com.sv.

Algarañaz, Luis, Andrey Barrantes, Evelyn Cooban, José Ernesto Pacas, and Michal Pothuis. (2011). Condiciones y Oportunidades para el Desarrollo de la Industria Aeroespacial en Costa Rica. Alajuela, Costa Rica: INCAE, ACAE, PROCOMER.

Ali, Khwaja. (2011). "Trends in Aviation & Impacts on MROs". Paper presented at the IATA 7th Maintenance Cost Conference. Singapore. from http://www.iata.org/workgroups/Documents/MCC-2011-SIN/Day_02/1400-1430_Boeing_Trends_in_Aviation_and_MRO_Opportunities.pdf.

Ayala, Hector. (2009). Querétaro: Crece Aeropuerto. *Diario de Querétaro*. September 11 from http://www.oem.com.mx/laprensa/notas/n1320992.htm.

Ayeni, P, T Baines, H Lightfoot, and P Ball. (2011). "State-of-the-art of 'LEAN" in the Aviation Maintenance, Repair, and Overhaul Industry." *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 225*(11): 2108-2123.

Boeing. (2012). Long-term Market: China. Retrieved September, 2012, from http://www.boeing.com/commercial/cmo/china.html.

Braddorn, Derek and Keith Hartley. (2007). "The Competitiveness of the UK Aerospace Industry." *Applied Economics, 39*(4-6): 715-726.

Cafaggi, Fabrizio. (2012). Accessing the GVC in a Changing Institutional Environment: Comparing Aeronautics and Coffee: Inter-American Development Bank.

Carillo, Jorge and Alfredo Hualde. (2007). "Potencialidades y limitaciones de sectores dinámicos de alto valor agregado: La industria aersoespacial en México". Paper presented at the Grupo de Trabjo, CLACSO "Trabajo, Empleo. Calificaciones Profesionales, Relaciones de Trabajo e Idenditidaes Laborales. Buenoes Aires. October 31.

Carillo, Jorge and Alfredo Hualde. (2011). Una maquiladora diferente? Competencias laborales profesionales en la industria aeroespacial en Baja California.

Casalet, Mónica, Edgar Buenrostro, Federico Stezano, Rubén Oliver, and Lucía Abelenda. (2011). Evolución y complejidad en el desarrollo de encadenamientos productivos en México: Los desafíos de la construcción del cluster aeroespacial en Querétaro. Santiago: CEPAL.

Case, Brendan. (2012). Delta Repair Center with Aeromexico to Boost Aerospace Hub. *Bloomberg*. from http://www.bloomberg.com/news/2012-08-31/delta-aeromexico-to-build-repair-center-in-central-mexico.html.

Clearwater. (2011). Aerospace Global Report 2011: IMAP.

CONNStep. (2012). About Us Retrieved November, 2012, from www.connstep.org

Cook, R. James and Earll M. Murman. (2011). Rising Above the Gathering Storm: STEM Education in Washington State. Conference: 2011 Annual Meeting of the Washington State Academy of Sciences, Seattle.

Cooke, Philip and Oliver Ehret. (2009). "Proximity and Procurement: A Study of Agglomeration in the Welsh Aerospace Industry." *European Planning Studies, 17*(4): 549-567.

Cubas, Gustavo. (2012). Costa Rica Field Research. Personal communication with P. Bamber, S. Frederick & G. Gereffi. July 5.

Daniel, Fran. (2009). Taking Off in Aviation: Prospects for Employment in Triad are Good in Flying, Related Sectors. *Winston-Salem Journal*. April 12 Retrieved September 2012, from http://www.journalnow.com/business/image_2a001cda-b7bd-5b4f-ae3c-c2c0f46e598c.html.

De Florio, Filippo. (2006). *Airworthiness: An Introduction to Aircrfat Certification*. Burlington: Elsevier.

de Lavigne, Chris. (2009). Singapore Aerospace Value Chain Study. Singapore: Frost and Sullivan.

Deloitte Manufacturing Group. (2012). 2012 Global Aerospace and Defense Industry Outlook: A Tale of Two Industries. Retrieved November, 2012, from http://www.deloitte.com/assets/Dcom-Global/Local%20Content/Articles/Manufacturing/dttl_2012%20aerospace%20and%20defense%20outlook_03_02_12.pdf.

EDB and SPRING. (2009). Singapore Aerospace Supplier Guide. Singapore: EDB, SPRING. http://www.spring.gov.sg/EnterpriseIndustry/IP/PE/Documents/Singapore_Aerospace_Supplier_Guide.pdf.

Ehret, Oliver and Philip Cooke. (2010). "Conceptualising aerospace outsourcing: Airbus UK and the lean supply approach." *International Journal of Technology Management, 50*(3): 300-317.

FAA. (2012). Federal Aviation Admnistration. Retrieved September, 2012, from www.faa.gov.

Fernandez-Stark, Karina and Penny Bamber. (2012). Costa Rica Field Research. San Jose. July 16-20.

Field Research. (2012). Costa Rica: Summer 2012 Series. Personal communication with P. Bamber, G. Gereffi & S. Frederick. July 2-6.

Frost & Sullivan. (2012). Analysis of the Global Avionics Market. August.

Gereffi, Gary and Karina Fernandez-Stark. (2011). Global Value Chain Analysis: A Primer. Durham, North Carolina, USA: Center on Globalization, Governance & Competitiveness (CGGC) Duke University. http://www.cggc.duke.edu/pdfs/2011-05-31_GVC_analysis_a_primer.pdf

Gifas. (2004). French Aerospace Industry Key Figures 2003-2004: Groupement des Industries Francaises Aeronautiques et Spatiales.

Goldstein, Andrea. (2002). "The Political Economy of High-tech Industries in Developing Countries: Aerospace in Brazil, Indonesia and South Africa." *Cambridge Journal of Economics, 26*(4): 521-538.

Government Accountability Office. (2011). NIST Manufacturing Extention Program Partnership Cost Share: Factors for Evaluating the Cost Share of Manufacturing Extension Partnership Program to Assist Small and Medium-Sized Manufacturers. Washington, D.C.: United States Congress.

Greensboro Economic Development Alliance. (2012). Aviataion Education & Workforce. Retrieved September, 2012, from http://www.greensboroeda.com/industry_clusters/aci_subs/cluster_education_workforce.asp.

Hickie, D. (2006). "Knowledge and Competitiveness in the Aerospace Industry: The Cases of Toulouse, Seattle and North-West England." *European Planning Studies, 14*(5): 697-716.

IBISWorld. (2012). Global Commerical Aircraft Manufacturing: Market Research Report. http://www.ibisworld.com/industry/global/global-commercial-aircraft-manufacturing.html.

Institution of Engineers. (2012, April). Aerospace Engineering. *The Singapore Engineer* (069/02/2012), 10-27.

Johansen, Kerstin, Mica Comstock and Mats Winroth. (2005). "Coordination in collaborative manufacturing mega-networks: A case study." *Journal of Engineering and Technology Management, 22*(3): 226-244.

Johnson, Tim. (2012). Mexico Takes Flight as Hub for Aerospace Industry. *McClatchy Newspapers*. July 18 from http://www.mcclatchydc.com/2012/07/18/156657/mexico-takes-flight-as-hub-for.html.

Kraemer-Mbula, Erika. (2008). Sectoral Analysis of the Aerospace Industry in South Africa: Institute for Economic Research on Innovation.

Lloyd, Caroline. (1999). "Regulating Employment: Implications for Skill Development in the Aerospace Industry." *European Journal of Industrial Relations, 5*(2): 163-185.

Lombardo, David. (2012). AFL-CIO: Arsa Not Interested in Repairs Station Security. Retrieved November 2012, from The Convention News Co.from http://ainonline.com/aviation-news/ainmxreports/2012-08-29/afl-cio-arsa-not-interested-repair-station-security.

Long, Katherine. (2011). Microsoft, Boeing pledge $50 million as tuitions set to shoot up. *The Seattle Times*. June 6 from http://seattletimes.com/html/localnews/2015246948_financialaid07m.html.

Lublinski, Alf Erko. (2003). "Does Geographic Proximity Matter? Evidence from Clustered and Non-clustered Aeronautic Firms in Germany." *Regional Studies, 37*(5): 453-467.

MacPherson, Alan. (2009). "The Emergence of a New International Competitor in the Commercial Aircraft Sector: The China Syndrome." *Futures, 41*(7): 482-489.

McBride, Mike. (2012). A Delicate Recover: Opportunities and Challenges in Today's MRO Market 2011-2021: Team SAI Consulting Services

McGuire, Steven. (2007). "The United States, Japan and the Aerospace Industry: From Captrue to Competitor?". *The Pacific Review, 20*(3): 329-350.

McKenna, Ed. (2008, November 1). Embedded Overall. *Avionics Today*.

Monge, Francisco. (2012). Aerospace and Military Limitations of the Constitution. Personal communication with P. Bamber, S. Frederick & G. Gereffi. December 10.

Niosi, Jorge and Majlinda Zhegu. (2010). "Multinational Corporations, Value Chains and Knowledge Spillover in the Global Aircraft Industry." *International Journal of Institutions and Economies 2*(2): 109-141.

Niosi, Jorge and Majlinda Zhegu. (2005). "Aerospace Clusters: Local or Global Knowledge Spillovers?". *Industry and Innovation, 12*(1): 5-29.

NIST. (2012). About the Manufacturing Extension Partnership. Retrieved November, 2012, from http://www.nist.gov/mep/about.cfm

Osse, Jose Sergio. (2012). China Plant Gives Embraer Asia Jet-Sales Boost: Corporate Brazil. Retrieved September, 2012, from http://www.bloomberg.com/news/2012-06-25/china-plant-gives-embraer-asia-jet-sales-boost-corporate-brazil.html.

Partnership, Prosperity. (2012). WSU Engineering Program Begins in Everett. from http://archive.constantcontact.com/fs044/1101581514240/archive/1111045061268.html

Pritchard, David and Alan MacPherson. (2004). Outsourcing US commercial aircraft technology and innovation: implications for the industry's long term design and build capability: Canada-United States Trade Center.

---. (2007). Strategic Destruction of the North American and European Commercial Aircraft Industry: Implications of the System Integration Business Model. Canada-United States Trade Center, Buffalo, NY.

Pwc. (2012). Aerospace & Defense: 2011 year in review and 2012 forecast: Pricewaterhousecooper, LLC.

Revista Summa. (2011). Aeroman: El Salvador necesita más técnicos e ingenieros. *Revista Summa*. Febrero 17 from http://www.revistasumma.com/negocios/9418-aeroman-el-salvador-necesita-mas-tecnicos-e-ingenieros.html.

Romero, Javier Martinez. (2010). The Development of Aerospace Clusters in Mexico. Montreal: The Global Network for Economics of Learning, Innovation, and

Rose-Anderssen, C., J. S. Baldwin and K. Ridgway. (2011). "Commercial aerospace supply chains." *Journal of Manufacturing Technology Management, 22*(1): 66-89.

Rose-Anderssen, Christen, James Baldwin, Keith Ridgway, Peter Allen, Liz Varga, and Mark Strathern. (2009). "A cladistic classification of commercial aerospace supply chain evolution." *Journal of Manufacturing Technology Management, 20*(2): 235-257.

Rose-Anderssen, Christen, James S. Baldwin, Keith Ridgway, Peter Allen, and Liz Varga. (2008). "Aerospace Supply Chains as Evolutionary Networks of Activities: Innovation via Risk-Sharing Partnerships." *Creativity and Innovation Management, 17*(4): 304-318.

RTI. (2009). Workforce Needs Assessment for the Aerospace Industry in North Carolina: Regional Technology Inc. http://www.goldenleaf.org/files/Aerospace_-_WorkforceNeedsAssessment_.pdf.

SAE International. (2012). SAE Aerospace Standards. Retrieved September, 2012, from http://standards.sae.org/aerospace/.

Schacht, Wendy. (2011). Manufacturing Extension Partnership Program: An Overview. Washington, D.C.: Congressional Research Service. April 25.

Secretaría de Economía. (2012). El Sector Aeronaútico en México. Mexico City: Secretaría de Economía.

Sim, Loo-Lee, Seow-Eng Ong, Adeesh Agarwal, Ali Parsa, and Ramin Keivani. (2003). "Singapore' Competitiveness as a Global City: Development Strategy, Institutions and Business Environment." *Cities, 20*(2): 115-127.

Singapore Workforce Development Agency. (2012). Aerospace WFD. Retrieved November, 2012, from http://www.wda.gov.sg/content/wdawebsite/L207-AboutWSQ/L301-WSQIndustryFramework-Aerospace.html.

Smith, Brad et. al. (2011). Higher Education Funding Task Force. Seattle. January. http://www.psrc.org/assets/5597/HETF-FullReport.pdf.

Smith, David J. and David Tranfield. (2005). "Talented suppliers? Strategic change and innovation in the UK aerospace industry." *R&D Management, 35*(1): 37-49.

Sorbie, Brendan. (2009). Queretaro Prepares for Massive Aerospace Growth. Retrieved November 2012, from http://www.flightglobal.com/news/articles/queretaro-prepares-for-massive-aerospace-growth-325253/.

Spafford, Chris, Ken Aso and Olivier Fainsilber. (2012). A Better Way to Assemble the Puzzle Pieces of the Networks for MROs: Oliver Wyman. http://www.oliverwyman.com/media/NYC-AGE97201-001-MRO_Better_Way_Final.pdf.

Spafford, Chris, Tim Hoyland and Roger Lehman. (2012). MRO Industry Landscape 2012: Oliver Wyman.

SPRING. (2012). Assistance Programs for SMEs. Singapore: SPRING. http://www.spring.gov.sg/Resources/Documents/Guidebook_Govt_Asst_Prog.pdf

Strauss, Karsten. (2012, November 12). Made in the USA: Bringing Industry Back Home. *Forbes*.

The Business Year. (2012). Sonic Boom. *The Business Year*,. from http://www.thebusinessyear.com/publication/article/12/942/mexico-2012/sonic-boom.

Thomas, Teri. (2012). UW is First US School to Give Credit for Classes, Certification Programs on Massive Open Online Course Platform. Retrieved November from http://www.washington.edu/news/2012/07/18/uw-is-first-u-s-school-to-give-credit-for-classes-certificate-programs-on-massive-open-online-course-platform/.

Tomesco, Frederic. (2012). Air Canada Sees C$120 Million Aveos Costs in 1st Quarter. *Bloomberg Businessweek*. April 26 from http://www.businessweek.com/news/2012-04-26/air-canada-sees-c-120-million-aveos-costs-in-1st-quarter.

U.S. Commercial Service. (2010). Aerospace Sector in Singapore. Washitngon, D.C. : U.S. Commercial Services. September 1.

U.S. Department of Commerce. (2005). The U.S. Jet Transport Industry: Competition, Regulation, and Global Market Factors Affecting U.S. Producers. Washington, D.C.:

U.S. Department of Commerce, International Trade Administration. http://www.trade.gov/mas/manufacturing/oaai/build/groups/public/@tg_oaai/documents/webcontent/tg_oaai_003737.pdf.

---. (2010). Flight Plan 2010: Analysis of the U.S. Aerospace Industry. Washington, D.C.: International Trade Admininstration, Department of Commerice.

US International Trade Commission. (1998). Changes in the Structure of the Asian Aerospace Industry: China, Korea, Indonesia and Singapore. In P. Anderson (Ed.), *The Changing Structure of hte Global Large Civil Aircraft Industry and Market: Implications for the Competitiveness of the US Industry* (Vol. 2012, pp. 5-34-35-38). Washington, D.C.: Diane Publishing Co.

Vasconcellos, Roberto Roma, Marcio Akira Harada, Vania Ferreira Fernandez Contreiro, André Luiz Correia, and Sérgio Costa. (2007). Impacts of Standardization Process in the Brazilian Space Sector: A Case Study of a R&D Institute. In G. Loureiro & R. Curran (Eds.), *Complex Systems Concurrent Engineering* (pp. 41-47): Springer London.

Washington State Legislature. (2012). RCW 28B.145.060. Opportunity Expansion Program Retrieved November 2012, from http://apps.leg.wa.gov/rcw/default.aspx?cite=28B.145.060.

Wipro. (2009). Aerospace Manufacturing Transfer Systems: Wipro Council for Industry Research.

WTO. (2010). WTO Issues Panel Report on Airbus Dispute. 2012,

Yang, Xuhao, Thanh Le, Liefeng Zhang, and Wenjie Zhang. (2011). The Boeing Company. Urbana-Champaign: University of Illinois. http://www.business.illinois.edu/finance/rcmp/research/BA2011-11.ppt.

Yuen, Belinda. (2009). Singapore Local Economic Development: The Case of the Economic Development Board. Singapore: The World Bank.