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Aerospace Industry: Current Status and Trends of the Global Value Chain

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Inter-American Development Bank
Productivity, Trade, and Innovation Sector

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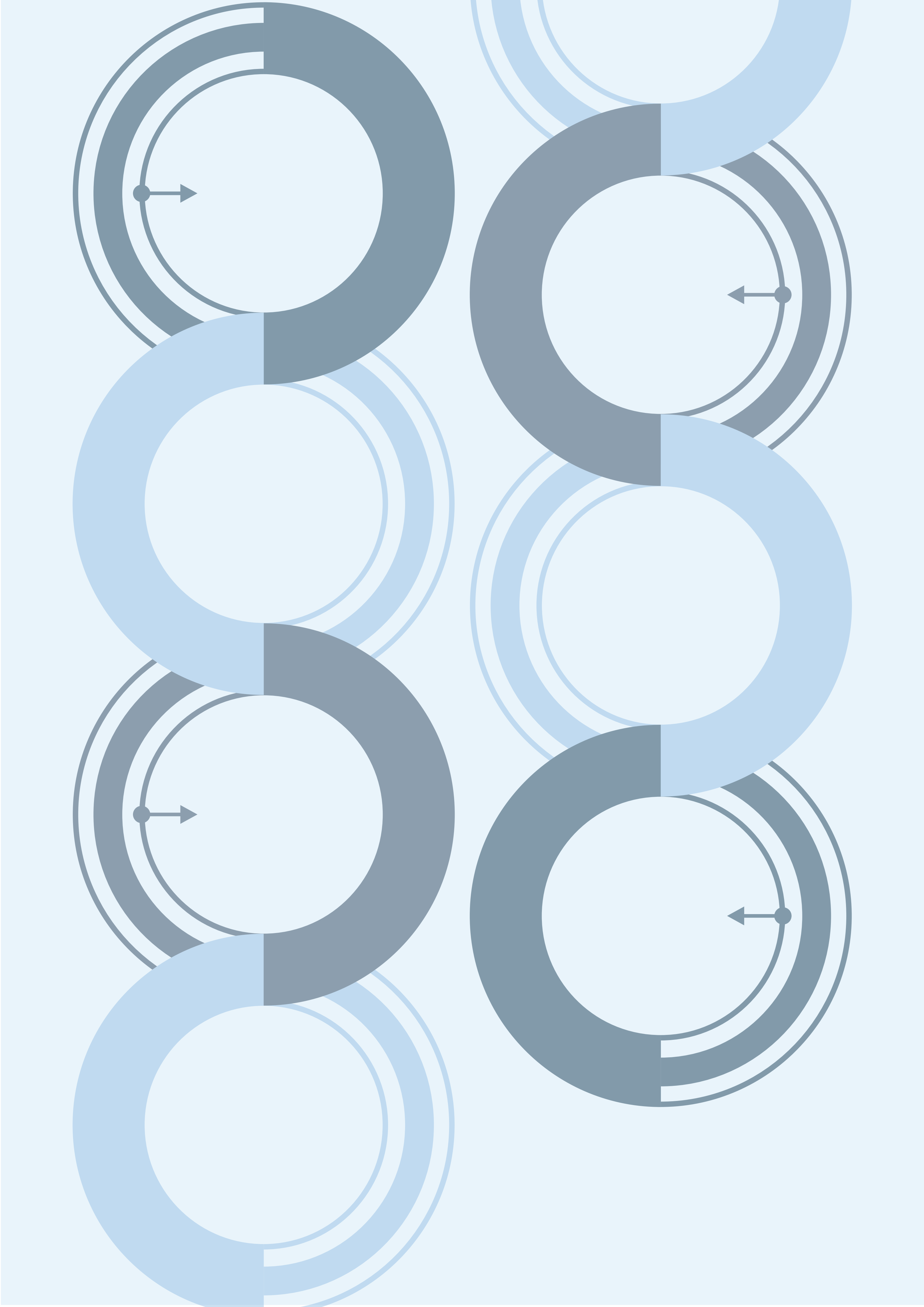
AEROSPACE INDUSTRY

CURRENT STATUS AND TRENDS OF THE GLOBAL VALUE CHAIN



IDB



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Summary

The aerospace industry is a high value-added sector characterized by a strong relationship with national governments due to issues related to sovereignty and the strategies intended to foster its industrial and technological capabilities (Hayward, 1994; Landoni & Ogilvie, 2019; McGuire, 2014). The aerospace industry is a case where the GVC approach is remarkably relevant due to the fragmentation of goods production and services provision in the industry. When defining the different stages of production in the aerospace industry, a tiered supply structure is commonly used: Moving up the value chain, products are more technologically complex and specific to the industry, requiring more innovation capabilities and a closer relationship with the lead firms.

International trade (exports) in final products and subparts grew steadily over the last decade (2010-2019), increasing an average of 6.7% annually until 2019. The development by value chain stage shows an increase in value chain fragmentation between 2010 and 2019, with a greater share of trade in subparts (tier 1/2 and tier 3)). Look at how country-specific exports have developed, we can observe that this increase is linked to the increase in Asia's share of the subpart market, especially in tiers 1 and 2 (increase in relative share from 19% to 25%). Exports from Singapore, Hong Kong and India in these tiers are particularly relevant. The impact of the COVID-19 pandemic, however, resulted in a decrease in international trade in 2020, setting it back to trade volumes equivalent to 2011. In 2022, exports began to recover, and by 2023, they had nearly returned to the levels observed in 2014.

Given the dynamics after the pandemic, geopolitical issues, and market and technology trends, the coming years are likely to see a value chain reconfiguration that will have relevant impacts to Latin American and Caribbean (LAC) countries. The US strategy has already been reoriented toward guaranteeing the supply of important raw materials for producing sensitive goods (The White House, 2021) as well as toward strengthening multinational alliances to increase political dominance in strategic regions (ALTAMAR, 2021; Isidore, 2021; Macias, 2021). Foreign trade restrictions (Lampert; Singh, 2025; Waldr, 2021) and countertrade strategies (generally called offset agreements) may be intensified as means of political domination or economic restriction, or to play technological catch-up (Martin, 2014; WTO, 2018). Additionally, increasing trade tensions around the world makes it difficult to predict future scenarios.

In this sense, this report aims to provide an overview of the aerospace industry at large, with a particular focus on its potential for LAC countries, in order to offer strategic insights and policy recommendations for the region. Technological developments (such as ICT, smart factories, new materials, and energy matrix/storage) and market/business trends (including supply chain consolidation and strategic repositioning) have influenced the strategies of companies and countries in the sector. LAC countries can leverage their competitive advantages to strengthen and expand their aerospace industries.

In order to offer recommendations for setting priorities, we employ four strategies:

1. Brazil and Mexico: Countries that reached relevant productive and commercial scale in the industry and therefore have solid industrial structures. These countries ranked third and tenth, respectively, in attracting foreign direct investment to their aerospace industries between 2009 and 2017, accounting for 11% of total global investment.
2. Argentina and Chile: Countries whose companies have historically been players in LAC's aerospace industry but are not competitive in the global value chain.
3. Costa Rica: A country with capacity in complex industries and where the aerospace industry is making moves.
4. Latecomer countries: Countries engaging in activities to make the most of their competitive advantages.

Two elements are crucial for developing an aerospace industry: education and science and technology (S&T) support. To protect their national competitive advantages, every country should establish policies that strengthen educational, scientific, and technological capacities to grow the sector sustainably.

Along with this analysis, some specific public policies are proposed.

In Brazil, policies are primarily aimed at scaling up companies with strong engineering and R&D capabilities, with a particular emphasis on Embraer and a select group of firms with the potential to become globally competitive. We also propose policies to enhance product assembly and component production by modernizing industrial processes (mitigating risks from disruptive technological trends) and strengthening advisory services in standards and certifications (such as NADCAP and AS9100). These recommendations apply to Mexico and Costa Rica as well.

In Mexico, policymakers should prioritize strategies that improve the business and production environment for existing foreign firms while attracting new companies to establish manufacturing operations. A key objective should be upgrading processes and products to boost the local industries value-added.

For Argentina and Chile, the focus should be on scaling up state-owned enterprises and advancing their technological capabilities. This requires public investments in engineering (both human capital and software) and modernizing or expanding production infrastructure.

Finally, for latecomer countries, we recommend leveraging labor cost advantages by entering global value chains at lower value-added stages – particularly through maintenance, repair, and overhaul (MRO) services.

1. DEFINING THE STATUS AND RECENT DYNAMICS OF THE GLOBAL AEROSPACE VALUE CHAIN

Measuring the aerospace market is a complex endeavor, primarily due to three factors: (i) the intricate nature of its products, which typically comprise thousands of components sourced from various economic sectors; (ii) the dual-use nature of aerospace technologies, spanning both civilian and military applications; and (iii) the industry's strategic role in national sovereignty, which often leads to restricted access to sensitive data. Consequently, national production statistics – usually presented in aggregate form – lack the precision needed for detailed analysis. An additional challenge lies in capturing the full scope of the value chain. Post-sales services, such as maintenance, repair, and overhaul (MRO), as well as training and customer support, represent a substantial share of the market but are inherently difficult to quantify. For instance, Aboulafia and Michaels (2018) estimate that civil and military MRO services accounted for 27% of the aerospace market in 2017.

Many consulting firms evaluate the aerospace market using quantitative and qualitative analyses based on reports from leading companies, industry association estimates, and national statistics. However, these estimates often vary significantly, and the lack of standardized methodologies makes it challenging to track long-term market trends consistently.[1]

To enable meaningful year-over-year comparisons, a unified analytical framework is required. Some studies (Bamber *et al*., 2013, 2016; Caliari *et al*., 2021; Niosi & Zhegu, 2005, 2010) address this by examining shifts in countries' international trade structures, leveraging UN Comtrade data to isolate aerospace-specific products. While this method excludes domestically consumed production, the globalized nature of aerospace supply chains helps offset this limitation.

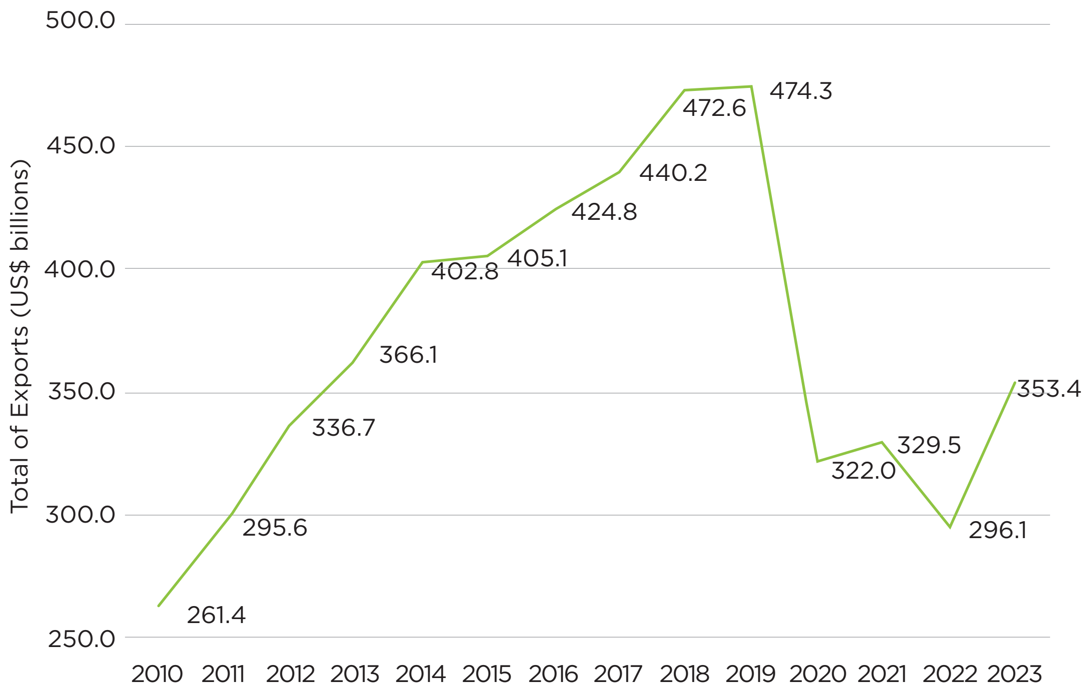
In this report, we adopt this trade-based approach, supplementing it with production trends from key aerospace-exporting nations, and market outlooks from specialized consulting firms. This combination ensures a balanced perspective on both trade dynamics and industry developments.

1. Some of these measurements will be presented in the production and market analysis part of this section.

INTERNATIONAL TRADE

The international trade data presented in this report are based on the aerospace product classifications given in Table A.1 (Appendix). As shown in Figure 1, exports grew steadily during the last decade, increasing an average of 6.7% annually until 2019. However, the COVID-19 pandemic significantly impacted international trade, resulting in a sharp decline in exports that fell to levels comparable to those observed in 2011. In 2022, exports began to recover, and by 2023, they had nearly returned to the levels observed in 2014. However, it has not yet returned to pre-pandemic levels.

Figure 1.
Evolution of exports (USD billions, current prices).



Source: UN Comtrade, HS02 6D codes, Reporters' exports to the world, Retrieved 24/03/2025. USA exports are retrieved by an inverse process: Imports reported by the world from the USA (necessary because the USA reports under HS880000 for 2009 onwards).

An analysis of trade evolution by region shows overall export growth across all areas, but with some significant differences worth noting. The two largest exporting regions – Europe and the USA + Canada – maintain their leadership in the aerospace industry, accounting for approximately 82% of global trade in 2023. However, this share represents a decline from the 86% recorded in 2010, reflecting the growth of Asian countries, which showed an average annual expansion rate of about 6.2% from 2010 to 2023. On the other hand, Latin American and Caribbean (LAC) countries, despite having increased their absolute trade value, saw their relative share decrease precisely due to Asia's greater dynamism. Additionally, the economic shock of the 2020s affected all exporting regions but was particularly severe for LAC countries, which experienced a 34.7% drop in sector exports.

Table 1.
Export statistics, by regions (USD billions, current prices).

REGION	2010	2015	2019	2020	2023	2020-2019	2023-2010
Europe	132.45	189.25	214.82	140.13	150.22	-34.8%	13.4%
USA+Canada	94.69	151.86	167.61	111.03	141.27	-33.8%	49.2%
Asia	25.47	50.87	77.62	60.54	55.78	-22.0%	119.0%
LAC	6.87	9.15	9.44	6.16	5.15	-34.7%	-25.1%
Oceania	0.91	1.73	2.35	2.17	0.53	-7.7%	-42.2%
Africa	1.00	2.20	2.49	2.01	0.50	-19.5%	-49.7%
Total	**261.39**	**405.06**	**474.32**	**322.02**	**353.45**	**-32.1%**	**35.2%**

Source: UN Comtrade, HS02 6D codes, Reporters' exports to the world, Retrieved 24/03/2025. Note: LAC = Latin American and Caribbean countries. USA exports are retrieved by an inverse process: imports reported by the world from the USA (needed because the USA reports under HS880000 for 2009 onwards).

The breakdown of trade statistics by exporting nation reveals critical insights into global competitive dynamics within the aerospace sector. This industry demonstrates remarkable concentration, with the top 20 exporters consistently accounting for over 92% of global trade throughout the period. In 2023, just four leading nations represented approximately 72% of total exports – reflecting the dominance of prime contractors like Boeing and Lockheed Martin (USA) and Airbus (France/Germany), along with their specialized supplier networks.

Asia's remarkable export expansion has been driven by four key markets: Singapore (+141% growth), Hong Kong (+377%), China (+146%), and India (+169%). This export surge aligns with the region's growing domestic demand. As Teal Group Corporation (2021) reports, China's share of global aircraft deliveries skyrocketed from just 2% in 2000 to 23% by 2018, underscoring its market transformation.

Latin American markets present a contrasting picture. Brazil has seen its position erode steadily, falling from 8th largest exporter in 2010 to 15th in both 2020 and 2023. Mexico showed initial promise (climbing from 23rd in 2010 to 18th in 2020) but subsequently declined to 22nd position by 2023.

Table 2.
Export statistics, by country (top 20, USD billions, current prices).

#	COUNTRY	2010	%	COUNTRY	2020	%	COUNTRY	2023	%
1	USA	81.9	31.4	USA	97.4	30.3	USA	126.3	35.7
2	France	54.9	21.0	France	40.2	12.5	France	49.2	13.9
3	Germany	37.0	14.2	Germany	36.9	11.5	UK	37.3	10.6
4	UK	14.0	5.4	UK	31.6	9.8	Germany	31.4	8.9
5	Canada	12.7	4.9	Singapore	17.8	5.5	Singapore	16.0	4.5
6	Singapore	6.6	2.5	Canada	13.6	4.2	Canada	15.0	4.2
7	Italy	6.0	2.3	Hong Kong	9.3	2.9	Hong Kong	12.3	3.5
8	Brazil	4.7	1.8	Spain	6.1	1.9	Ireland	6.3	1.8

9	Japan	4.3	1.6	Japan	5.6	1.7	China	5.7	1.6
10	Spain	4.3	1.6	Ireland	5.0	1.5	Spain	5.4	1.5
11	Netherlands	3.1	1.2	China	4.8	1.5	Poland	5.2	1.5
12	Hong Kong	2.6	1.0	Netherlands	4.2	1.3	Netherlands	4.6	1.3
13	China	2.3	0.9	India	4.2	1.3	India	4.5	1.3
14	Ireland	2.0	0.7	Thailand	3.7	1.2	Arab Emirates	3.9	1.1
15	Israel	1.8	0.7	Brazil	3.2	1.0	Brazil	3.6	1.0
16	Belgium	1.7	0.7	Arab Emirates	3.0	0.9	Japan	3.1	0.9
17	India	1.7	0.6	Poland	2.9	0.9	Thailand	2.8	0.8
18	Rep. of Korea	1.6	0.6	Malaysia	2.4	0.8	Rep. of Korea	2.2	0.6
19	Switzerland	1.5	0.6	Rep. of Korea	2.4	0.8	Italy	2.0	0.6
20	Thailand	1.4	0.5	Israel	2.4	0.7	Israel	2.0	0.6
	TOTAL	**246.1**	**94.2**		**296.6**	**92.1**		**338.7**	**95.8**

Source: UN Comtrade. HS02 6D codes. Reporters' exports to the world. Retrieved 24/03/2025. Note: UAE = United Arab Emirates. USA exports are retrieved by an inverse process: imports reported by the world from the USA (needed because the USA reports under HS880000 for 2009 onwards).

MARKET AND PRODUCTION

As mentioned above, there are a number of potential issues when comparing market and production data. Nonetheless, analyzing them can provide us with insights that corroborate specific patterns, and despite differences in scale, it may be possible to find similarities in growth patterns.

We therefore present some studies on the aerospace industry and estimates of the size of the global market for certain years in Table 3, below. While the varying methodologies used can introduce unknown factors that distort how the market has evolved,[2] estimates of average market growth between 2010-2019 and the 2020 decline are in line with the evolution observed in the international trade data (Figure 1). Despite the lack of consolidated data for the 2021-2022 period, estimates from consulting firms indicate an average annual growth of 3.8% starting from 2020, with a return of market to pre-pandemic levels.

Table 3.
Studies' estimates of aerospace market value (USD billions, current prices).

STUDIES	MARKET VALUE (USD BILLIONS)	YEAR
(Deloitte, 2010)	382	2009
(Deloitte, 2015)	612.8	2011
	648.5	2012
	669.5	2013
	682.2	2014

2. Different studies can produce significantly different results depending on the year in question (for example, 14% in 2018). Comparing the evolution using studies with different methodologies can signal a dynamic that does not match the reality of the market value (for instance, the market value estimated by Aboulafia and Michaels in 2017 and the one estimated by PwC in 2019 indicating a false market downturn). The methodology can change even within the same consultancy (for example, Deloitte's reports sometimes have conflicting results over time).

(Deloitte, 2017a)	674.4	2016
(Aboulafia & Michaels, 2018)	838	2017
(Alix Partners, 2019)	812	2018
	865	2019
(PwC, 2021)	757.6	2019
	697	2020
(The Business Research Company, 2020)	736.4	2020
(PWC, 2024)	829	2023
(Zion Market Research, 2023)	750	2023
(Statista, 2023)	829	2023

Source: Prepared by the authors.

Lastly, production data for select countries are presented in Table 4 below. The particularities of data availability for each country make it difficult to gather comparable statistics[3] or even to obtain statistics solely for the aerospace industry. In addition to differences in measurement, approaches are often constrained by sovereignty issues.[4] Regardless, the data obtained represent the productive capacity of 32 countries that were responsible for 84.1% of total exports in 2023. As we can see, the production data can reflect lower values compared to international trade data, possibly raising questions as to specific issues of methodology regarding exports and production.[5]

Table 4.
Aerospace industry, production of selected countries (USD billions, current prices).

REGION/ COUNTRY	2010	2015	2020	2021	2022	2023	2021-2010	2022-2010	2023-2010
USA	185.47	255.33	212.85	206.51	264.68	327.60	11.35	42.67	76.56
European Union	82.53	105.27	83.17	80.60	83.02	104.74	-2.34	0.59	26.91
Singapore	5.36	6.11	7.08	7.85	9.56	11.60	46.46	78.36	116.42
Brazil	5.12	5.08	2.75	2.96	3.26		-42.19	-36.33	
Mexico	0.63	1.28	1.37	1.25			98.41		
Total	**279.11**	**373.07**	**307.22**	**298.17**	**360.52**	**443.94**	**6.83**	**29.16**	**59.04**

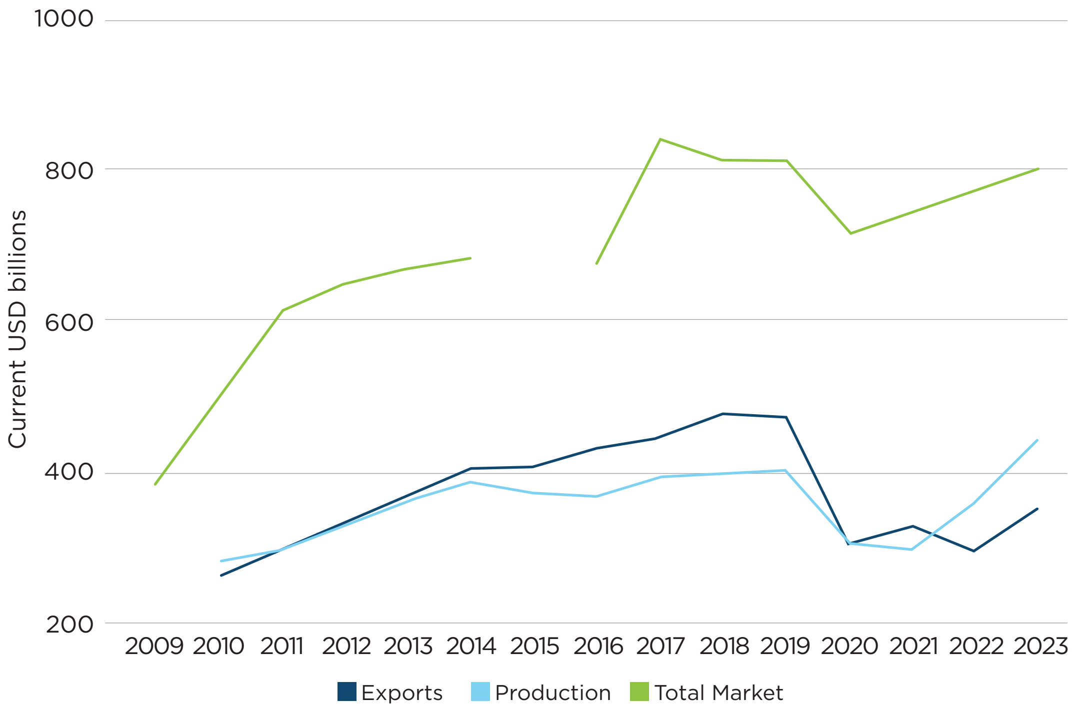
Source: Prepared by the authors. Data from country/regional data repositories. From 2020 onwards, the United Kingdom data included in the European Union dataset originate from a British repository. Data for Mexico are available up to 2021. Data for Brazil are available up to 2022.

Despite this, the production data also confirm the market's growth dynamics over the past 10 years. The growth in US, European Union, Singapore, and Mexican production is also captured, along with a decline in Brazilian production. Finally, for

3. The problem of comparability in production statistics arises from two issues: First, while classification may be consistent at the national level (NACE for Europe, US ISIC for the US, CNAE for Brazil, for example), comparisons use the classifications employed by each country, which can vary. Second, an analysis confined only to the aerospace industry sector will exclude several subparts of horizontal sectors for which the aerospace industry is just one of its sources of demand.
4. For example, in the case of the European Union, production data only include civilian products, which can lead to significant underestimation; according to Teal Group (2021), the market for military products accounted for 31.6% of the total market in 2020.
5. Specifically, it is possible that export data are impacted by issues with double counting (subparts incorporated into intermediary products that are further re-exported). If re-exports are significant, figures for overall exports can outstrip production. We still use these figures to compare the US with the EU, even though trade within the US is not captured by international statistics, while trade among European countries is, and is quite important.

elucidation purposes, Figure 2 below presents a measurement of exports, production and market share (estimated by consulting firms) in order to validate the observation of a similar pattern.

Figure 2.
Comparison of exports, production, and market estimates (USD billions, current prices).

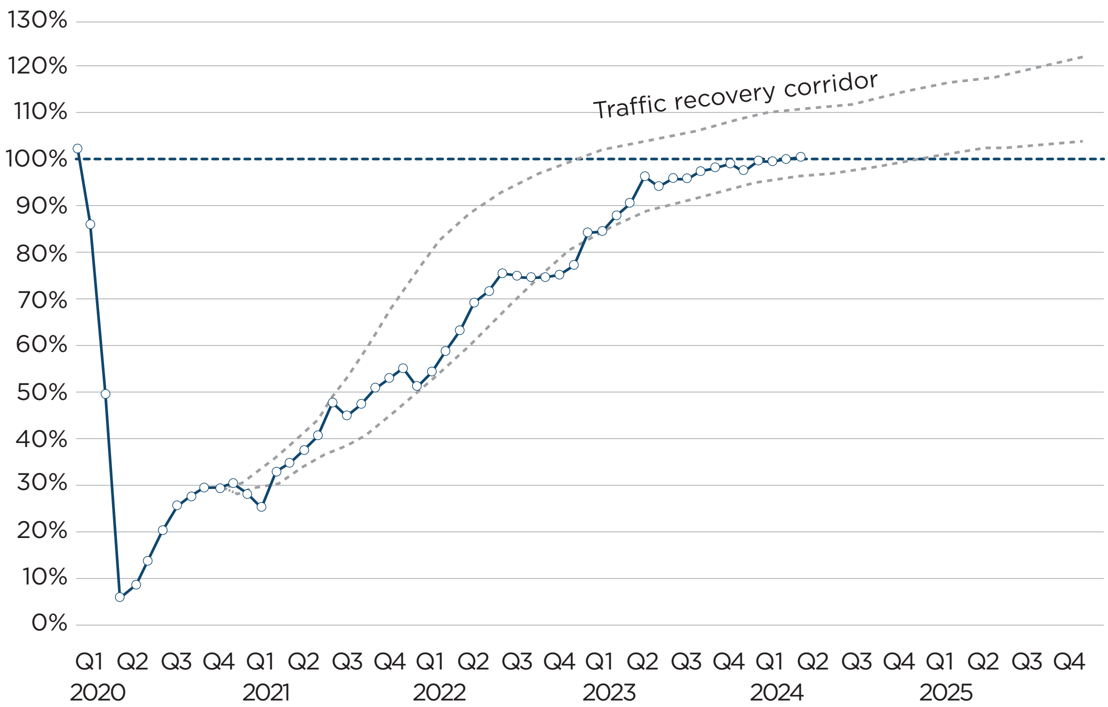


Source: Prepared by the authors. Data from UN Comtrade, country/regional data repositories and consulting firms.

• FORECASTS

The drop in demand for aviation due to the COVID-19 pandemic led to a shock in the market, significantly impacting the growth trend observed in recent years. This also led to a decrease in orders of new aircraft, impacting the entire supply chain, along with early retirement for some aircraft. The market value of the leading companies declined to 2006 levels (Teal Group Corporation, 2021). Estimates suggested that returning to the pre-pandemic long-term trend could take until late 2023 or early 2024 (AeroDynamic Advisory, 2021; IATA, 2021; Teal Group Corporation, 2021), what was ultimately confirmed (AIRBUS, 2024).

Figure 3.
World Air traffic.



Source: (AIRBUS, 2024).

The long-term market forecasts from the two largest companies in the industry, Airbus and Boeing, are also of significant importance. On average, both projections predict an approximately 87% increase in the global fleet by 2043, with strong growth in the Asia-Pacific, Africa, and Middle East regions.

Table 5.
Airbus-Boeing Forecast Comparison, total fleet by region.

	AIRBUS FORECAST (2019-2043)			BOEING FORECAST (2023-2043)			DIFFERENCE
REGION	2019	2043	VARIATION	2023	2043	VARIATION	
Africa	670	1460	118%	695	1650	137%	19.5%
Asia-Pacific	7441	19510	162%	8220	20040	144%	-18.4%
Europe and CIS	6163	8050	31%	6595	11105	68%	37.8%
Latin America	1459	2570	76%	1640	3025	84%	8.3%
Middle East	1355	3740	176%	1610	3505	118%	-58.4%
North America	5593	7100	27%	7990	10845	36%	8.8%
World	**22681**	**42430**	**87%**	**26750**	**50170**	**88%**	**0.5%**

Source: (AIRBUS, 2019, 2024; BOEING, 2024)

Further analysis can be observed by region and product segment (based on Boeing Forecast 2023–2043). Following the growth forecast for the Asia-Pacific, Africa, and Middle East markets, the company envisions growth across all aircraft segments, except for regional markets, where it anticipates growth only in the Asian market.

Table 6.
Boeing Forecast (2023–2043), by region and segment.

	ASIA-PACIFIC	NORTH AMERICA	EUROPE	MIDDLE EAST	LATIN AMERICA	AFRICA	WORLD
Regional Jet	174%	-44%	-52%	0%	-73%	-43%	-28%
Single Aisle	152%	62%	78%	124%	93%	193%	101%
Widebody	177%	50%	76%	118%	112%	154%	105%
Freighter	176%	25%	46%	118%	47%	233%	67%
Total	**158%**	**36%**	**68%**	**118%**	**84%**	**137%**	**88%**

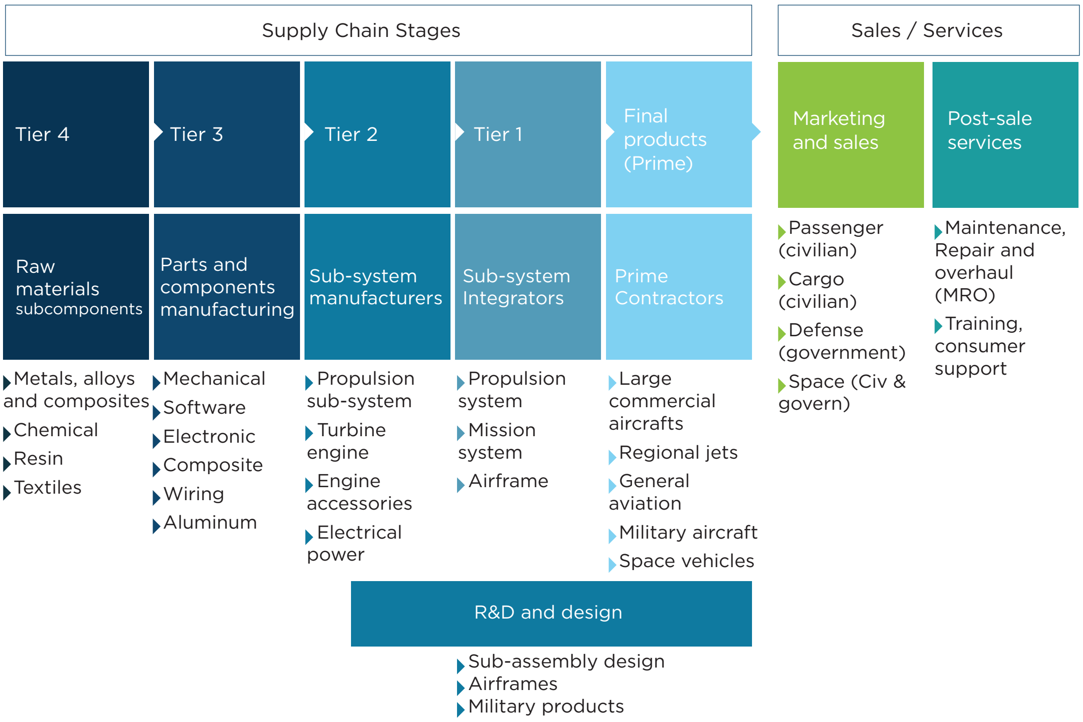
Source: (BOEING, 2024)

2.
AEROSPACE GLOBAL VALUE CHAIN (GVC): MAIN STAGES OF GOODS AND SERVICES

The global value chain (GVC) approach analyzes the structure of an industry's value chain from a global perspective to generate industry-specific insights (Frederick, 2019). A value chain encompasses the full range of activities required to bring a product to completion, including design, production, marketing, distribution, customer support, and after-sales services. When these activities are carried out by different firms located in different countries, the value chain is examined within a global contexto – thus forming the concept of the GVC (Gereffi et al., 2005; Humphrey & Schmitz, 2002).

The aerospace industry is a prime example where the GVC approach is particularly relevant, given the high degree of fragmentation in both goods production and service provision. To define the stages of production in the aerospace industry, a tiered supply chain structure is commonly employed (Bamber et al., 2013, 2016; Caliari et al., 2021; Niosi & Zhegu, 2005, 2010; Sturgeon et al., 2013). The figure below illustrates the tiered structure of the aeronautics value chain, broken down into seven stages, covering supply chain (manufacturing), sales, and post-sale services.

Figure 4.
Value chain stages: Aerospace industry.



Source: Prepared by the authors based on Bamber et al. (2016) and Sturgeon et al. (2013).

- **Tier 4. Raw materials and subcomponents:** This upstream stage mainly involves raw materials and components that can have multiple purposes or feed into other value chains. The tier 4 suppliers provide relatively low value-added commodity parts including metals, alloys, chemicals, resins, and textile subparts, but they are also responsible for the production of higher value-added parts such as composites[6] The goods produced by tier 4 firms are usually used in the next two value chain stages (tier 3 and tier 2).

- **Tier 3. Parts and components manufacturing:** In tier 3, suppliers manufacture the specific and generic components required for aircraft sub-systems. Tier 3 components include high strength fasteners and pins, instrumentation fittings and tubing, hydraulic fittings, and hoses (Hamilton, 2021). In some cases, tier 3 suppliers also produce components for other industries, such as the automotive industry. Additionally, the scale required to be competitive gives rise to specialized distributors with global distribution networks that serve the downstream stages of the chain (tiers 2 and 1, final products and MRO) (Bamber *et al.*, 2016).

- **Tier 2. Subsystem manufacturers:** Tier 2 companies are primarily responsible for producing subsystems that are then used in the next production chain stage (tier 1). Tier 2 companies supply key parts like flight controllers (computer systems, avionic devices), airframe sections (wing flaps, gear boxes, missile nose cones, fuselage structures, transmissions, airfoils, and tires), and turbines (Bamber *et al.*, 2013; Hamilton, 2021).

6. Composites are comprised of two or more separated materials that, when combined, lead to improve properties over the individual components. Composites are used for a wide range of final products in the aerospace industry (fuselage, wing flaps, rudder, elevators, radome, spuliers, floor beams and panels, helicopter main and tail rotor blades, space vehicles, missiles and rockets, etc.) (SMITH, 2013).

They manage a significant degree of technological complexity, and their technological capacity is often comparable to that of a tier 1 company, but they usually operate on a smaller scale and with narrower profit margins than their customers.

- **Tier 1. Subsystem integrators:** Tier 1 companies are the integrators of the subsystems produced by the tier 2 companies. They are the end suppliers of the propulsion systems (engines), control systems (avionics), wings, landing gear, fuselages, and electronic warfare systems. Tier 1 companies have advanced technological capabilities and are key players in the supply chain. Their products are, as a rule, subject to strict regulations and standardization, and they therefore have a close symbiotic relationship with prime contractors. Their products are also likely to be highly specialized and/or customized.

- **Final products (prime contractors):** Also known as original equipment manufacturers (OEM), these companies are responsible for fully integrating the systems needed for the final product to function. The final products in the aerospace industry include large commercial aircraft (LCA), regional jets, general aviation aircraft (e.g., business jets, turboprops and rotorcraft), military aircraft, and space vehicles. Due to high fixed and R&D costs, product life cycle is usually long and the market is concentrated around a few firms, oligopolistic in their submarkets.

- **R&D and design:** This is one of the main value chain stages because of the competitive characteristics of the industry—that is, increasing R&D costs, design complexity, long product life cycle, and strict regulatory standards (Niosi & Zhegu, 2010). Product research and development and product design is primarily carried out by prime contractors, but in recent years, new forms of organization have led to increasing cooperation between prime contractors and their suppliers from tiers upstream in the value chain (tier 1 and tier 2) in the form of so-called risk-sharing partnerships (Wagner & Baur, 2015). A more detailed description of this kind of partnership will be presented in Section 3 of this report. Lastly, there are a number of companies that specialize in providing design and engineering services to clients at different stages of the chain (tier 2 up to Prime Contractors) and in different countries.

- **Marketing and sales:** The marketing and sales stage can involve multiple arrangements, but it is primarily the domain of the prime contractors. Large commercial aircraft are purchased both directly from manufacturers by airlines and by aircraft operating lessors (AOL), which then lease aircraft to commercial airlines. Several AOL are big companies that offer services ranging from short- to long-term leases. An important benefit of leasing is flexibility in fleet deployment: the airline does not have to wait the long period between ordering the aircraft and its delivery by the prime contractor[7]. Clients ordering cargo aircraft can include everything from businesses and medical rescue operations to individuals and postal service firms. Also, governments can be important client in different markets, as in the cases of state-owned airlines, defense procurement (Dunne, 1995), and space vehicles. In this latter case, the recent market reconfiguration also highlights the importance of business-to-business (B2B) relationships (Robinson & Mazzucato, 2019).

- **Post-sales services:** post-sales services include the entire range of services required for the operation (parts replacement, maintenance, repair and overhaul (MRO), and training and customer support). These are complex processes with high

7. Available in: https://www.statista.com/statistics/674016/aviation-industry-aircraft-operating-lessors-fleet-size/. Accessed on 16/04/2025.

costs requiring a wide distribution network that can provide replacements with quick turnaround. As indicated by Bamber *et al*. (2016), the profit margins for these services can be quite high, and they account for a significant portion of manufacturing companies' profitability. With the increase in sector-specific competitiveness, companies' post-sales services (OEMs and tier 1 companies) have evolved to establish relationships with regional/national service providers. These days, OEMs, tier 1 suppliers, airlines, third-party airline suppliers, and independent suppliers all compete, and while OEMs have dominated a significant portion of the market, the market for independent suppliers is expected to account for about 60% of the entire market by 2027.

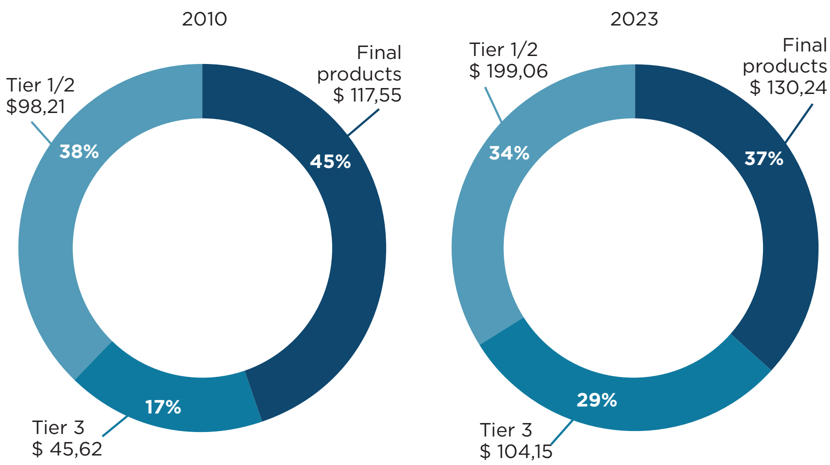
INTERNATIONAL TRADE DATA BY TIER

To better assess competitiveness across regions and product categories, we analyze exports based on their position within the value chain. The upstream segment (Tier 4), which primarily comprises raw materials and multi-purpose components serving various industries, poses challenges for aerospace-specific measurement. Consequently, this tier has been excluded from our analysis.

As we move toward higher tiers in the value chain, products become increasingly technology-intensive and industry-specific, requiring greater innovation capacity and stronger integration with OEMs. Due to the overlapping classification of products under HS codes for Tiers 1 and 2, these tiers have been consolidated into a single category for analytical purposes.

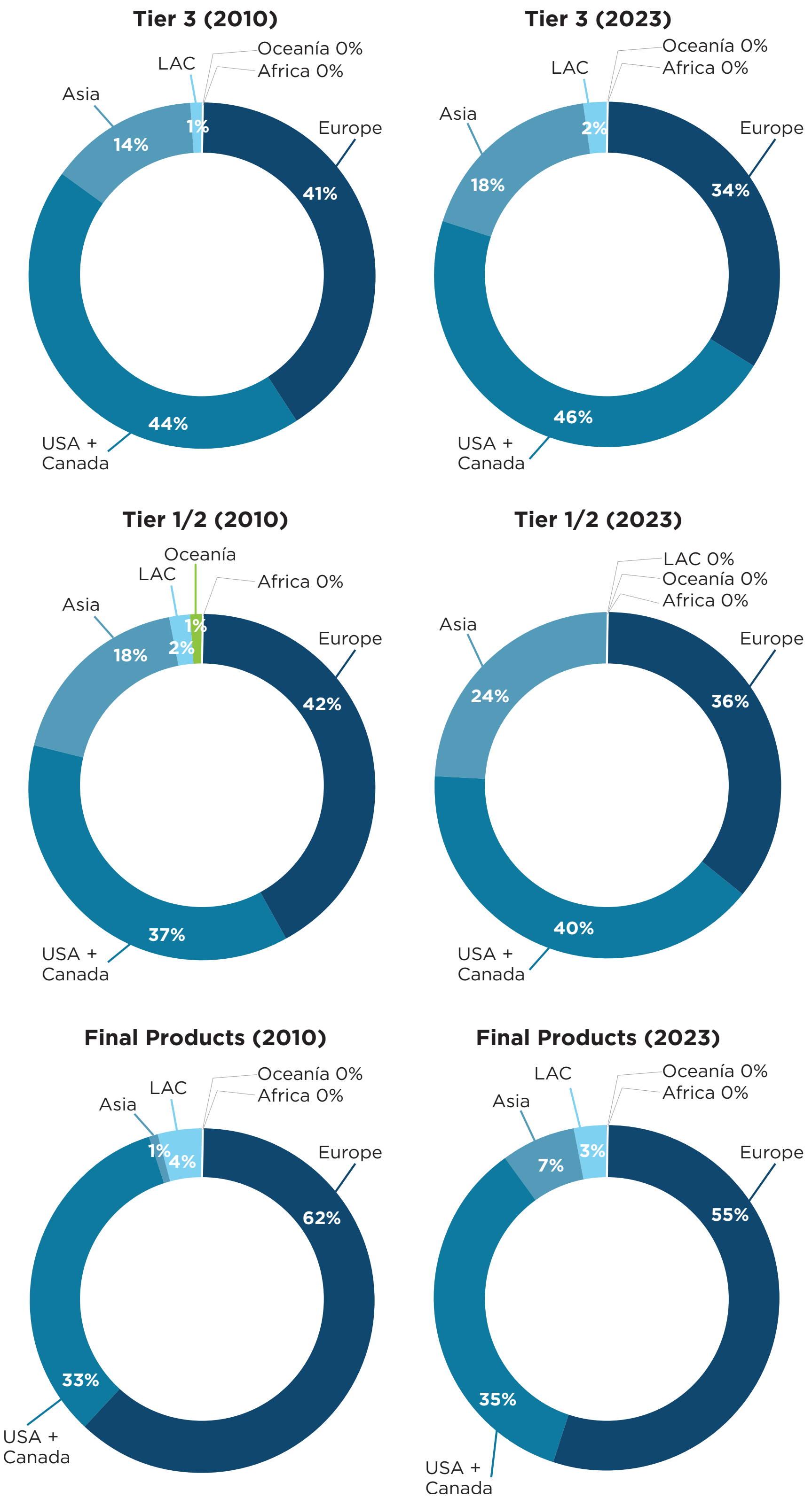
The first observation from tier-specific export trends is the increase in Tier 3's share of exports between 2010 and 2023, accompanied by a rise in export values for both final products and the combined Tier 1/2 category. Alongside Figure 6, which breaks down tier participation by region, we note that this trend is driven by Asia's growing share of the subparts market, while the United States maintains a strong market presence. Export growth from Singapore, Hong Kong, and India in these tiers is particularly noteworthy (Table 7).

Figure 5.
International trade data (exports), by tier.



Source: UN Comtrade. HS02 6D codes. Reporters' exports to the world. Retrieved 24/03/2025. US exports are retrieved using an inverse process: imports reported by the world from the US (necessary because the US reports under HS880000 for 2009 onwards).

Figure 6.
International trade data (exports), by tier and continent.



Source: UN Comtrade.

Regarding regions, the dominance of exports from Europe and USA + Canada is clearly associated with the final products – that is, the prime contractors –, but these regions also hold a considerable share of the subparts market—in both tier 1/2 and tier 3 – accounting for 76% and 80% of total trade, respectively. Although Europe have been losing relative share in the subparts market, the increase in production between 2010 and 2023 was considerable, signaling the importance of domestic production at all stages of the production chain.

In Latin America, the two dominant economies exhibit markedly different specializations across value-chain tiers. Brazil's export portfolio is weighted toward final products – largely driven by Embraer – whereas Mexico's exports are concentrated in tier-3 and tier-1/2 manufacturing, which together accounted for 85.3 % and 14.7 % of its export basket in 2023, respectively. In that same year, Mexico ranked twenty-second in the global export ranking.

Table 7.
Export statistics, by countries and products (top 20, USD billions).

	2010				2023			
#	COUNTRY	T3	T1/2	FP	COUNTRY	T3	T1/2	FP
1	USA	18.90	31.34	31.72	USA	45.68	42.33	38.29
2	France	4.06	10.01	40.82	France	8.31	10.89	30.04
3	Germany	1.91	11.59	23.51	United Kingdom	13.76	21.49	2.08
4	United Kingdom	7.11	6.88	0.01	Germany	2.22	2.64	26.50
5	Canada	1.30	4.70	6.74	Singapore	7.85	7.95	0.22
6	Singapore	1.37	4.99	0.28	Canada	2.49	4.88	7.61
7	Italy	0.95	2.75	2.26	Hong Kong	2.71	9.60	0.01
8	Brazil	0.04	0.67	4.00	Ireland	0.57	0.95	4.75
9	Japan	1.67	2.61	0.04	China	2.39	0.36	2.92
10	Spain	0.36	2.65	1.26	Spain	0.89	1.95	2.52
11	Netherlands	1.55	1.39	0.11	Poland	2.68	1.69	0.79
12	Hong Kong	1.32	1.25	0.01	Netherlands	2.24	1.53	0.84
13	China	0.71	1.31	0.29	India	0.28	3.68	0.50
14	Ireland	0.22	0.74	1.00	United Arab Emirates	0.18	2.32	1.42
15	Israel	0.12	1.51	0.19	Brazil	0.50	0.08	2.99
16	Belgium	0.55	0.80	0.40	Japan	3.04	0.01	0.03
17	India	0.03	1.59	0.04	Thailand	0.47	1.22	1.09
18	Rep. of Korea	0.11	1.39	0.11	Rep. of Korea	0.46	0.64	1.09
19	Switzerland	0.10	0.74	0.62	Italy	1.55	0.14	0.35
20	Thailand	0.16	1.21	0.05	Israel	0.23	0.43	1.36
	Total	**42.53**	**90.10**	**113.48**		**98.51**	**114.77**	**125.40**

Source: UN Comtrade. HS02 6D codes. Reporters' exports to the world. Retrieved 24/03/2025. Note: UAE: United Arab Emirates; T3: Tier 3; T1/2: Tier 1 and Tier 2; FP: Final products. US exports are retrieved by an inverse process: imports reported by the world from the US (necessary because the US reports under HS880000 for 2009 onwards).

COMPETITIVENESS FACTORS

The industry is reasonably stable at the regional level, especially the key countries for each stage of production. However, value chain movements may result from a number of factors.

Low-cost production

The ability to connect value chains to countries with lower production costs has generated reasonable reorganizations around new productive clusters (Michaels, 2018; Niosi & Zhegu, 2010). These movements are more significant at value chain stages where labor costs tend to be significant and where technological complexity is less important. The upstream value chain stages related to standardized subparts or predefined production packages (easier to control through governance and foreign direct investment) are more associated with this productive reordering.

Downstream companies (tiers 1 and 2 companies) also tend to seek competitive advantages by exploring low labor cost in developing countries. However, the main strategy is to maintain insourced production through the companies' own production facilities (foreign direct investment) in order to control technical requirements. There is also a preference to produce less technologically-intense products in these facilities (Field Research, 2021).

Science & Technology (S&T) capabilities

Scientific and technological capabilities are important for directing productive and R&D activities, especially given the sector's unique characteristics. This factor usually acts as a centrifugal force in the industry and is central to understanding how a small number of companies and countries continue to be competitive and maintain stable governance.

In reality, two factors operate in tandem to maintain a certain degree of productive stability: first, the path dependence of technological development (Hayward, 1994); and second, the importance of a system of innovation having a cumulative effect in terms of maintaining the companies' capabilities and producing the support structures needed to carry out the scientific and technological activities. In this sense, while the relationship between a country's competitiveness and innovation system is largely product specific, innovation capabilities tend to be more relevant when moving up the value chain from basic components to the final products embodying different technologies. In other words, the country competitiveness at the stages of the supply chain where high value-added products are manufactured tend to be tied more closely to the strength of the innovation system. Caliari *et al.* (2021) show that countries' technological capabilities are directly correlated to final producer and tier 1/2 output, but inversely to tier 3 production.

Such stability does not mean, however, that a country's sector will not be able to catch up. Cases such as Singapore, Hong Kong, and others offer weighty examples of how the existence of an extensive innovation system can promote the industry's development. These countries have increased their participation in the subpart production value chain (tiers 1, 2 and 3, with emphasis on the first two) considerably, led by both OEM facilities and local firms. They offer examples of why establishing national capacity can provide better results when it comes to adding value. As indicated by an expert during an interview: "the big OEM are putting investment in expensive economies that they weren't in the past, they were not chasing labor arbitrage as they were before" (Field Research, 2021).

Political and economic power

Much of countries' capabilities in the aerospace industry are in some way related to government participation, since aerospace industry's productive and technological capacity is seen as important for economic and political influence (Dunne, 1995). This is because of both the technology itself (which enables significant gains in productivity and social well-being) and the close relationship to military productive and technological capacity, given the need to keep the technologies required for national sovereignty under direct control (Ikegami, 2013).

This relationship is stronger with companies in higher value-added stages, which are also typically the companies with the greatest governance capacity in the chain (downstream stages) (Paarlberg, 2004). Most recently, and following the COVID-19 pandemic and increasing economic conflict between the east (China) and the west (mainly the US), the strategy has also been oriented towards guaranteeing the supply of important raw materials for producing sensitive goods (The White House, 2021) as well as strengthening multinational alliances to increase political dominance in strategic regions (ALTAMAR, 2021; Isidore, 2021; Macias, 2021). Additionally, foreign trade restrictions and countertrade strategies (generally called offset agreements)[8] are used for political domination or economic restriction (Waldr, 2021) (the former) or to play technological catch-up (Martin, 2014; WTO, 2018) (the latter).

Logistics

Even in the face of cost pressures and demand issues, logistics remains important for competitive differentiation. This is clear in the evolution of two large productive clusters that took advantage of the geographic proximity to large producing countries: Mexico and Morocco. According to an expert interviewed for this report, "While the US companies need to create a complex logistical strategy to bring subparts from Asia, Mexican production only needs to cross the US border by truck" (Field Research, 2021). This statement illustrates the importance of establishing a production cluster in Morocco, a few kilometers away from Airbus's largest production centers in Europe (Michaels, 2018).

Demand for subparts can also be an impediment to relocating value chain activities. The case of Brazil is a good example. Even though it has one of the main prime contractors, it does not have significant structures for producing subparts for the final product. Interviews also highlight that "there is no strong economic justification for there to be a migration of suppliers to Brazilian territory, even if the São José dos Campos cluster has relevant engineering capabilities" (Field Research, 2021).

Logistics is also an important factor in providing after-sales services. Due to global demand and the need for constant contact between suppliers and the final products' buyers, it is usually necessary to establish offices in a large number of countries to facilitate logistical processes worldwide. As will be discussed later in this report (logistics analysis stage), this has created close relationships between companies and large specialized global operators.

8. Offset agreements are associated with international government acquisitions and include a wide range of countervailing industrial, commercial, and technological measures. These agreements are expected to encourage local development through benefits arising from compensation practices such as co-production, licensed production, subcontractor production, overseas investment, technology transfer, and countertrade activities (Martin, 2014; Ribeiro & Inácio Júnior, 2019; WTO, 2018).

Location (close to Prime Contractor)

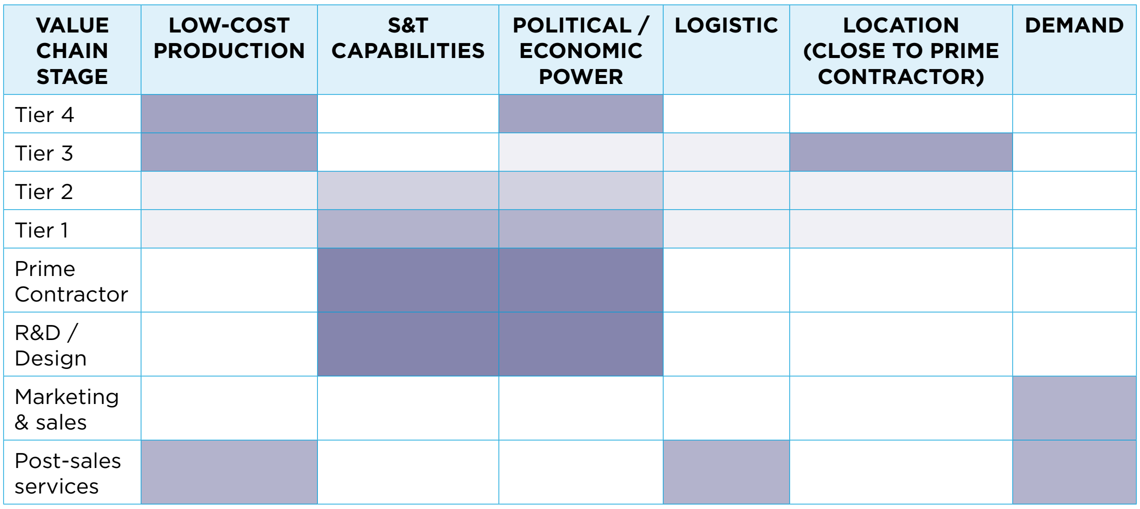
Proximity of certain subparts types to system integrators (prime contractors or tier 1 companies) seems to be a factor for competitiveness when strict production process control is needed, which usually the case in very asymmetric governance relationships. Certain processes must be controlled to ensure sustainability in tight supply chains. For an example, the interviews indicated that some subparts made directly from raw materials are produced close to the final facility because of the need to control and reduce costs and materials loss – for instance, it can take up to 5kg of aluminum, to produce 1kg of certain subparts (field research, 2021).

Demand

Demand may be an important factor for the location of production structures, one example of this being the productive reorganization seen in recent years with the increase in Asian demand. The economic growth of China (the major costumer for passenger airplanes in recent years) is related to the national strategy to increase its world political influence, and the presence of downstream companies in the region is intended to reduce competitive pressure from new players (Commercial Aircraft Corporation of China – COMAC,[9] mainly). Being close to demand also entails a need to locate the final stages of the chain, those related to the sales and post-sales services.

To summarize the main forces discussed above, Chart 1 presents the stages of the value chain alongside their corresponding competitiveness factors. Darker cells indicate a higher relevance of each factor for the respective stage of the value chain.

Chart 1.
Competitiveness factors by value chain stages.



Source: Prepared by the authors. Note: Darker shading indicates higher relative importance of each factor for the respective stage of the value chain.

9. http://english.comac.cc/. Accessed on 10/22/2021.

3. VALUE CHAIN: MAIN COMPANIES AND COUNTRIES BY VALUE CHAIN STAGES

Mapping the main companies and countries at each value chain stage was done by searching through sector-specific publications, academic papers, and interviews with experts, later combined with data from the Orbis database.[10] To provide a broad overview of the leading companies and select other potentially relevant companies, a methodology was established with the following steps:

1. Economic activities (NACE classification) associated with the aerospace industry products HS code (COMTRADE HS code) were collected, along with the economic activities of the largest companies in the aerospace industry in 2021;[11]

2. Within these categories, keywords from the product or service description were used to select the companies likely to be operating in the aerospace industry (given that the classifications are very broad).[12]

This selection process enabled us to identify 915 companies operating between 2017 and 2021, with a combined revenue of approximately $1.8 trillion and around 4.6 million employees. Although all are active in the aerospace industry, many of these firms also produce goods for other industrial sectors, making it difficult to precisely measure their participation on the aerospace industry. Therefore, the list was refined based on the following criteria: (i) major companies already covered in the referenced publications or

10. The Orbis platform was accessed in conjunction with the Science and Technology Group at the Universidade Federal de Minas Gerais. Unfortunately, the platform data was accessible only through 2021.
11. The list of the largest companies in the aerospace industry was based on market sources, specifically the following: Value Today (https://bit.ly/3ivbl4D); Aviation Outlook (https://bit.ly/3BduC7H); Sales Artillery (https://bit.ly/2YrNxgH); Statista (https://bit.ly/3lbPd6T). Links accessed from 05/03/2025 to 16/04/2025.
12. The following keywords were used: aerospace, aeronautical, aeronautic, aircraft, spacecraft, spaceship, satellites, helicopter(s), rotorcraft, air traffic management, radar, business jet, wings.

cited by experts during interviews; (ii) other firms potentially involved in the industry; and (iii) companies selected for their role in different stages of the value chain.

Following this filtering, the list of the main companies presented in Table below was generated and then sorted according to value chain stage. To do this, three specific issues must be highlighted.

First, companies from upstream value chain stages (tier 4) are not included for the same reason expressed in the previous section (product scope). The value chain governance (governed by Prime Contractors) means that excluding tier 4 companies does not present any significant challenges in terms of outcomes. Second, as highlighted in Table, there is no information in the Orbis platform on some relevant tier 2 companies. This is possibly due to the characteristics of the platform itself, as it tends to be biased towards large companies with open capital structure.

Finally, we have also included an extra category (at the bottom of the table) for value chain stages with business groups linked specifically to the defense[13] or space sector. This is because these companies are, for various reasons (sovereignty, technological control, absence of market), structured specifically to verticalize production, from subparts to the final product, and can therefore not be included in a value chain stage classification.

Table 8.
Main companies by value chain stages (USD values in millions).

VALUE CHAIN STAGE	COMPANY	COUNTRY	LAST AVAILABLE YEAR	OPERATING TURNOVER	EMPLOYEES
Final Products	Airbus Se	Netherlands	2020	61408.9	131,349
	Boeing Company (The)	USA	2020	58656.0	141,000
	Bombardier Inc	Canada	2020	15462.0	16,000
	Avic Airborne System Co., Ltd.	China	2019	13496.0	
	Textron Inc	USA	2020	11651.0	33,000
	Saab Ab	Sweden	2020	4348.4	18,073
	Embraer S.A.	Brazil	2020	3831.4	15,658
	Hindustan Aeronautics Limited	India	2019	2819.1	27,384
	Korea Aerospace Industries Co.,Ltd.	South Korea	2020	2596.6	
	Joint Stock Company Aviation Holding Company Sukhoi	Russia	2020	1897.2	19,925
	Joint Stock Company Russian Aircraft Corporation Mig	Russia	2018	1289.2	24,663

13. In this case, an additional analysis was considered observing the SIPRI Arms Industry Database (https://bit.ly/3aWNyfg).

Tier 1	Honeywell International Inc	USA	2020	32637.0	103,000
	Safran	France	2020	21634.9	78,892
	Thales	France	2020	20908.5	80,702
	Rolls-Royce Holdings Plc	UK	2020	15867.8	48,200
	Parker Hannifin Corp	USA	2021	14347.6	54,640
	Aero Engine Corporation	China	2019	7044.0	
	Zodiac Aerospace	France	2017	6093.4	32,568
	MTU Aero Engines Ag	Germany	2020	4940.3	10,313
	Aecc Aviation Power Co.,Ltd.	China	2020	4402.1	34,977
	Spirit Aerosystems Holdings, Inc.	USA	2020	3404.8	14,500
	Stelia Aerospace	France	2019	2630.6	4,319
	Triumph Group Inc	USA	2020	1869.7	1,247
	Premium Aerotec Gmbh	Germany	2020	1789.9	7,920
	Shaanxi Aircraft Industry (Group) Co., Ltd.	China	2018	1664.1	5,100
	Joint-Stock Company United Engine Corporation	Russia	2020	1480.4	14,069
	Publichnoe Aktsionernoe Obshestvo Odk Ufimskoe Motorostoritelnoe Proizvodstvennoe Obedinenie	Russia	2020	1348.2	
	Fokker Technologies Group B.V.	Netherlands	2019	1198.1	5,355
	Ultra Electronics Holdings Plc	UK	2020	1153.8	4,253
	Daher Aerospace	France	2019	1150.0	5,403
	Fesher Aviation Component (Zhenjiang) Company Limited	China	2020	1052.8	180
	Gkn Aerospace Services Limited	UK	2019	1039.9	3,717
	Jamco Corporation	Japan	2020	452.1	2,649
	Societe Nationale De Construction Aerospatiale	Belgium	2020	248.6	1,479
	Avcorp Industries Inc.	Canada	2020	126.6	

Tier 2	Atlas Air Worldwide Holdings, Inc.	USA	2020	3211.1	4,061
	Kaman Corp	USA	2020	784.5	3,193
	Facc Ag	Austria	2020	658.6	2,655
	Applied Research Associates Inc	USA	2020	658	1,200
	Aernnova Aerospace SA	Spain	2020	306.7	
	Meggitt (Uk) Limited	UK	2019	208.7	741
	AASC	USA			
	Aerosud	South Africa			
	Aim Aerospace	USA			
	Airborne	Netherlands			
	Ascent Aerospace	USA			
	Avantus Aerospace	USA			
	Comtek	Canada			
	Cotesa	Germany			
	DTC	Netherlands			
	Duqueine	France			
	Epsilon Composite	France			
	Gt Greene Tweed	USA			
	Hydrojet	USA			
	Sekisui	USA			
	Shimtech Composites	USA			
	Sigma	USA			
	Sogeclair	France			
	Stark	USA			
	Unitech Aerospace	USA			
	Victrex	UK			
Defense/ Aerospace	Lockheed Martin Corp	USA	2020	65398.0	114,000
	Raytheon Technologies Corporation	USA	2020	56587.0	181,000
	General Dynamics Corp	USA	2020	37925.0	100,700
	China Aerospace Science And Industry Corporation Limited	China	2019	37075.2	320
	Northrop Grumman Corporation	USA	2020	36799.0	97,000
	Bae Systems Plc	UK	2020	26161.9	81,000
	Leonardo S.P.A.	Italy	2020	17060.3	49,882
	L3 Technologies Inc	USA	2018	10244.0	31,000
	Almaz-Antey	Russia	2019	9657.0	
	Huntington Ingalls Industries	USA	2019	8899.0	
	Dassault Aviation	France	2020	6828.5	12,441
	EDGE	United Arab Emirates	2019	5000.0	
	Israel Aerospace Industries Limited	Israel	2019	4111.0	14,922
	Rafael Advanced Defense Systems	Israel	2016	2164.8	
	Bharat Electronics Limited	India	2019	1692.9	9,279
	Elta Systems Ltd	Israel	2016	1002.6	

Source: Prepared by the authors.

The table supports the export data presented in the previous section, underscoring the prominence of USA and European companies. Additionally, firms from other countries or regions appear as relevant players in specific market niches. In the final product stages, the major civil aviation manufacturers – Boeing, Airbus, Embraer, and Bombardier – stand out. However, it is important to note that these firms, like other final product manufacturers, operate across various niches, serving the business aviation sector, the military, the space industry, and other production segments.

The list of Tier 1 companies also reinforces the centrality of the USA-Europe dyad, with some participation from Chinese firms (Aero Engine Corporation, AECC Aviation Power, Shaanxi Aircraft Industry, and Fesher Aviation Component) and Russian firms (Joint-Stock Company United Engine Corporation and Public Joint-Stock Company UEC-Ufa Engine Industrial Association). Tier 2 companies follow a similar pattern, with minimal deviation – perhaps only the notable presence of Eurosud in South Africa outside the main dyad.

Among companies focused specifically on defense and aerospace, some notable players outside the dominant axis include firms from China, India, and Israel. The presence of leading nations throughout all value chain stages highlights the importance of governance in both economic and military domains. Strategic relationships between producers and national governments are crucial. In essence, the production capabilities of USA and European firms reflect the broader economic and military strength of these nations – an observation that also applies to China and Russia. Europe, in particular, stands out for its strategies to distribute production among countries via consortium arrangements.

Similarly, emerging countries and/or nations facing regional political instability tend to adopt strategies aimed at controlling sensitive stages of value chain governance (Paarlberg, 2004; Squeff, 2016), particularly through the creation of final product firms or those focused on military and aerospace production. Table 10, which organizes companies by country of origin, reinforces this analysis.

Table 9.
Main countries by value chain stages: operating turnover (USB billions).

COUNTRY	PRIME CONTRACTOR	TIER 1	TIER 2/3	DEFENSE AEROSPACE	TOTAL
USA	70.31	52.26	4.65	215.85	343.07
China	13.50	14.16		37.08	64.73
Netherlands	61.41	1.20			62.61
France		52.42		6.83	59.25
United Kingdom		18.06	0.21	26.16	44.43
Italy				17.06	17.06
Russia	3.19	2.83		9.66	15.67
Canada	15.46	0.13			15.59
Israel				7.28	7.28
Germany		6.73			6.73

United Arab Emirates				5.00	5.00
India	2.82			1.69	4.51
Sweden	4.35				4.35
Brazil	3.83				3.83
South Korea	2.60				2.60
Austria			0.66		0.66
Japan		0.45			0.45
Spain			0.31		0.31
Belgium		0.25			0.25

Source: Prepared by the authors.

CONTRACTUAL ARRANGEMENTS AMONG THE MAIN ACTORS

The technological and manufacturing complexity, inherent to the production of final products and their subparts, and the scope of the value chain are crucial for forming different types of contractual relationships between buyers and suppliers. These relationships depend on the complexity of the transactions, supplier capabilities, and company and country interests. The following is an overview of some of the most important contractual arrangements.

Risk-sharing partnerships (RSP)

Regular surveys conducted by consulting firm Ernst & Young using companies' annual reports have highlighted the challenges faced by the sector's main players. The most important risks involve financial, compliance, strategic, and operational issues (Ernst Young, 2020), which are associated with industry dynamics as well as global economic and political volatility. This instability, plus the rise in product development costs, has led the industry to change the types of relationships between the main players.

Whereas prime contractors used to typically internalize the entire R&D and design process, providing product specifications to suppliers, in the recent decades, these companies focused son their core competence and delegated greater responsibilities to large suppliers in the form of large work packages, establishing what is conventionally called risk-sharing partnerships (RSPs). This contractual arrangement involves division of labor and risk, as well as revenue sharing. It is common between Prime Contractors and tier 1 companies, but there also are cases of this type of relationship between tier 1 and tier 2 companies, depending on the technological capabilities of the tier 2 firms (Wagner & Baur, 2015).

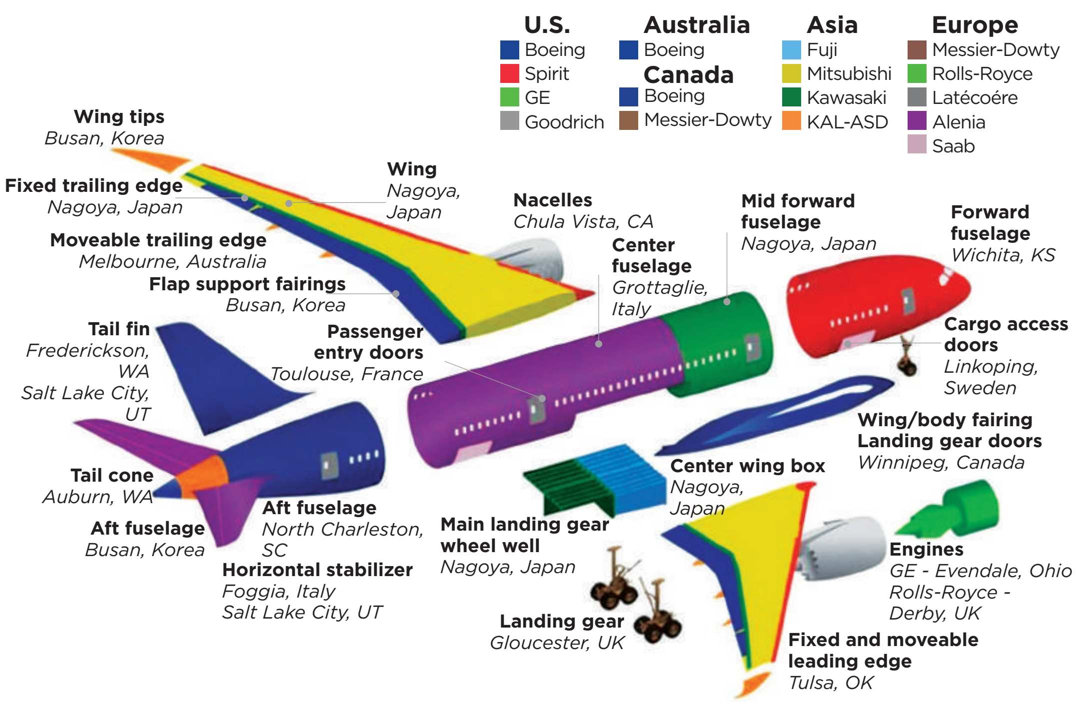
In such arrangements, the tier 1 companies are also responsible for managing their chains, increasing R&D capabilities and delegating other responsibilities to upstream companies, even though in these cases, technological and design complexity is lower, often because of the supplier's control strategy and defined product specifications (Bamber *et al.*, 2013; Cooke & Ehret, 2009; Niosi & Zhegu, 2005).

Remarkable examples of risk partnerships are ones developed by Embraer in the

1990s for the ERJ-145 / ERJ-170 / ERJ-190 (Figueiredo *et al.*, 2008); Airbus for the A350 XWB (Evrard & Alonso, 2013); and Boeing for the 787 Dreamliner (Rosello & Steenhuis, 2018). In addition to the division of risk, labor, and revenue, an important productive and technological reconfiguration is the reduction in the number of qualified suppliers over time. For Embraer, for instance, the number of suppliers involved in the ERJ-170 and ERJ-190 was 40, compared to 400 involved in the ERJ-145 (Figueiredo *et al.*, 2008), and the number of risk-sharing partners was increased from 4 to 16 (Bamber *et al.*, 2013). For the A350 XWB program, about 75% of production was outsourced, higher than in previous programs, like the 40% for the A380 or the 10–20% for the A320 and A330. Also, and the number of direct suppliers was drastically reduced, from 300 for the A320–330 program to 58 for the A350 XWB (Mocenco, 2021). Regarding the Boeing 787, only its final assembly is carried out at the company's facilities, in Everett, and practically all structural components and systems are manufactured by its risk-sharing partners, both domestic and foreign (Ferreira, 2009).

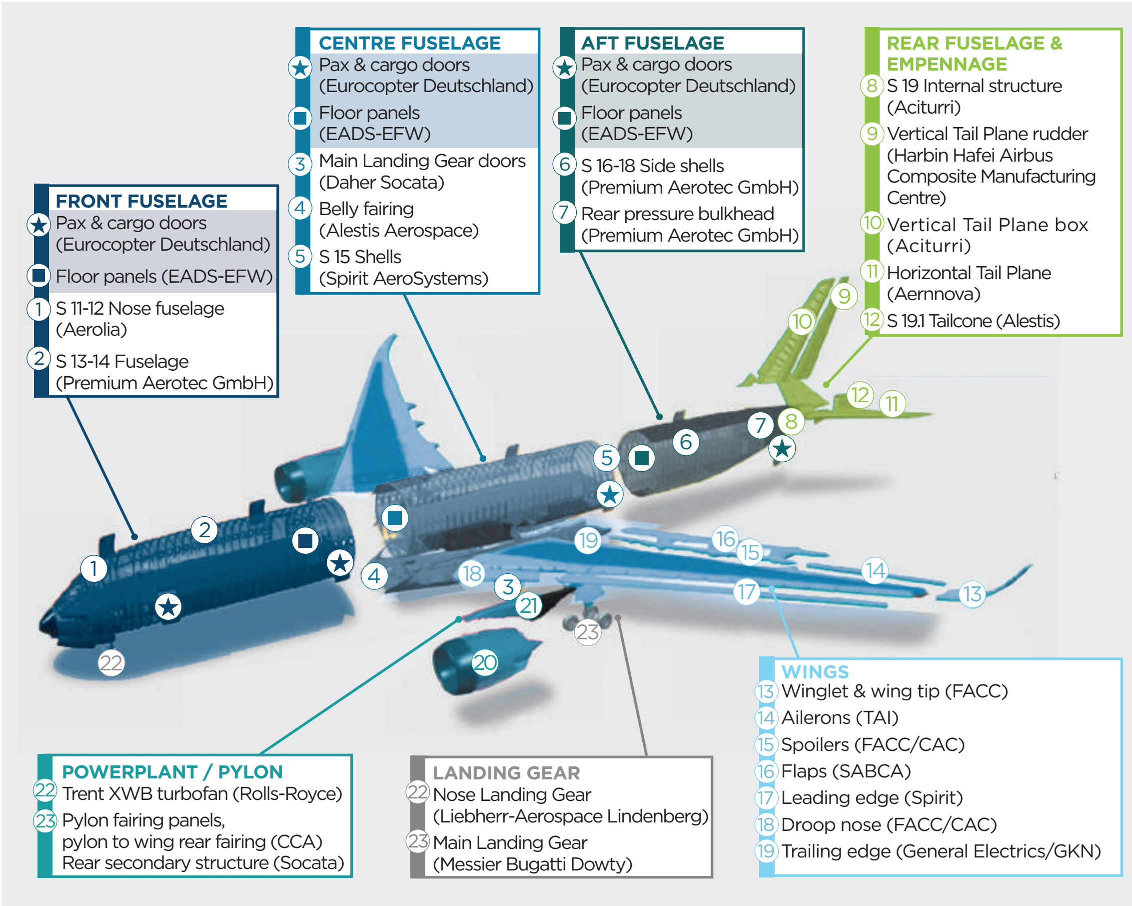
Figures 7 and 8, below, show the reduction in the number of subpart suppliers for the airplane programs. This is thanks to symmetrical relationship between suppliers and prime contractors: Larger and more technically advanced suppliers establish a different type of relationship, in which power, risk, and returns are better distributed compared to in previous models characterized by higher fragmentation. RSPs are also interesting because they increase the share of outsourcing. More outsourcing to fewer companies means that tier 1 and tier 2 companies are becoming bigger and increasingly take an active role in the GVC. This is evidenced by the increased share of tiers 1 and 2 in international trade, as discussed in the previous section.

Figure 7.
Main suppliers for the 787 Dreamliner.



Source: (Rosello & Steenhuis, 2018).

Figure 8.
Main suppliers for the Airbus A350XWB.



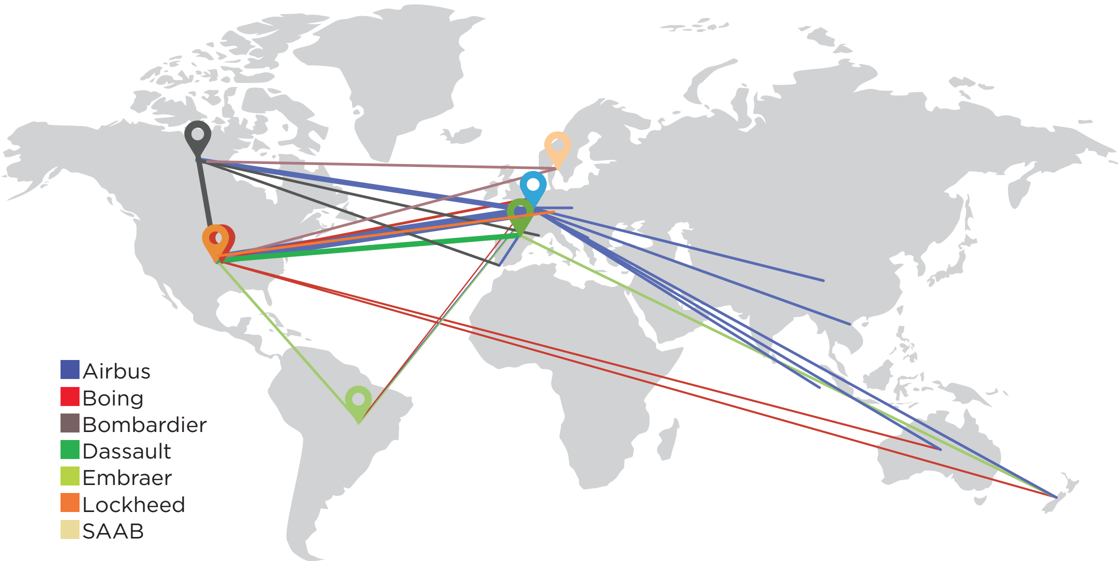
Source: (Evrard & Alonso, 2013).

Foreign Direct Investment (FDI)

FDI is a case of how different strategies can often be combined. When accessing emerging markets in search of lower production costs (frequently due to the host country's requirements), there is often a need to maintain technological appropriability, and political influence may also be an issue. The figures below show the ownership structure of relevant final product and defense/aerospace companies (Figure 9) and tier 1 companies (Figure 10).[14] In the former case, as they are few, the company classifies itself (the global ultimate owner – GUO). In the second case, the classification uses the company's country of origin, specifically because there is a large number of companies. Table 10 provides additional analysis of prime contractors and defense/aerospace companies, highlighting the main countries where the companies' subsidiaries are located in descending order (top 10 countries).

14. To limit the analysis to owned and majority-controlled companies in the aeronautical industry, only companies where the GUO holds more than 50% of the share capital and companies in the aeronautical industry (NACE 3030) were considered.

Figure 9.
Ownership structure: relevant companies (prime contractors and defense/aerospace).



Source: Prepared by the authors from Orbis database. Note: colored lines represent the ownership from a given company in each country. For example, Boeing (red, a US company) owns companies in Canada, New Zealand, Australia, and Europe.

Table 10.
Number of subsidiaries from relevant companies (prime contractors and defense/aerospace), by country.

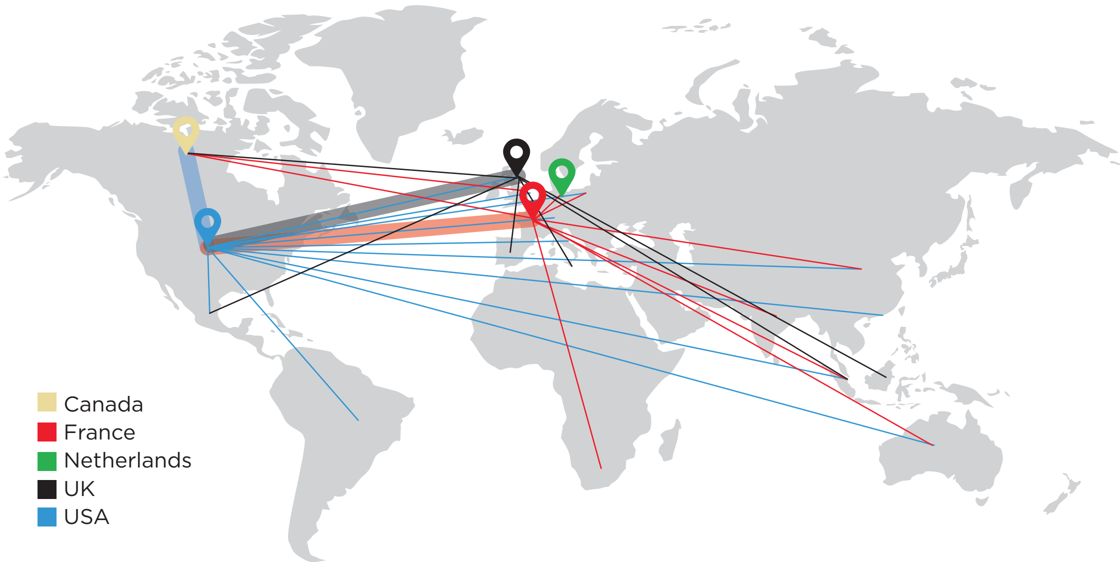
COUNTRIES	AIRBUS	BOEING	BOMBARDIER	SAAB	EMBRAER	LOCKHEED	DASSAULT	TOTAL
USA	176		66	5	27		35	309
Canada	14	33		2		12		61
Germany	10		1					11
France	11							11
Spain	8		1					9
New Zealand	2	2					2	6
Australia	2	3						5
United Kingdom	4							4
Poland	2					2		4
Portugal	1				3			4

Source: Prepared by the authors from Orbis database.

Most of the cross ownership is between the major world markets, and the companies' ownership structure is generally limited to few countries. The number of subsidiaries of foreign prime contractors located in the US (309) is remarkable and indication of the importance to these companies of both private and public US markets (especially the defense market). The symbiotic relationship between Europe and Airbus (companies in Germany, France, Spain, Poland, and Portugal) is also important, indicating the companies' concentric outsourcing movement (Evrard & Alonso, 2013).

Canada and Brazil have a secondary position, but follow the same pattern, with a significant number of subsidiaries in the US, the main market for their leading companies – Bombardier and Embraer, respectively. Lastly, the presence of subsidiaries in Oceania countries is also an interesting indicator of their political and economic influence in the region (Macias, 2021).

Figure 10.
Ownership structure: Tier 1's main companies.



Source: Prepared by the authors from Orbis database. Note: colored lines represent the ownership by companies from a given country of firms in other countries. For example, companies from France (red) own a great number of companies in the US, but also in Asia, South Africa, Australia, and others.

The main tier 1 companies are also observed to have greater cross-ownership between the major world markets. However, ownership control by firms in major countries of firms in countries of Latin America, Asia, and Oceania is also observed. While these statements can be drawn from the different data listed above, it is difficult to generalize for the entire range of countries. Regardless, the significance of low-cost countries/regions can be highlighted, with a special focus on Mexico and Asia (India and Indonesia), and the presence of Western companies in China may be more tailored to government requirements to operate in the domestic market (field research, 2021).

Joint Ventures, Mergers and Acquisitions

Joint ventures (JV) and mergers and acquisitions (M&A) are used to internalize or share knowledge and technology. Sector and technology profiles lead to the use of such strategies to explore related capabilities in order to increase the competitive capacity in specific markets, develop new technologies/products, and/or access new and often related markets (Florio *et al.*, 2017).

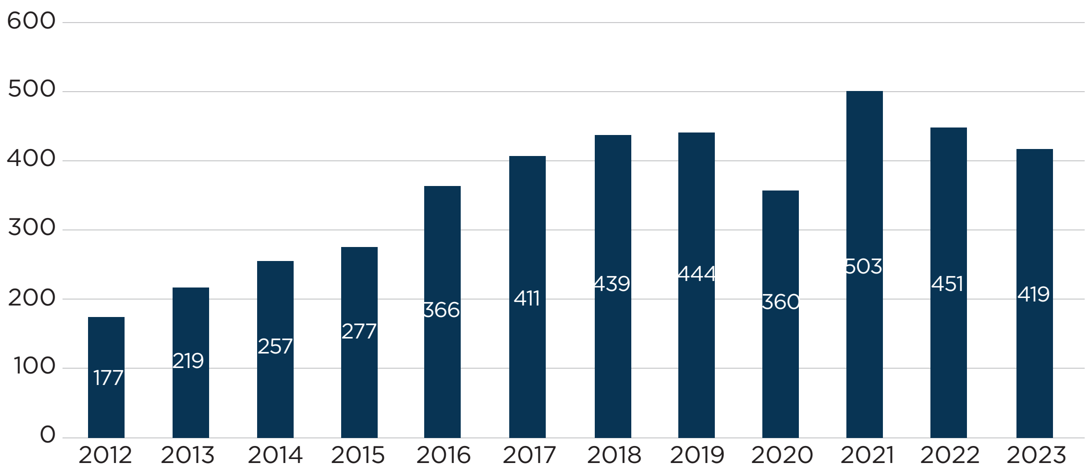
Florio *et al.* (2017) cite the prevalence of mature countries in JVs, notably Europe, US, Canada, Japan and Israel. Furthermore, the authors show that, during a recent period, a large confluence of JV investments was directed towards China, India, and the Middle East, encouraged by the search for new markets and the development of defense products. During this process, regulatory changes, access to technologies, the need for local partners, and an initial industrial base were important motivators.

JV relationship profiles also vary. Strategies such as CFM International (the JV between Boeing and Safran) represent a means of improving competitive capacity (Boeing, 2019). JVs between companies operating at different value chain stages may also provide an important opportunity for technological improvements. Such is the case with the JVs between Airbus and DB Schenker (DB Schenker, 2018) and the JV between Gulfstream and Israel Aerospace Industries, for example. In addition, the entry in related markets may be exemplified by the cases of Airbus-Leonardo (ATR in regional turboprop) and Leonardo-Thales JVs (Telespazio[15] and Thales Alenia Space[16]), and the increase in the product scope is a strategy pursued by the newly-formed Embraer-Fokker JV (Aviacionline, 2021).

Regarding M&A, the collapse of demand due to the COVID-19 pandemic also impacted the number of deals, which had been trending up since 2012. Despite this drop, data for the last quarter of 2020 already showed some action returning, driven mainly by M&A of companies with strong government ties (financial and political support). From 2021 onwards, the volume of transactions has already returned to pre-COVID levels. As observed by Alix Partners, there are two core drivers in defense activity: emerging defense technologies[17] and the divestiture of noncore businesses following recent large mergers (Alix Partners, 2021).

This conjunctural movement is also related to a structural shift in recent years from a pattern of mega acquisitions to strategic acquisitions in search of new technologies, products, and markets. In essence, such deals are likely to be focused on growth rather than economies of scale. Companies tend to use acquisitions to gain new capabilities, access emerging technologies, and expand geographically (Deloitte, 2017b). Supporting this analysis, KPMG (2021) notes three main trends that are becoming intertwined: geopolitics, the COVID-19 pandemic, and the digital transformation.

Figure 11.
Number of M&A transactions.



Source: (Alix Partners, 2021) until 2020, (Meridian Capital, 2024) from 2021.

15. https://www.telespazio.com/en/home. Accessed on 09/20/2021.
16. https://www.thalesgroup.com/en/global/activities/space. Accessed on 09/20/2021.
17. For example, Raytheon Technologies' acquisition of Blue Canyon, Lockheed Martin's purchase of Aerojet Rocketdyne.

Summary of contractual arrangements along the production chain

In addition to the significance of the contractual arrangements described above, the industry has several other types of relationships that are closely related to partnership complexity and the company capabilities. Table 11 shows some examples of contractual arrangements using governance types like those described by Gereffi *et al.* (2005).

Table 11.
Examples of arrangements between suppliers.

TIER	PART	SUPPLIERS	MAIN CONTRACT ARRANGEMENTS
1	Gear	Pratt & Whitney, GE Aviation, Rolls Royce	. Risk-sharing partnerships
1	Landing gear	Liebherr, Messier Buggaty, Eleb	. Risk-sharing partnerships
1	Avionics	Collins, Honeywell, Thales, L3Harris, Garmin, Elbit Systems	. Risk-sharing partnerships
1	Wings	Embraer Évora, Aernnova, Kawasaki, Spirit	. Modular / Relational . High cooperation. Ex.: training/qualification
1/2	Electrical components	Parker, Liebherr, Collins, Safran, Woodward, Moog, Bae Systems	. Relational
2	Seats	Safran Seats, Recaro, Geven, Haeco, Colins, Encore	. Modular (certification, norms)
3	Composite materials	Toray, Hexcel, Cytec	. Relational (confidence relationship)
3	Resins, metals	Aleris, Arconic, Constellium	. Market / Modular (certification, norms) . Production control: OEM providing raw materials, controlling specifications.

Source: Prepared by the authors.

The further upstream in the value chain, the less explicit coordination there is. Regardless, contractual coordination by market is particularly difficult due to product specifications and the need of adapting production to the restrict industry regulation. Because the final products have a long-life cycle and a high fixed cost of development, the subpart specifications from the R&D process usually create technological lock-ins that are often associated with the supplier's lock-in.[18] Thus, longstanding relationships and control of technical specifications by the prime contractors are frequent.

Even in subparts that allow for less explicit coordination and greater market governance, reduced risks and increased reliability is provided by third parties who provide qualified product lists[19] to guarantee information symmetry for products available on the market.

18. For example, if a certain number of composites is specified for some subparts of the fuselage in the product development process, this material cannot be modified after product certification. Even for further downstream stages such as avionics and engines, switching suppliers after final certification is complex and rarely done.
19. See, for example, IHS Markit (https://bit.ly/3muiicV).

4. LOGISTICS

The high complexity of systems, a central characteristic of the aerospace industry, is directly linked to the importance of the design stage in defining the fixed costs over a product's life cycle. By the end of the design and development phase, more than 70% of the lifecycle fixed costs have been incurred, a figure that increases to 95% with the completion of production of the first unit (Vaskic & Paetzold, 2019). Internationalizing subparts manufacturing, in turn, adds transportation costs and logistical complexities, especially when it involves heavy products (mainly structures) and/or high added value products (e.g., motors). Together, these two features – high specificity of assets and global trade dynamics – make logistics an important stage in manufacturing and after-sales services.

Coordination of the logistical process usually follows activity-based costing (ABC) system standards. (Kemsaram *et al.*, 2019; Pohlen & Londe, 1994). Essentially, a subpart's cost as a proportion of the final product cost will determine how it is transported and with what priority.[20]

In addition, centripetal and centrifugal forces act at the same time to define the location of the production plants, so it is not trivial to find a stylized logistic pattern in the value chain that is followed by the main companies in the industry. On the one hand, the growth of Asia's participation in international trade increases the need for better control over parts and systems supply logistics, especially in tier 1 and tier 2 (precisely the production stages where the region has increased its world trade share the most). On the other hand, new production and localization trends may cause the largest companies to adjust their strategies and provide a growth opportunity for companies with competitive potential.[21]

20. Higher value-added products (for example engines, nacelles, and avionics) represent a greater portion of the cost of the production process and fast transport of them is prioritized (usually by air). Lower value-added products (seats, cabling, plastic materials, some structures, among others) account for less of the final cost of the aircraft and can be transported with options that cost loss and take longer (usually by sea). This strategy responds to the need to maintain healthy cash flow (field research, 2021).

21. Prime contractors and tier 1 companies have increased production process control for less specialized suppliers (tiers 2/3/4) by establishing subcontract strategies and defining production parameters, often turning upstream companies into mere service providers. The aim of is to reduce production costs, especially in metallurgical processes where the cost of loss is usually high. The strategy is also associated with increasing geographical approximation of OEMs to their suppliers (field research, 2021).

Moreover, outsourcing to more advantageous regions is or will most likely be constrained. One relevant constraint is geopolitical. For example, due to the symbiotic relationship between Europe and Airbus, outsourcing is concentric. Despite the rise of transnational venture partners, the technology core of the industry remains in Europe (Evrard & Alonso, 2013). Additionally, newer production strategies in the US aim to change the value chain structure by onshoring (The White House, 2021), as well as by increasing production in neighboring countries by consolidating political and trade partnerships (ALTAMAR, 2021). However, demand may push things in the opposite direction: Parts of the chain can often be moved to other countries to supply specific products in different markets.[22]

Lastly, the need for efficient logistical support in the after-sales service market (where small production batch sizes and the high cost of spare parts become even more pressing issues), has also increased the need to work with reliable logistics, with global capillarity, and an adequate logistical control structure.[23]

TECHNOLOGIES AND PROCESSES TO IMPROVE LOGISTIC

Logistics Support Analysis (LSA)

To better adapt to logistics challenges, the Logistics Support Analysis (LSA) has become an important tool for producers. LSA was initially conceived as logistical support for the in-service phase of defense products by the US Department of Defense through MIL-STD-1388 (DoD-USA, 1983). LSA is a structural approach aimed at providing better maintenance efficiency and reducing the cost of providing support by pre-planning all aspects of Integrated Logistics Support (ILS).

The Aerospace and Defense Industries Association of Europe (ASD) developed LSA for civilian activities by establishing a workgroup with the American Aerospace Industries Association (AIA) to look at jointly developing international LSA standards. The final draft of S3000L (Issue 0.1) was released in 2009, and is today in Issue 2.0, having been updated several times over the years (ASD & AIA, 2021).

S3000L covers all processes and requirements governing the performance of LSA activities. As presented by ASD and AIA (2021, p.22), some examples of typical deliverables of an LSA process include: (i) a reliable and maintainable product – due to the influence on a design from a product support perspective –, (ii) a cost-efficient support system, (iii) product data on supportability, and (iv) support that incorporates identification and description of maintenance tasks (corrective and preventive) and operational support tasks.

K-PL concepts

When classifying logistics plan levels, the term party logistics (PL) describes how responsibility is delegated between the manufacturer and the logistics operator in the

22. Two relevant examples are: (i) Airbus, which produces helicopters in the US and Brazil for their militaries, and (ii) the fragmentation of ownership of large companies in emerging markets in Asia. However, even in these cases, transferring production lines serves specific interests, and subpart production is often kept in the same places.
23. As noted by DB Schenker (2018): "For example, DB Schenker recently worked with Airbus to develop a streamlined logistics and transportation system for the latter, which is ramping up final assembly line production in Mobile, Alabama, to be able to handle five commercial passenger twin-engine jet airliners (A320s) per month. Airbus partnered with DB Schenker to develop a logistics plan to accommodate the manufacturer's larger, ocean-going vessels. Those vessels are now being used for the international transport of four complete airplanes (a number that will increase to five in 2019) per month. Using its new roll-on/roll-off terminal, barge, and newly-dredged section of river, Airbus can now use larger vessels to transfer the huge components by water' (DB SCHENKER, 2018, p.4).

product delivery process. Four different classifications are currently defined: 1PL, 2PL, 3PL, and 4PL. Producer companies play a greater role in the logistics process at the initial levels, with outsourcing increasing as the levels move from 1-PL (total control of the manufacturer) to 2-PL (outsourced delivery), 3-PL (increase of responsibility for storage and distribution), and 4-PL (similar to 3-PL, but with complete operations management).

Increasing logistics outsourcing by establishing partnerships with logistics providers operating in large K-PL also enables producers to focus on their core activities and the logistics providers to focus on their specializations, introducing cutting-edge technologies into the logistics process (robotization, internet of things, and automation, for instance). This trend follows the pattern of increasingly short contracts in the industry (risk-sharing partnerships) (field research, 2021).

Additive Manufacturing (AM)

Additive manufacturing is a technology with the potential to change logistics pressures. AM comprises a "broad class of processes based on continuous deposition of material, layer-by-layer, until a physical object is automatically built following instructions from a computer with a virtual model designed in a Computer-Aided Design (CAD) system" (J. V. L. Silva & Rezende, 2013).

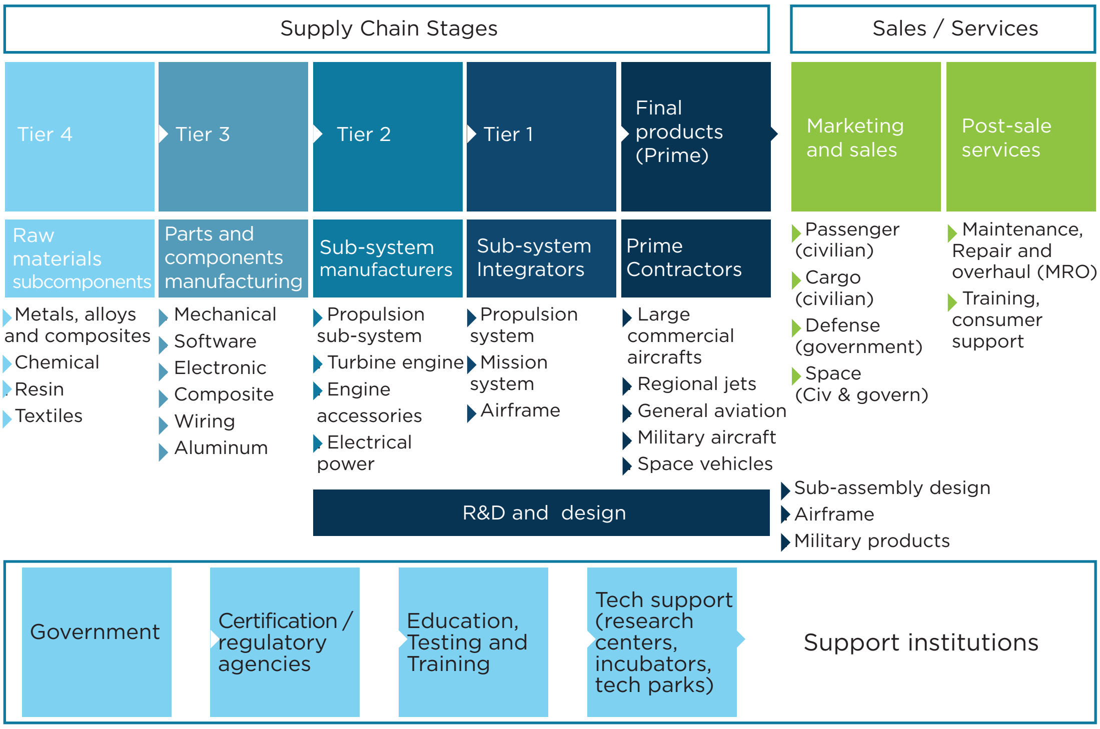
AM could change the logistics process by modifying the logistics from final products to raw materials, verticalizing production in search of economies of scale. One example of this is how the process of producing the fuel nozzles for the GE CFM-56 engine (GE Aviation, 2014) was modified. Additive manufacturing made it possible to reduce the number of parts need to produce the 23-piece subpart to just 1 piece, also reducing production process losses to 0% thanks to the AM process (for each 1kg of fuel nozzle, 10kg of material had been needed). In addition to modifying the transported product, reducing the number of parts can eliminate suppliers from the production process. Again, for GE's fuel nozzle, approximately 10 subparts produced by outside suppliers were no longer needed (field research, 2021).

5. KEY INSTITUTIONAL ACTORS

The concept of the innovation system (IS) provides a suitable theoretical framework for describing the relevant institutional actors in the aerospace industry. The relevance of IS for the aerospace industry GVC is widely acknowledge, as the national environment is key to improving productive, scientific, and technological capabilities (Caliari *et al.*, 2021). In the context of an IS, the process of generating innovations is approached as a complex and dynamic social system involving a network of different agents and institutions that interact and, from those interactions, promote, modify, and disseminate new knowledge and technologies (Freeman, 1995; Lundvall, 1992). At the sector level, Malerba (2002, p.250) defines a sectoral innovation system as "a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production, and sale of those products." The assumption is that a series of factors impacts innovation, including market features, innovation networks, and regulatory regimes (Mazzucato & Robinson, 2018).

In this sense, it is important to highlight, once again, the structure of the value chain and the main institutional actors that support value chain evolution, to then review the relevant characteristics of these actors.

Figure 12.
Value chain stages and support institutions: Aerospace industry.



Source: Prepared by the authors based on Bamber et al. (2016) and Sturgeon et al. (2013).

- ## GOVERNMENT

The aerospace industry is a high value-added sector characterized by a strong relationship with national governments due to issues related to sovereignty and the strategies intended to foster its industrial and technological capabilities (Hayward, 1994; Landoni & Ogilvie, 2019; McGuire, 2014). These two characteristics, although distinct, do overlap.

The close relationship between aerospace products and military equipment is a key reason for aerospace sovereignty. There is a wide range of aerospace products that are linked to military use, and their producers therefore maintain close relationships with national governments. This is, thus, an important characteristic of the defense markets, and it also impacts the aerospace market through the significant role played by public demand (Dunne, 1995; Markusen, 1986)[24]. According to Aboulafia (2021), 32% of the new aircraft deliveries in 2020 were for military purposes. In addition to direct demand for this equipment for deterrence (hard power), countries wield indirect power when they are the sources of the companies' controlling capital. Essentially, by possessing highly complex technology that is of military and productive importance, the aerospace industry provides host nations with soft power they can use for negotiating clout and international influence (field research, 2021).

24. There is an extensive and relevant academic production exploring the relationship between defense spending and economic growth as well as works that recover the role that defense has historically played in the development of new technologies (DeVore & Weiss, 2014; Mazzucato & Robinson, 2018; Mowery & Rosenberg, 2005; RUTTAN, 2006 to name a few).

Moreover, while a government's monopsony power guarantees its ability to define demand – in terms of both scale and product scope– the state mechanisms supporting R&D can affect technological trajectories, thus shaping the supply structure (Dunne, 1995). Defense R&D is an important component of government R&D, especially in developed countries, and its impact on innovation is remarkable. In looking at a range of OECD countries, Moretti *et al.* (2021) suggest that a 10% increase in defense R&D results in a 4% increase in private R&D. Spillover effects between countries were also observed (defense R&D in one country may positively impact private R&D in other countries).

Despite the importance of technological appropriability (Reppy, 2000), both for companies and at the national level, the cost pressure towards internationalization (Hayward, 2005) – e.g., greater participation in global value chains – and R&D (Ikegami, 2013; Landoni & Ogilvie, 2019) leads countries to change their previous strategic model of focusing on productive scale and scope. This new context presents a dilemma: achieving greater efficiency through global-scale productive specialization versus the potential erosion of national sovereignty caused by the high risk of losing control over critical technologies or production techniques. However, in light of recent nationalist policies aimed at restructuring value chains, national strategies now appear to be shifting toward a new balance—favoring the reshoring of technology and production (field research, 2021).

Furthermore, since the 1990s, attempts to reshore capabilities have led to more technology, production, and trade policies, commonly called offset programs, as mentioned in Section 2. These offset programs are associated with international government acquisitions and include a wide range of overlapping industrial, trade, and technology measures. The agreements are expected to encourage local development through benefits arising from compensation practices such as co-production, licensed production, subcontractor production, overseas investment, technology transfer, and countertrade activities, especially in the case of fairly industrialized developing countries (Martin, 2014; Ribeiro & Inácio Júnior, 2019; WTO, 2018). In short, offset programs can be used to upgrade firms from countries that are lagging behind, especially by narrowing gaps in production and technology.

- ## CERTIFICATION AND REGULATORY AGENCIES

The risks inherent in aerospace activities demand constant oversight from both regulatory bodies and certification authorities. The International Civil Aviation Organization (ICAO) is one of the most influential entities in setting standards and issuing recommendations for the operation of the aerospace industry and the commercial aviation market. A specialized agency of the United Nations, ICAO was established under the Chicago Convention in 1944 to promote international cooperation and diplomacy in air transportation among its member states. Today, it is the second-largest multilateral agency in the world, with 193 member countries (ICAO, 2021).

Despite its importance, the agency holds no regulatory authority and does not issue certifications. Its primary role is to maintain an administrative and technical structure responsible for developing standards and issuing recommendations, which are defined through an assembly in which all member countries participate (ICAO, 2021). In short, the ICAO establishes the minimum safety and airworthiness standards of products and components, which must be respected by the signatory countries. Any developer of an aeronautical product from an ICAO member country must seek product certification[25]

25. For the sake of example, the regulatory agencies of the USA and Europe are, respectively, the Federal Aviation Administration – FAA (https://www.faa.gov/aircraft/air_cert/) and the European Union Aviation Safety Agency – EASA (https://www.easa.europa.eu/domains/aircraft-products/aircraft-certification).

from their national agency by demonstrating to the competent authority that their product complies with ICAO safety requirements (field research, 2021).

National agencies may unilaterally decide to use stricter certification and regulatory standards than those established by the ICAO. These differences that may arise among the signatory countries can create specific bilateral issues for product certification (for example, when a product certified with the ICAO minimum standards must be authorized in a country with stricter requirements). Despite this, globally, the civil aviation market normally directs developers of aeronautical products and components comply with the strictest operating standards, reducing the number problems generated by the standards heterogeneity.

Non-governmental organizations (NGOs) also have a significant influence on guidelines and market trajectories. Two of the most important NGOs are:

1. International Air Transport Association (IATA): This association represents some 290 airlines, accounting for 82% of total air traffic. They support aviation activities and help draft industry policy on critical aviation issues. Priorities include safety, financial resilience, and environmental sustainability.

2. Industry associations: These groups seek to bring together the companies in the industry's value chain and lead the industry on development of international standards and market regulations. The International Coordinating Council of Aerospace Industries Associations (ICCAIA) is the international organization of aerospace industry associations that represent companies from the US (Aerospace Industry Association – AIA), Europe (AeroSpace and Defence Industries Association of Europe – ASD), Canada (Aerospace Industries Association of Canada – AIAC), Brazil (Aerospace Industries Association of Brazil – AIAB), Japan (Society of Japanese Aerospace Companies – SJAC), Russia (Union of Aviation Industrialists – UAI), Mexico (Federación Mexicana de la Industria Aeroespacial – FEMIA), and Singapore (Association of Aerospace Industries – AAIS).[26]

The productive fragmentation has also generated a need to establish quality management systems to control standardization information and production quality. The AS9100 certification is an internationally-recognized quality standard specific to the aerospace industry. The largest companies adopt it as a standard requirement for supplier registration. The system was first released in October 1999 (Revision A), with periodic improvements since then, and the "companies which wants to implement a quality management system that conforms to the quality standard, has to improve the existing documentation related to the operating procedures, training, and procedures for corrective action" (Tîtu & Ioan, 2019, p.223). The National Aerospace and Defense Contractors Accreditation Program (NADCAP) is a global cooperative accreditation program in the aerospace industry whose goal is to improve quality and reduce production costs, especially by maintaining levels of production excellence. Auditing process are established by prime contractors and tier 1 companies and carried out by the Performance Review Institute (Bamber *et al.*, 2016).

Finally, because of the dual nature of the technologies used in the commercial and defense areas and the need to maintain constant control of sensitive technologies,

26. So, representing about 92% of the total exports in 2019.

some management regulations and technology controls are required. The Wassenaar Arrangement[27] is the main one at an international level and is a voluntary export control regime that currently has 42 signatory countries. Not being a party to this arrangement can be an impediment to access specific and important technologies for certain products and equipment and prevent companies in developing countries from upgrading (Bamber *et al.*, 2016).

- **EDUCATION, TESTING AND TRAINING**

The technological particularities of the industry are also reflected in the importance of having a strong scientific basis on which to rely. The ability to generate and access specialized labor and technical training is crucial for companies to stay competitive and up to date (field research, 2021). This is also why internal learning is important (learning-by-doing, learning-by-using), as is learning by interaction (learning-by-interacting), in the sense that educational and training capacity helps shape firms' internal absorptive capacities (Zahra & George, 2002).

The industry's challenges and drivers mean curricula must be constantly amended and updated so learning structures can meet these new challenges (Lappas & Kourousis, 2016). Logically, this educational structure is also closely associated with the challenges of basic and applied scientific research, and it shapes – and is shaped by –the industry development.

Given these characteristics, the challenges usually overlap with the restructuring of and interaction between educational institutions and other innovation system participants. Proper symbiosis among academia-industry-government is needed so challenges can be pursued (Hotur *et al.*, 2013). In this sense, the limits of academic curriculum when it comes to the needs of professionals – aside from extremely focused professionals – needs to be addressed, and the constant knowledge updates after graduation plays a central role in the sector's knowledge creation and development (Reichmann, 2021).

- **TECH SUPPORT: RESEARCH CENTERS, INCUBATORS, TECHNOLOGY PARKS**

In the same sense, participation of actors who develop or contribute to scientific and technological capacities is central to the aerospace industry's competitiveness. A country's capacity for technological development is closely related to its ability to compete at the stages in the industry's value chain with significant added value, and outcomes in this area depend on productive, scientific and technological actors (Caliari *et al.*, 2021). Interactions between companies and universities or research institutes are therefore common, and technology parks and incubators important for developing the aerospace industry.

The history of the aerospace industry's development in the US and Europe – both of which host the biggest players in the industry – is defined precisely by the academia-industry-government triad (Landoni & Ogilvie, 2019; Mazzucato & Robinson, 2018; D. C. Mowery, 2009; D. Mowery & Rosenberg, 2005). In 2019, the global aerospace and defense sector invested US$32 billion in R&D, almost half of it (US$15.9 billion) coming from the US (Statista, 2019). Combining the seven major countries in the aerospace industry, ATI (2019) notes that almost US$200 billion were invested in R&D in 2013-2017.

27. https://www.wassenaar.org/participating-states/. Accessed on 09/25/2021.

Additionally, scientific and technological development may have spillover effects and help increase market and social returns. ATI (2019) conducted a literature review aimed at measuring social and market spillover from the aerospace industry. The results show that in almost all cases, the social return exceeded the private return. In interviews, the experts noted almost unanimously that the industry was moving toward returning to local R&D investment following the COVID-19 pandemics. This movement was driven by two main factors: (i) An abundance of credit made available by the national governments and (ii) a return to technological ownership and control of key products/technologies in the value chain (Field Research, 2021).

6. TRENDS IN THE AEROSPACE INDUSTRY

TECHNOLOGY

A wide range of technological innovations are emerging, (Manyika *et al.*, 2013; OECD, 2017) = many of which have a high potential for transforming companies' competitiveness and the global structure of the aerospace industry. The aerospace industry has been acutely impacted by these transformations, first, because it is a technology-intensive industrial sector, and second, because it is an industry that makes complex products that integrate a diverse array of technologies from other industrial sectors (Ferreira & Neris Junior, 2020).

The main innovations that have been affecting the global aerospace industry can be grouped – with a certain degree of discretion – into four clusters of innovative technologies.

INFORMATION AND COMMUNICATIONS TECHNOLOGY (ICT)

ICT has had a decisive impact on the aerospace industry. Disruptive technologies originating in the ICT sector have increasingly been incorporated into aerospace systems, including: (i) artificial intelligence (AI), (ii) communication networks, and (iii) the Internet of Things (IoT). Although each of these technologies has distinct characteristics, they are complementary and increasingly integrated.

Artificial intelligence (AI) has expanded rapidly in recent years due to two main drivers. First, the massive volume of data generated by digitalization. Second, advancements in data storage, processing, and analysis, enabled by more powerful hardware and sophisticated software. Among the most prominent AI tools are big data, machine learning, and deep learning. Big data involves large-scale storage and fast retrieval of information, while machine learning and deep learning are advanced algorithmic systems that autonomously improve their performance over time (IBM, 2021). The aerospace industry increasingly uses AI to monitor and enhance aircraft performance—most notably through predictive maintenance. Beyond aircraft systems, AI also enables the analysis of passenger and cargo data to optimize operations and personalize services through a model known as servitization (World Economic Forum, 2021). Additionally, AI has been applied to improve human-machine interfaces, including the use of voice commands and image recognition, making it a key technology for the development of autonomous piloting.

Communication networks play a critical role in the aerospace sector, particularly through the implementation of a "system of systems" architecture—a complex integration of specific, heterogeneous, and interdependent systems designed to fulfill a broad operational mission (Boehm & Lane, 2006; Nielsen et al., 2015). In civil aviation, this includes advanced air traffic management systems; in military contexts, it supports network-centric warfare systems (SESAR-FAA, 2016). Both depend on real-time data communication technologies, commonly referred to as datalinks. These networks, together with AI-driven data processing, are essential to the performance and evolution of the aerospace industry. In this context, network performance and cybersecurity are paramount—requiring robust encryption, firewalls, and other protective measures.

The Internet of Things (IoT) enables the capture of real-time data through sensors and the execution of actions via actuators. IoT technologies are inherently integrated with both AI and communication networks: the former allows intelligent processing of collected data, while the latter ensures efficient and reliable transmission. Data from onboard sensors, combined with external sources from the "system of systems," must be analyzed in real time using AI—both onboard and on the ground—to enable in-flight autonomy (Bordeaux-Rego, 2017). This integration leads to improved aircraft performance, enhanced safety, cost reduction, and maintenance optimization via predictive models.

Despite significant growth in sensor usage, the combined deployment of AI, communication networks, and IoT for autonomous aerospace operations remains limited. This is largely due to the stringent certification processes required to ensure their reliability and safety. Consequently, the most disruptive innovations are currently being applied primarily to unmanned aerial vehicles (UAVs), where automation is advancing more rapidly.

• SMART FACTORIES

The smart factory encompasses a set of innovative and interrelated technologies that are being directly incorporated into the aerospace industry's production process (Naveiro, 2017). In addition to being intrinsically associated with the ICT innovations previously described, the smart factory advances five key technologies: (i) robotics, used in repetitive activities that need high precision. Here, automation has shown significant progress in segments with large production scales, standardized products, and high human workload, such as producing metal components, aerostructures, and interiors, in addition to increasingly being used in the assembly of large commercial aircraft (Weber, 2015); (ii) additive manufacturing, also known as 3D printing, which is advancing, particularly for components with high design complexity and high added value (e.g., the fuel nozzles of the GE CFM-56 engine, previously mentioned); (iii) innovative production processes, with emphasis on technologies for joining of metal or composites parts without rivets or welding, such as laser beam welding (LBW) and friction stir welding (FSW) (Siqueira *et al.*, 2014); (iv) production virtualization, usually through computer simulation of products and production processes with high realism and reliability; and (v) computerized production control, or so-called cyber-physical systems (Diegues & Roselino, 2020).

- **NEW MATERIALS**

Innovations associated with materials technologies are of central importance to the aerospace industry because of the need for components that are light weight, high strength, and very safe when building aircraft. Disruptive innovations in materials – such as replacing aluminum with composites in the B-787 and A350-XWB– impact the aircraft conception, design, production, and performance (Ferreira & Neris Jr, 2020). Currently, the main innovations introduced in materials technologies incorporate nanostructures, both in light metal alloys and in composites, which are now reinforced with carbon nanotubes (Chu, 2020). Another important set of innovations is the development of high entropy alloys (HEA) that combine multiple elements. Also noteworthy are the technological advances in metals, polymers, and ceramics used in additive manufacturing, as well as the growing importance of "rare earths," particularly as an input for producing high-capacity magnets, used in innovative low-weight, high-performance electric motors (Carvalho, 2017).

- **ENERGY MATRIX AND STORAGE**

The main objective of technological innovations in energy for the aerospace industry is to enable development of an aircraft that does not use conventional fuels and therefore meets two important demands: First, for increased energy efficiency, resulting in lower operating costs; and second, to contribute to reducing greenhouse gas emissions, and, by doing so, comply with strict sustainability policies aimed at decarbonizing the aerospace industry. Currently, the most advanced projects involve the use of electric motors powered by rechargeable batteries. This technology is already used in small unmanned aerial vehicles and in some experimental models of light aircrafts (Torresi, 2017). However, the expectation is that this technology will be introduced in a hybrid form – joined with the traditional technology – and progressively, in aircrafts of increasing size (Ferreira & Neris Junior, 2020). Following this logic, the first category of aircraft that will incorporate hybrid propulsion technology is small regional aircraft. In addition to the aircraft electrification strategy, another technological path recently discovered is the use of liquid hydrogen as aircraft fuel. However, the challenge lies in how to transport the hydrogen, which requires four times as much storage space, reinforced, spherical structures, and a cryogenic environment (Ubiratam, 2020). Despite these challenges, innovations in the energy sources used by aircrafts – electric batteries or hydrogen – must be gradually incorporated by the aerospace industry, particularly by the commercial aviation segment.

To track these technology trends, keywords from papers, industry reports, and interviews were used to search aerospace technology patent documents in the USPTO database (Table A.2 in the appendix section).[28] All patents between 2010-2021 were

28. The keywords considered were: ICT (5G, blockchain, automated guided vehicles, autonomous flight systems, machine learning, artificial intelligence, internet of things, digital twins); Smart Factories (structural health monitoring, smart automation, additive manufacturing, 3D printing, robotics); New Materials (composite, smart material); Energy (electric fuel, hydrogen fuel, sustainable air fuel, sustainable aviation fuel, electrification).

considered. The number of patents is presented in Table 12 and shows the difference on the technological maturity levels of the trends, highlighting how, in addition to ICT, new materials have been playing a prominent role in the industry's applied research.

The low number of patents for smart factories and energy may be for two reasons: first, fewer patents is normal because the technologies are applied to industrial processes, which are usually protected by other means of appropriability. Second, the results must be associated with low levels of technological maturity. Developing clean fuel alternatives, for instance, is currently at a lower technology readiness level (TRL)[29] and, in most cases, the economic feasibility on a productive scale has not yet been proven.

Table 12.
USPTO patents by technology trends.

TECHNOLOGY TREND	PATENT CITATION	PATENTS	CITATION / PATENTS
ICT	131	90	1.46
Smart factories	0	11	0.00
New materials	198	1333	0.15
Energy matrix and storage	21	16	1.31

Source: Prepared by the authors using USPTO data.

- **MARKET / BUSINESS MODEL**

Supply chain consolidation: upstream movements

The large amount of capital required to participate in new projects through risk-sharing partnerships has increased further over the last decade as a result of tier 1 consolidation. This has resulted in the upstream stages of the supply chain raising quality and production certification requirements for suppliers and forcing strategies to seek efficiency and economy of scale throughout the entire chain (Bamber *et al.*, 2016). This structural change has further increased the power of supplier companies in terms of both technological capabilities and in distribution of the value added all along the value chain (Serfati & Sauviat, 2018). Nevertheless, suppliers' revenues are often lower than those of prime contractors, with a very few exceptions (see the previous Table 9). Movements that reduce consolidation after the COVID-19 pandemic are not expected. In fact, acceleration is likely, especially among small companies with less specialization in the supply base (tier 2/3) (KPMG, 2021).

Supply chain consolidation: servitization

The revenue earned by manufacturing companies from services (customer support)– notably prime contractors and tier 1 companies – has become very important for obtaining profits. MRO services have increased revenues for Boeing (20%), Airbus (15%), and specialized suppliers (engines and electronics, for example); the latter, in fact, may see more than half of their sales coming from MRO (Serfati & Sauviat, 2018). Also, a new customer support strategy – predictive maintenance – and the use of new technologies – 3D printing – tend to streamline MRO solutions, as well as customize and shorten repair cycles.

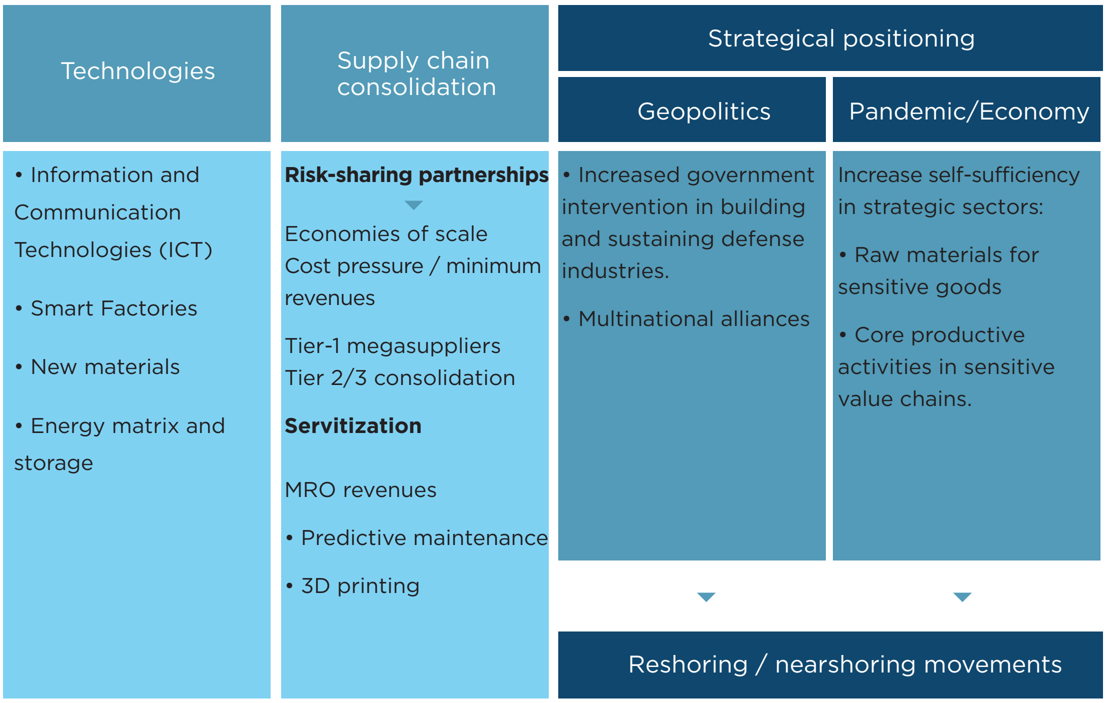
29. Technology Readiness Levels (TRL) are a measurement system used to assess the maturity of a particular technology. They were developed by NASA and are currently used in the aerospace industry to measure technological feasibility. Each technology project is evaluated against the parameters for each technology level and it is then assigned a TRL rating based on the project progress. There are nine technology readiness levels. TRL 1 is the lowest and TRL 9 is the highest (text from https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level. Accessed on 10/15/2021).

Strategic movements

The consolidations should continue as a result of strategic moves driven by two main factors: geopolitics and the COVID-19 pandemic/economy. Increasing geopolitical tensions have also increased government interventions to build and maintain the defense industry. The US launched the Trusted Capital Marketplace Program in 2020 in an attempt to control defense industry capital.[30] Also, multinational alliances to assert political dominance in strategic regions have sought to guarantee power outside borders by establishing production and technology partnerships with companies from allied countries (ALTAMAR, 2021; Isidore, 2021; Macias, 2021). The conjuncture collapses caused by the COVID-19 pandemic also intensified governments' role in strengthening policies that increase self-sufficiency in strategic sectors. The strategy has focused on guaranteeing the supply of important raw materials for producing sensitive goods (The White House, 2021), as well as on repositioning core productive activities in sensitive value chains, like in aerospace (Fefer *et al.*, 2020). In response to these two trends, reshoring and nearshoring movements are expected.

Figure 13 provides a vision overview of these trends. Although some of them have been discussed and observed for some time, any possible trend arising from the strategic reconfiguration (geopolitics and COVID-19 pandemic/economy) is fairly recent and increasingly importance for public policy discussions and, therefore, the companies' alignment.

Figure 13.
Trends in the Aerospace Industry.



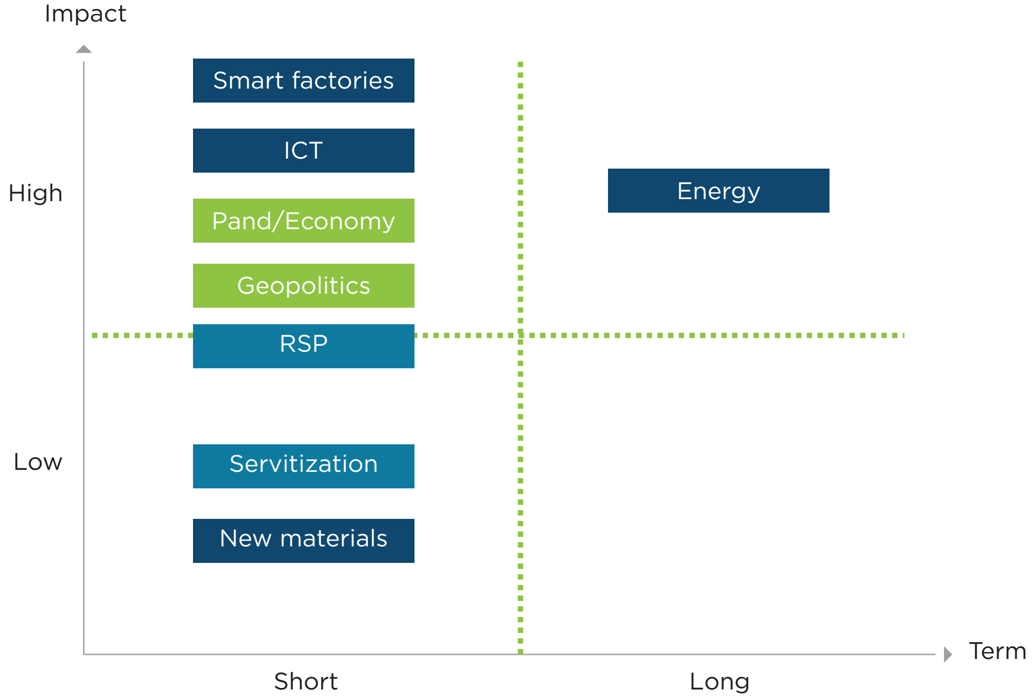
Source: Prepared by the authors.

In Figure 14, we propose a relationship between trend term and impact. Binary values (high/low for impact, short/long for term) are for ease of understanding and the suggested positions for trends in each quadrant does not indicate rank with respect to other trends in the same quadrant.

30. https://www.acq.osd.mil/tc/. Accessed on 10/10/2021.

The assumption is that technological and market movements are expected to impact the industry in the short term, and they may have varying impacts on value chain reconfiguration. The new materials, for example, are technologies that have been applied for some time, but due to the long lifecycle of the product, they do not seem to cause constant reconfigurations in the production structure. Similarly, the servitization process should lead to greater value chain governance of the major players (final products and tier 1 companies) in the final stages of the value chain, but it does not seem to involve deep changes in the industrial structure.

Figure 14.
Trends in the aerospace industry.



Source: the authors.

Other trends, however, appear poised to have a more significant impact on the industry in the short term. Although already a consolidated business model, Risk-Sharing Partnerships (RSPs) could trigger structural changes across the entire value chain—particularly through the consolidation of companies with higher value-added capabilities. Moreover, mature technologies such as ICT and smart factories, already adopted across various industries, could reshape the configuration of industrial parks. This transformation may generate distributional conflicts over profits and employment, thereby increasing pressure on national governments to intervene. In addition, recent economic and geopolitical shifts may already be prompting new productive reconfigurations in the short run. Alongside reshoring and nearshoring, there is growing speculation about productive restructuring aimed at ensuring redundancy in strategic segments.

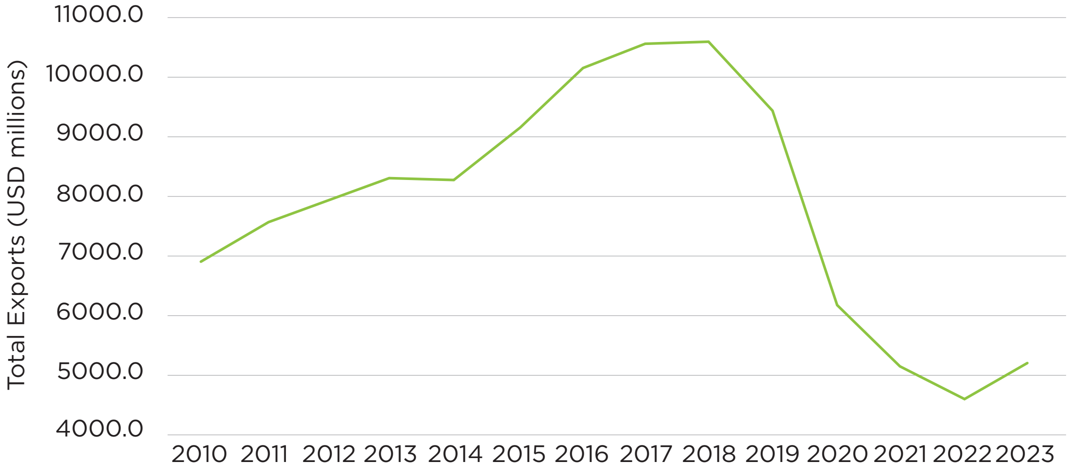
Finally, clean fuels represent a potentially major technological breakthrough with far-reaching implications for the entire value chain. However, due to the current immaturity of these technologies, any substantial transformation is expected to occur only in the long term.

7. LAC COUNTRIES: INTERNATIONAL TRADE DATA AND COMPETITIVE POSITIONING BY VALUE CHAIN STAGE

The detailed analysis of the aerospace industry in LAC countries will use the same structure as the analysis of the global industry (section 1), but focus on the countries' international trade structure. This is due to the lack of information on production and market for all the countries in the region. The international trade data presented here are based on the aeronautical product classifications described in Table A.1 (Appendix).

Figure 15 shows a significant growth in exports between 2010 and 2018 (54%), followed by a slight decrease in 2019 (-11%) and then a collapse of exports in 2020 to approximately US$6 billion. However, the lowest point in the historical series was reached in 2022, when exports fell below US$5 billion. In 2023, a slight increase was observed, indicating a modest recovery. In short, the dynamics of the LAC countries over the period closely track global trends, though the COVID-19 pandemic had a greater impact on the region's exports than on the global average.

Figure 15.
Evolution of exports, LAC countries (USD millions, current prices).



Source: UN Comtrade, HS02 6D codes, Reporters' exports to the World, Retrieved 24/03/2025.

A granular analysis of country-level export data reveals critical insights about competitive dynamics (Table 13). Even in 2010, exports were highly concentrated, with Brazil and Mexico jointly representing nearly 86% of regional exports. This trend intensified significantly over the decade – by 2023, the duo accounted for 97% of all exports.

Table 13.
Aerospace industry exports, by Latin American countries (top 20, USD millions, current prices).

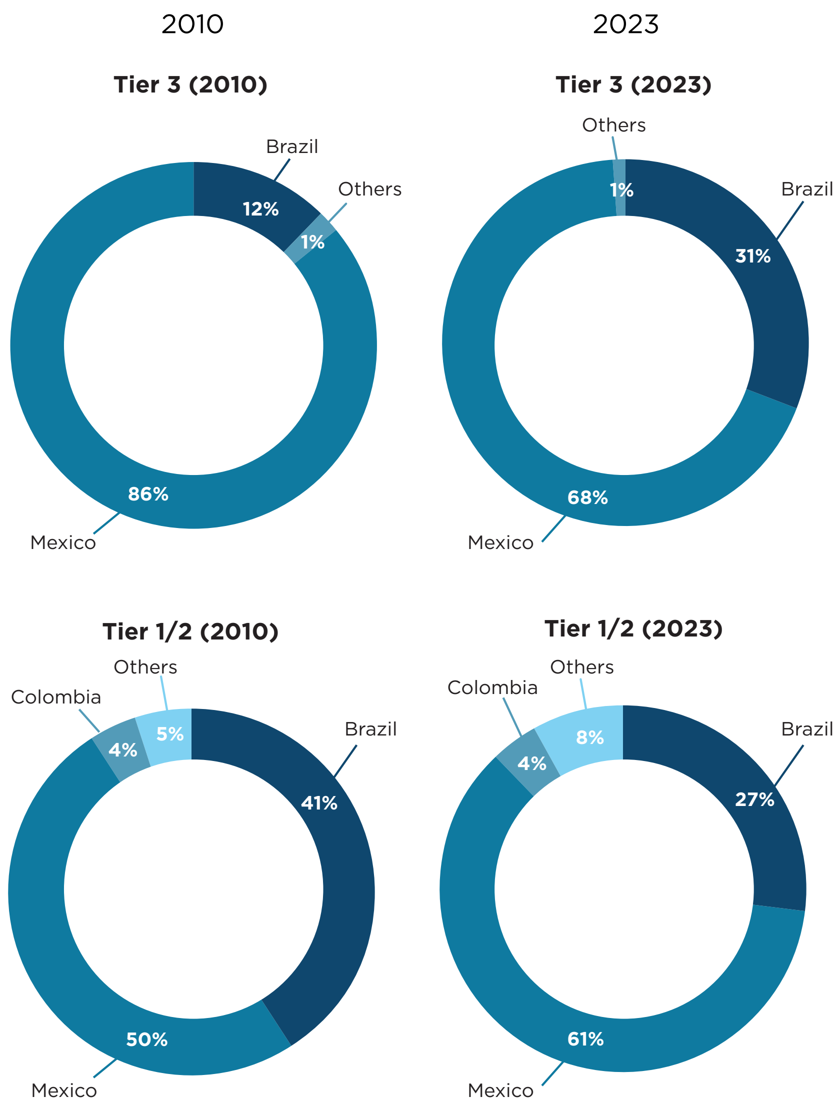
COUNTRY	2010	%	COUNTRY	2023	%
Brazil	4703.5	68.5%	Brazil	3579.3	71.0%
Mexico	1202.6	17.5%	Mexico	1310.1	25.8%
Argentina	605.9	8.8%	Colombia	37.0	0.7%
Colombia	228.4	3.3%	Chile	32.1	0.6%
Venezuela	44.1	0.6%	Bolivia	29.0	0.6%
Ecuador	22.3	0.3%	Peru	23.2	0.5%
Costa Rica	19.4	0.3%	Timor-Leste	19.1	0.4%
Peru	14.7	0.2%	Ecuador	12.0	0.2%
Chile	12.0	0.2%	Guatemala	7.7	0.2%
Jamaica	7.6	0.1%	Paraguay	4.3	0.1%
Paraguay	2.3	0.0%	Costa Rica	3.6	0.1%
Trinidad and Tobago	2.0	0.0%	Dominican Rep.	3.1	0.1%
Guatemala	1.8	0.0%	Uruguay	2.4	0.0%
Barbados	1.3	0.0%	Barbados	2.1	0.0%
Bahamas	0.9	0.0%	Suriname	1.7	0.0%
Guyana	0.7	0.0%	Belize	1.5	0.0%
Saint Lucia	0.4	0.0%	Argentina	1.4	0.0%
Nicaragua	0.3	0.0%	Honduras	1.0	0.0%
Suriname	0.3	0.0%	Nicaragua	0.9	0.0%
Panama	0.3	0.0%	Bahamas	0.3	0.0%
Total	**6870.9**	**1.0**		**5071.6**	**1.0**

Source: UN Comtrade. HS02 6D codes. Reporters' exports to the world. Retrieved 24/03/2025.

Breaking down the exports by value chain stages reveals the different industry specialties of each country (Figure 15). Brazil mainly produces final products, thanks mainly to Embraer. Mexico focuses on the upstream stages of the value chain, with tier 3 and tier 1/2 manufacturing representing 83% and 14% of its export basket in 2023, respectively.

Other Latin American countries show low export values across all value chain stages, with some relative importance in final products accounting for 7% of the region's total exports. Argentina's case requires careful analysis. Until 2017, the country exported an average of USD 450 million in final products annually. However, this figure plummeted to just USD 7 million in 2018 and USD 34 million in 2019, dropping to zero in 2023. This sharp decline reflects both the historical capacity of its domestic industry and severe recent challenges.

Figure 16.
Aerospace Industry exports by tiers, LAC countries



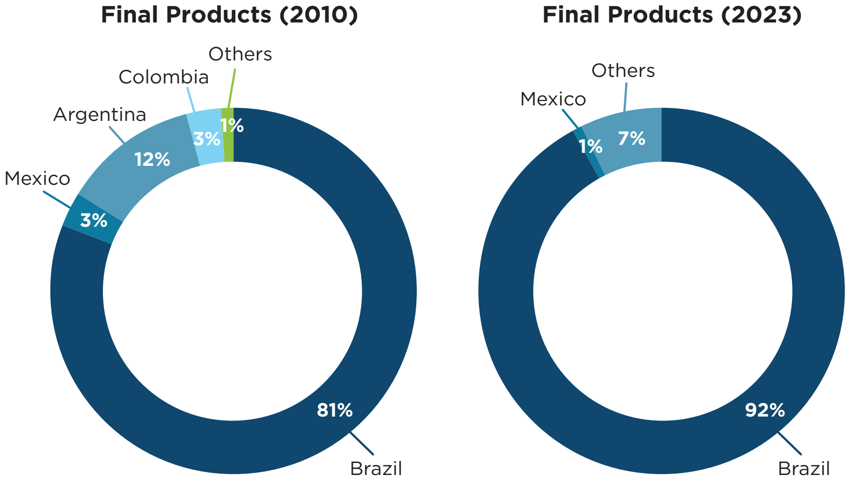


Table 14.
Aerospace industry exports, by LAC countries and products (top 20, USD millions, current prices).

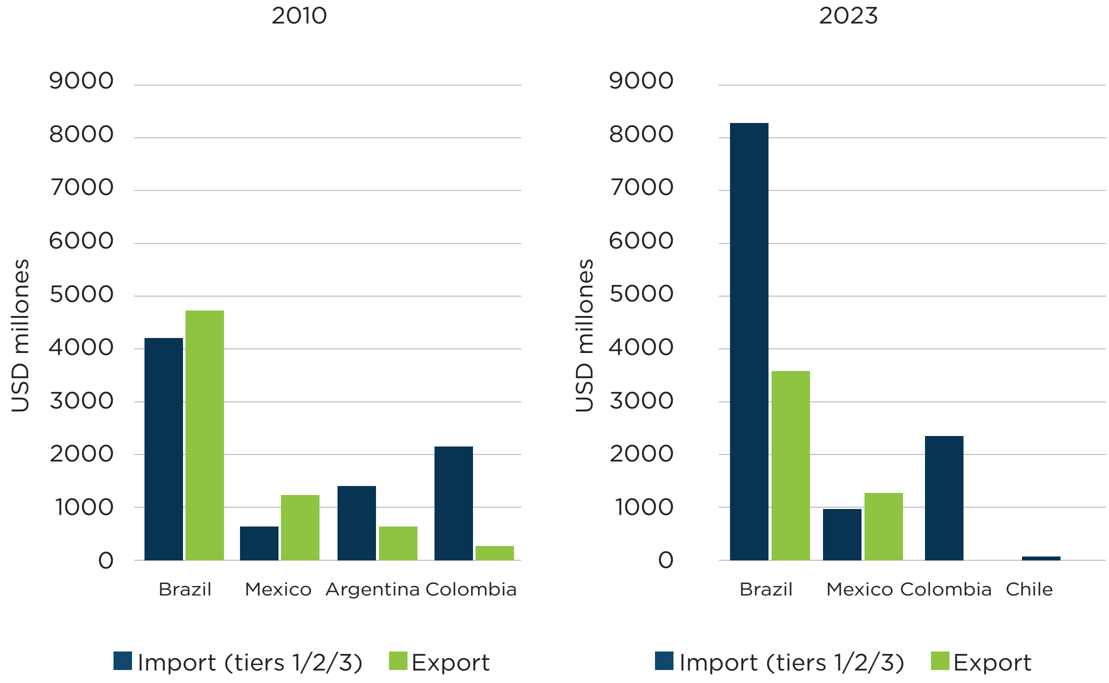
	2010				2023			
#	**COUNTRY**	**T3**	**T1/2**	**FP**	**COUNTRY**	**T3**	**T1/2**	**FP**
1	Brazil	35.13	669.60	3998.78	Brazil	502.79	82.24	2994.25
2	Mexico	240.89	814.37	147.37	Mexico	1090.62	187.45	32.02
3	Argentina	1.22	3.36	601.34	Colombia	2.08	12.22	22.73
4	Colombia	0.42	62.24	165.74	Chile	1.07	2.93	28.08
5	Venezuela	0.35	15.80	27.94	Bolivia	0.00	0.00	28.96
6	Ecuador	0.30	21.57	0.44	Peru	0.35	1.26	21.58
7	Costa Rica	0.02	19.35	0.00	Timor-Leste	0.00	19.13	0.00
8	Peru	1.22	8.48	5.00	Ecuador	1.68	1.29	9.02
9	Chile	0.50	9.84	1.66	Guatemala	0.01	0.98	5.68
10	Jamaica	0.12	6.06	1.41	Paraguay	0.07	0.11	4.07
11	Paraguay	0.00	0.00	2.27	Costa Rica	2.03	0.61	0.94
12	Trinidad and Tobago	0.00	0.02	2.02	Dominican Rep.	0.55	0.14	2.43
13	Guatemala	0.06	1.34	0.44	Argentina	1.02	0.37	1.42
14	Barbados	0.06	1.23	0.00	Uruguay	0.00	0.09	2.28
15	Guyana	0.00	0.66	0.00	Barbados	0.00	2.05	0.00
16	Panama	0.12	0.17	0.02	Suriname	0.00	1.69	0.00
17	Antigua and Barbuda	0.01	0.24	0.06	Belize	0.00	1.44	0.00
18	Belize	0.02	0.09	0.05	Honduras	0.00	0.88	0.00
19	El Salvador	0.05	0.02	0.04	Nicaragua	0.03	0.83	0.00
20	Dominican Rep.	0.04	0.05	0.00	Bahamas	0.00	0.15	0.16
	Total	**280.53**	**1634.50**	**4954.58**	**Total**	**1602.34**	**316.94**	**3153.77**

Source: UN Comtrade. HS02 6D codes. Reporters' exports to the world. Retrieved 24/03/2025.

Brazil's significant participation in subparts exports (Tiers 1–3) deserves particular attention. This outcome is largely attributed to its *drawback* policy – a foreign trade instrument that exempts exporters from taxes on imported components used in the production of goods destined for foreign markets. Initially adopted mainly by Tier 1 and Tier 2 suppliers, this mechanism has since spread throughout Brazil's aeronautical supply chain.

Figure 17 illustrates the impact of this policy by comparing the value of imported subparts (Tiers 1–3) with total exports for the four largest exporters in both 2010 and 2023. Brazil's consistently high ratios in both years directly reflect the influence of this strategic export promotion measure.

Figure 17.
Export (total) and import (tiers 1/2/3) statistics, by Latin American country (top 4, USD millions).

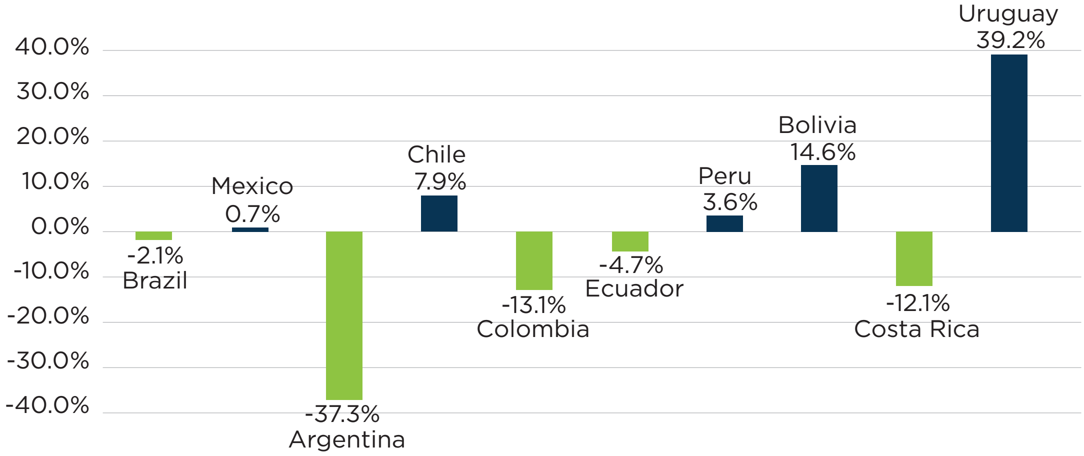


Source: UN Comtrade. HS02 6D codes. Reporters' exports to the world. Retrieved 24/03/2025.

Observing annual growth

To refine our understanding of the export capacities of the main LAC countries, we looked at the geometric average growth rate of total aerospace exports over the period of analysis, shown in Figure 18. In this analysis, a group of new countries stands out (in addition to the two main exporters) with high average annual export growth rates, namely, Uruguay, Bolivia, Chile, and Peru, in that order.

Figure 18.
Annual export growth (2010-2023), top 10 export countries.



Source: UN Comtrade. HS02 6D codes. Reporters' exports to the world. Retrieved 24/03/2025.

However, average annual growth rates should be interpreted alongside trend and magnitude data, as they can be distorted by exceptional fluctuations in outlier years and baseline effects from low initial values. Figure 19 presents this complementary analysis for the previously highlighted countries, with linear trendlines included to visualize underlying trajectories more clearly.

Figure 19.
Annual evolution of exports and linear trends, selected countries.

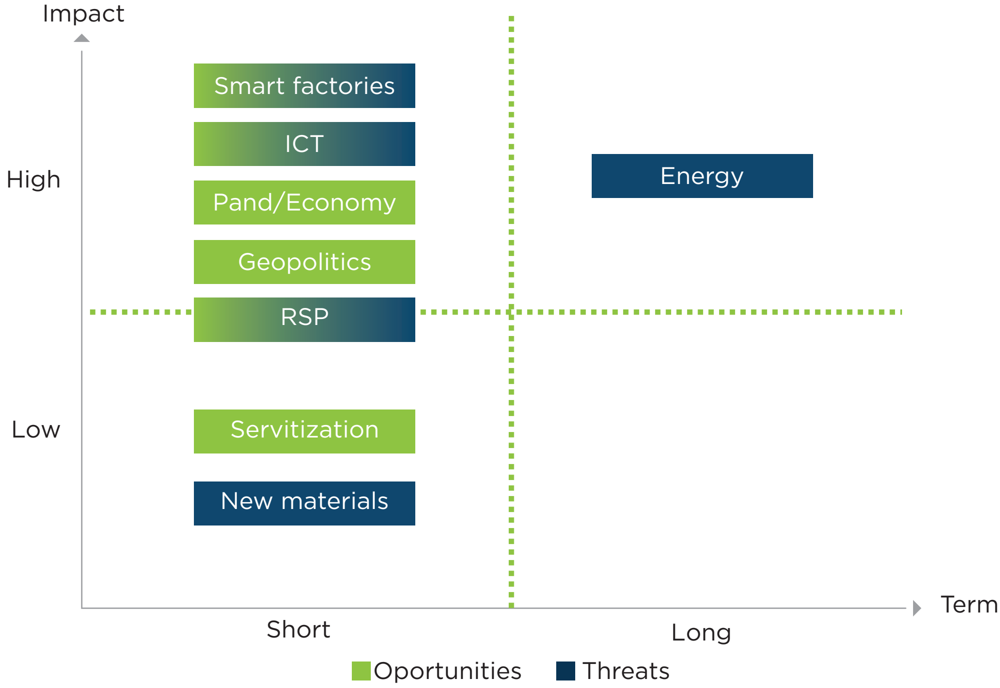
Source: UN Comtrade. HS02 6D codes. Reporters' exports to the world. Retrieved 24/03/2025.

The combined analysis reveals distinct export patterns across these economies. Chile's notably high average annual growth stems primarily from a dramatic surge in 2020, after which exports reverted to baseline levels. Uruguay followed a similar trajectory, reaching its peak in 2015. In contrast, Bolivia and Peru exhibited relatively stable trade flows, with occasional growth spikes in isolated years that nonetheless remained marginal in absolute terms given the aerospace industry's scale requirements.

8.
OPPORTUNITIES AND THREATS IN THE FACE OF NEW TRENDS IN THE SECTOR

The opportunities and threats facing the aerospace industry are associated with technological, market, and business model trends. Figure 20 shows the trends highlighted in the section 6, but with the possible impacts they could have on the structure of the LAC aerospace industry. Essentially, opportunities or threats are related to the generalization of the average structure of the region's competitiveness factors. Clearly, when identifying specific policy proposals, national issues may be important for the argument. The X axis shows the term in which a trend is expected to impact the industry (short-term or long-term), while the Y axis shows magnitude (high or low). Colors are related to opportunity (green) or threat (blue).

Figure 20.
Trends presenting opportunities and threats, LAC aerospace industry.



Source: Prepared by the authors.

Opportunities

Geopolitics/COVID-19 pandemic and economy

The better opportunities expected for LA countries are associated with the short-term reconfiguration caused by the COVID-19 pandemic, its impact on the economy, and the geopolitical strategies. Although distinct, these factors are quite interconnected. While issues surrounding control and geopolitical influence have been intensifying in recent years with the quick rise of China, they have intensified with the value chain disruption caused by the COVID-19 pandemic. Although the aerospace industry is less dependent on Asian production than other productive sectors, it has seen exports from Asian countries increase by around 196% among 2010-2019, to account for 16% of world trade in 2019. Nevertheless, we note that the US is the main trading partner of the three countries driving this growth period (Singapore, India, and South Korea), accounting for at least a quarter of total aerospace exports from these countries.

In this regard, the US Congress's research service proposed some guidelines for strengthening value chains: (i) rethink business models and seek to build in redundancies for resilience; (ii) focus more on shorter local or regional value chains; and (iii) utilize emerging technologies to decrease and diversify risk and costs (Fefer *et al.*, 2020). Later, a White House document prepared by the president's advisors noted a need to rebuild resilience in the value chains that are central to US economic and political power (semiconductors, large-capacity batteries, critical mineral materials, and pharmaceutical compounds/products) (The White House, 2021). The document notes repeatedly that these products are used in the aerospace industry and crucial for technological dominance and national security.

The general move of increasing the participation of the Western Hemisphere in certain supply chains signals opportunities for LAC countries. In a survey of 260 global supply chain leaders in February and March 2020, Gartner Consulting found that 33% had already moved sourcing and manufacturing activities out of China or planned to do so in the next two to three years (Gartner, 2021).

Servitization

Given the reshoring/nearshoring movement, the servitization trend (MRO facilities) seems be a clear opportunity to for LAC countries, given that they compete on lower cost of labor and these service activities are quite labor-intensive.

Opportunities or threats (ambiguous)

Risk-sharing partnerships (RSPs)

RSPs can offer opportunities when it comes to sector consolidation and reducing production costs. At the same time, the technologies embedded in large suppliers' products and subparts (tiers 1 and 2) limit and pose a threat to attracting this production, and it is very important to densify the local innovation system to be able to supply these components.

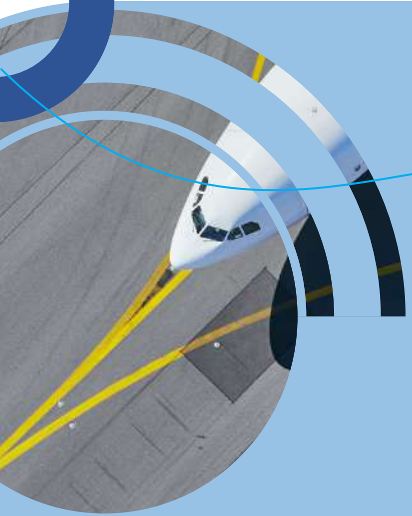
ICT and smart factories

Along with increasing technological complexity, digitized manufacturing is increasingly important, as are R&D, embedding ICT services, and smart factories. The pressure to reduce costs and delivery time (of products and projects) is an important indicator of these trends, which represent both opportunities – given the geographic proximity, geopolitical alignment, and the opportunity to provide raw materials to additive manufacturing – and threats to the ambitions of LAC countries, due to the immaturity of their innovation systems.

Threats

New materials and energy

The technological trends arising from the inclusion of new materials in production systems and clean energy are threats to region's competitiveness due to the immaturity of innovation systems.



9. COUNTRY PRIORITIES

Country priorities follow four strategies:

1. Brazil and Mexico: countries that have acquired significant productive and commercial scale in the industry and, therefore, have solid industrial structures. From 2009 to 2017, Brazil and Mexico stood in third and tenth place in the aerospace industry, respectively, in terms of attracting foreign direct investment, account for 11% of total global investment.

2. Argentina and Chile: countries whose companies have historically been players in LAC's aerospace industry but are not competitive in the global value chain.

3. Costa Rica: a country with capacity in complex industries and where the aerospace industry is making moves.

4. Latecomer countries: countries engaging in activities to make the most of their competitive advantages.

- **Brazil**

The Brazilian aerospace industry begins in the late 1940s, when the Aeronautical Technical Center (Centro Tecnológico de Aeronáutica, CTA) was created by the Brazilian Air Force (FAB), along with a school for aerospace engineers (Instituto Tecnológico de Aeronáutica, ITA) and, four years later, a research and development center (Instituto de Pesquisa e Desenvolvimento, IPD).[31] These science and technology investments and capabilities laid the groundwork for launching Brazil's leading aerospace company, Embraer. Focusing industrial and innovation policies on a single company by establishing Embraer as a state-owned enterprise was the government's strategy to address the challenges and risks inherent to producing highly technological goods in an emerging context that had already experienced serious commercial and technological setbacks (Cabral, 1987; Ferreira, 2009; Francelino *et al.*, 2019).

31. The inspiration came from the Massachusetts Institute of Technology (MIT), and the school quickly became a national center of excellence. In addition, the institute provided the human resources foundation for the establishment of the IPD within the CTA itself for research and development (R&D) in key areas of aeronautical applications (Bernardes, 2000; Botelho, 1999).

Embraer was also conceived under a market strategy that enabled it to gain access to a little-explored market, namely, regional aviation (Silva, 2008). Public procurement contracts with the federal government also helped.[32] Embraer did not depend on adapting imported technologies to the national conditions, optimizing them using reverse engineering. Instead, Embraer acquired its own productive and technological abilities thanks to government investments and efforts.

The 1990s saw the privatization of Embraer, but first, the company launched development of a regional jet aircraft, the ERJ-145. This was the first aircraft where risk-sharing partnerships were used.[33,34] The literature shows that the E-Jet family of commercial jets, launched in 2003, launched Embraer to prominence and global competitiveness (Ferreira, 2009). the company is currently producing the second generation of the aircraft family (known as the E-2 family). The company currently has the following portfolio, shown in Table below. The main clients and production sites are presented in the Appendix to this report (Tables A.3 and A.4).

Table 15.
Embraer product portfolio.

COMMERCIAL AIRJETS	BUSINESS JETS	DEFENSE PRODUCTS	AGRICULTURE	PROJECTS
E-145	Phenom 100 EV	KC-390 Millennium	Ipanema	**Military (Brazilian Ministry of Defense)**
E-170	Phenom 300E	A-29 Super Tucano		Radar SABER MB60
E-175	Praetor 500	F-X2 Gripen NG (SAAB partnership)		Unmanned Combat Air Vehicle (UCAV)
E-190	Praetor 600			Short Take Off Utility Transport (STOUT)
E-195				
E175-E2				**Commercial**
E190-E2				Electrical Vertical Take-off and landing (eVTOL)
E195-E2				eVTOL Air Traffic Management

Source: Prepared by the authors with data from Embraer Reports.

32. EMB-110 Bandeirante was a public procurement contract from the Brazilian Air Force (FAB). Embraer had also worked under licensed production of the MB-326 advanced trainer jet from the Italian company Aermacchi (known as the AT-26 Xavante at the FAB), in addition to the Ministry of Agriculture's requests for the Ipanema aircraft (Dalla Costa & Souza-Santos, 2010). In the 1970s, Embraer was hired by the FAB to develop the EMB-312 Tucano turboprop military trainer aircraft, a simple but innovative model that was exported to several countries. In the 1980s, Embraer entered the AMX tactical fighter jet program, but this time participating in the development together with the Italian companies Aermacchi and Aeritalia.
33. Despite this, a huge part of the funding for the development of the ERJ-145 still came from the government. Of the US$380 million, 30% was provided by BNDES (alongside 39% from risk partners and 31% from Embraer itself). In addition, support provided by the federal government through lines of credit from BNDES-Exim (BNDES) and PROEX-Equalisation (Banco do Brasil) was crucial for exports. These two state-owned banks created a financing structure for export of aircraft similar to the ones used by its competitors in the international market (Ferreira, 2009).
34. The ERJ-145 had four risk-sharing partners. The other jets of the ERJ family (ERJ-170/190) had 12 partners, namely: C&D (interior-USA), Liebher (landing gear-Germany), Hamilton Sundstrand (tail cone, electric system, air management system-USA), Latecoere (center fuselage and doors-France), Sonaca (center fuselage and slats-Belgium), GEAE (engines and nacelles-USA), Saint Gobain (radome-USA), Kawasaki (wing stub, control surface, wing main box and winglets-Japan), Honeywell-Grimes (avionics, lights, wingtips-USA), Gamesa (empennages, rear fuselage-Spain), Parker (fuel system, flight control system, hydraulic system-USA) (Figueiredo et al., 2008).

The Brazilian Air Force (FAB) is still for a big player in terms of public procurement. In recent years, the development of the KC-390 (a military transport aircraft) and the offset agreement[35] for the Gripen NG fighter aircraft (F-X2 program) with Swedish company SAAB have been the main programs improving the capabilities of aerospace companies and scientific institutions in the Brazilian innovation system.[36]. Furthermore, starting in 2005, a FAB regulation establishes that any imports of goods or services valuing more than US$5 million must include an offset agreement for the Brazilian companies.[37] The FAB has thus increased its capacity to control agreements with the aim of improving the Brazilian industry.

In this context, as much as it has developed itself over time, Embraer has also been one of the main success stories of Brazil's industrial and innovation policy. Since the beginning of the 21st century, it has had a prominent position in the aerospace GVC and is now the third largest manufacturer of commercial aircraft worldwide.

Nonetheless, insertion of Brazilian tier 2 or 3 companies is still weak (in the metalworking segment is mainly SMEs). Tier 1 is even weaker, with few firms positioned as top-tier suppliers, with some foreign subsidiaries in aerostructure production. However, none of them are part of the international production chain of other large aerospace companies, other than Embraer subsidiary EDE, which produces landing gear. In 2010-2018, Embraer was responsible for 86% of jobs in the sector, on average, surrounded by a base of SMEs (companies with 35 employees on average). In this sense, the progress of Brazil's aeronautical industry is intertwined with the success of its leading company.

A search was carried out in the Brazilian Aerospace Cluster website[38] and in the companies' own websites to gauge companies' areas of activity. The Brazilian Aerospace Cluster classifies companies' "competences" and "areas of activity" in 50 different categories.[39] We have narrowed these classifications for a clearer overview of the industrial core,[40] resulting in Table 16. Given the available classifications, it is not possible to fully distinguish the stages of the value chain at which companies are included. Nevertheless, we tried to present the range of value change stages related to those areas of activity. Some cases, such as aircraft manufacturing, consider the full range of value chain production stages, while in others, the pertinent stage (e.g., MRO) can be distinguished more clearly. A total of 108 companies are on the list.

Companies can be classified under more than one area of activity; on average, they are in 3.65 different categories. The most common areas of activity are manufacturing (80%), specialized services (61%), systems (49%), and R&D/engineering (48%). Of the companies that do some type of manufacturing, 52.5% (42 companies) of them are

35. Offset agreements are associated with international government acquisitions and include a wide range of countervailing industrial, commercial, and technological measures. These agreements are intended to encourage local development through benefits arising from compensation practices such as co-production, licensed production, subcontractor production, overseas investment, technology transfer, and countertrade activities (Martin, 2014; Ribeiro & Inácio Júnior, 2019; WTO, 2018).

36. The estimated budget for those programs is US$4.5 billion and US$5.4 billion, respectively.

37. Nowadays, a compensation agreement remains for imports over US$50 million (article 12, Portaria Normativa nº 61/GM, 24 October 2018). Agreements of lesser value may also include compensation projects.

38. The sector project Brazilian Aerospace Cluster is carried out by the International Business Development Department of the São José dos Campos Technological Park, in partnership with the Brazilian Trade and Investment Promotion Agency (Apex-Brasil). Information extracted from https://aerospacebrazil.com.br/. Accessed on 11/09/2021.

39. Companies are presented how they classified themselves, except for companies that were not on the list (in this case, the activity areas were proposed by the research team). Companies could answer in the affirmative to more than one classification.

40. The compatibility of classifications is presented in the appendix to this report (Table A.5).

also engaged in R&D/engineering activities. Similarly, 73.6% (39 companies) of systems integrator companies also responded affirmatively to R&D/engineering. This indicates that most aerospace companies in the country that have R&D capabilities also engage in engineering (Ferreira, 2009; Field Research, 2021; Francelino *et al.*, 2019; Gomes *et al.*, 2017). Indeed, Boeing's interest in Embraer was widely seen as an interest in the company's engineering capabilities (Gates, 2018; Leeham, 2018).

Table 16.
Brazilian Aerospace Industrial Complex, areas of activity.

MOST LIKELY VALUE CHAIN STAGES	AREAS OF EXPERTISE	#	%
Final products	Prime contractors	2	1%
Prime contractors, tiers 1/2	R&D/Engineering	52	48%
Tiers 1/2	Systems	53	49%
Tiers 1/2/3	Manufacturing	86	80%
Prime contractors, tiers 1/2/3	Defense and space system	26	24%
Tiers 3/4	Basic Materials	24	22%
Support institutions / post-sales services	Specialized services	61	56%
Post-sales services	MRO	23	21%
Post-sales services	Flight services	8	7%
-	Others	31	29%
	Total companies	**108**	

Source: Prepared by the authors with data from Brazilian Aerospace Cluster and companies' websites. Note: MRO: Maintenance, repair, and overhaul.

The origin of the controlling capital (Table 17) indicates the specialization of the Brazilian aerospace industry. The industry is comprised mostly of companies with national capital focused on manufacturing, and a large part of them demonstrate the capacity to develop some advanced activities (R&D/engineering and systems). Additionally, a significant group of companies indicates that they engage in providing specialized services.

Table 17.
Brazilian Aerospace Industrial Complex, by origin of controlling capital.

MOST LIKELY VALUE CHAIN STAGES	AREAS OF ACTIVITY	BRAZIL	EUROPE	US	OTHER COUNTRIES
Final products	Prime contractor	1	1	0	0
Prime contractors, Tiers 1/2	R&D/Engineering	41	7	1	3
Tiers 1/2	Systems	41	9	1	2
Tiers 1/2/3	Manufacturing	84	15	3	4
Prime contractors, Tiers 1/2/3	Defense and space system	19	5	0	2
Tiers 3/4	Basic Materials	15	7	1	1
Support inst / post-sale services	Specialized services	50	6	2	3
Post-sale services	MRO	17	3	2	1
Post-sale services	Flight services	7	1	0	0
.	Others	25	5	0	0
	Companies by country	**84**	**17**	**3**	**4**
	%	**78%**	**16%**	**3%**	**4%**

Source: Prepared by the authors with data from Brazilian Aerospace Cluster and companies' websites. Note: MRO: Maintenance, repair, and overhaul.

- **Mexico**

The public policy specific to the aerospace industry in Mexico was implemented in the 2000s under a program for developing emerging industrial sectors (Ketels *et al.*, 2015). Nevertheless, some companies have been operating in the industry since the 1960s in the Baja California region.[41] This lag between vertical policy and productive capacity in certain regions reflects the difference between the objectives and the current capabilities of the country's main aerospace clusters.

In the border regions, the aerospace industry developed thanks to its proximity to the USA through the Maquila Program, launched in 1964 by the Secretaría de Comercio y Fomento Industrial (SECOFI). The program grants factories permit to operate with preferential tariffs. All subparts that make up a product can enter Mexico duty free and the products can subsequently be exported at lower tariffs than those of other countries.[42] Currently, the main border regions with companies in the aerospace industry are Baja California, Sonora, and Chihuahua. The strategy is based on the ability to reduce labor costs without burdening the companies with the cost of trade taxes. Other tax facilities often guaranteed by the regions themselves also contributes to the program.

Despite increasing production, the strategy suffered from several criticisms, including of its inability to produce technological spillovers in the domestic industrial sector (Buitelaar *et al.*, 1999). The lack of relationships with domestic suppliers (Casalet *et al.*, 2011; Martínez-Romero, 2011), high employee turnover (Bergin *et al.*, 2009), and disconnect from the innovation system (Vázquez & Bocanegra, 2018) are some of the other criticisms.

The policy to stimulate emerging sectors in the 2000s was not established with any different strategy for attracting foreign capital. It was instead a complementary strategy that aimed also to build scientific and technological capabilities. The focus this time was on Querétaro,[43] with specific infrastructure policies (Querétaro International Airport), direct investment of around US$200 million, the establishment of a national aeronautical university (UNAQ), and moves to attract a foreign anchor company (Bombardier), all leading to the development of the cluster in the region (Ketels *et al.*, 2015). The state is also strategic thanks to its good engineering base and strategic location on the Pan-American highway between Mexico City and the US border.

41. Interview with Tomás Sibaja, president of the Cluster Aeroespacial Baja California. Available in: https://bit.ly/3BFr-CAd. Accessed on 11/04/2021.
42. Tariff classification 9806.00.06. It allows tariff-free imports for assembly or manufacture of aircraft or aircraft parts as well as for goods intended to the repair or maintenance of aircraft or aircraft parts, also benefiting MRO activities.
43. Nevertheless, it is worth mentioning the existence of two aerospace companies in the region before the industrial policy, namely: Turborreactores, a Mexican company specialized in turbine manufacturing settled in Querétaro in 1980 and later, in 1999, General Electric-IQ, which started designing turbines and components.

Figure 21.
Location and Distribution of the Aerospace Industry in Mexico.

Source: (Secretaría de Economia, 2017).

Today, the Mexican aerospace industry has five main production clusters: in Baja California, Querétaro, Sonora, Chihuahua, and Nuevo Léon; together they comprised 256 companies and almost 50,000 employees in 2017 (Secretaría de Economia, 2017). These five clusters were responsible for 67% of aerospace exports in 2014, and in 2019, 89% of the aerospace exports went to the US (COMTRADE data).

Mexican companies were analyzed using the same approach applied to Brazilian firms. In this case, the list of companies affiliated with the Mexican Federation of the Aerospace Industry (FEMIA) served as the basis for analysis.[44] For this list, the companies are asked about their business model and main products/services available. The research team was tasked with making the companies' information compatible with the previously-defined areas of activity,[45] and the result is presented in Table 18.

Table 18.
Mexican Aerospace Industrial Complex, areas of activity

MOST LIKELY VALUE CHAIN STAGES	AREAS OF ACTIVITY	#	%
Final product	Prime contractor	3	3%
Prime contractors, Tiers 1/2	R&D/Engineering	7	7%
Tiers1/2	Systems	7	7%
Tiers 1/2/3	Manufacturing	59	58%
Prime contractors, Tiers 1/2/3	Defense and space system	1	1%
Tiers 3/4	Basic Materials	14	14%
Support institutions / post-sale services	Specialized services	26	25%
Post-sale services	MRO	8	8%
Post-sale services	Flight services	2	2%
.	Others	3	3%
	Total of companies	**102**	

Source: Prepared by the authors with data from FEMIA. Note: MRO: Maintenance, repair, and overhaul.

44. https://femiamx.com/#!/-miembros/. Accessed on 11/09/2021.
45. Although it is a similar exercise, the two countries' information is not comparable. In the case of Brazil, the the companiesself-report areas of activity, while for Mexico, classification was based on a review of the company's information.

The review found that the Mexican companies mostly operate in manufacturing (59%) and specialized services (25%). Few companies identify themselves as operating in more valuable stages of the value chain, such as R&D/engineering and systems.[46] Although it cannot be compared to Brazil, it is clear that in Mexico, these activities are not really part of the companies' core activities, at least at Mexico's industrial sites. Even prime contractors (Airbus, Boeing and Bombardier), reporting engaging in manufacturing activities.

Examination of the origin of the companies' controlling capital found that most companies are controlled by foreign capital (62%), with the US and Europe playing an outsized role.[47] This is as expected given Mexico's policy of attracting foreign capital. Moreover, according to an estimate by the Federación Mexicana de la Industria Aeroespacial (FEMIA) estimate, in 2019, FDI by country of origin was 48% from the USA and 36% from Canada, largely explained by the granted under the North American Free Trade Agreement (NAFTA).

There are, however, a considerable number of Mexican companies, most of them doing manufacturing activities (Table 19). A closer look at the productive activities of these companies finds that they mostly operate in tiers 2 and 3, producing parts, tools, and structural components.

Table 19.
Mexican Aerospace Industrial Complex, by origin of controlling capital.

MOST LIKELY VALUE CHAIN STAGES	AREAS OF ACTIVITY	USA	MEXICO	CANADA	EUROPE	JAPAN
Final products	Prime contractor	1	0	1	1	.
Prime contractors, Tiers 1/2	R&D/Engineering	3	2	.	2	.
Tiers 1/2	Systems	5	.	2	2	.
Tiers 1/2/3	Manufacturing	18	20	5	16	.
Prime contractors, Tiers 1/2/3	Defense / space system	.	1	.	.	.
Tiers 3/4	Basic Materials	5	6	2	.	1
Support inst / post-sale services	Specialized services	9	11	1	4	1
Post-sale services	MRO	1	3	.	4	.
Post-sale services	Flight services	.	2	.	.	.
.	Others	1	1	.	.	.
	Companies by country	**31**	**39**	**6**	**24**	**2**
	%	**30%**	**38%**	**6%**	**24%**	**2%**

Source: Prepared by the authors with data from FEMIA and company's websites. Note: MRO: Maintenance, repair, and overhaul.

46. The International Trade Administration of the US Department of Commerce estimates similar values: 79% of the firms are manufacturers, 10% focus on design and engineering, and 11% operate in MRO services. Available at: https://www.trade.gov/country-commercial-guides/mexico-aerospace. Accessed on 11/09/2021.
47. There are companies from France, Germany, Italy, Spain, and UK.

Moreover, the US government has emphasized the challenges faced by OEM firms in identifying specialized, fully certified local suppliers with advanced technical capabilities and adequate logistical infrastructure. It also notes that the current mix of local Tier 2 and Tier 3 suppliers remains insufficient (Department of Commerce, 2021). To better understand this issue, it is useful to revisit the country's public policy framework.

As part of its industrial policy in the 2000s, the federal government implemented a strategy aimed at strengthening and developing value chain suppliers, alongside initiatives to support micro, small, and medium-sized enterprises (Casalet et al., 2011). These policies were deemed essential to increase the participation of local suppliers. According to the consultancy firm Consultores Internacionales, commissioned by the Mexican Federation of the Aerospace Industry (FEMIA), only 5% of intermediate consumption was sourced from local suppliers (Consultores Internacionales, 2015).

However, the policy has had limited impact on the aerospace industry specifically. Based on interviews with Mexican experts, there is little evidence that the federal government is currently pursuing a coherent strategic policy for the sector. Interviewees highlighted the absence of targeted technology and production policies, particularly noting the challenges faced by SMEs (Field Research, 2021).

A review of the Mexican Secretariat of Economy's website supports these observations. The section on programs and initiatives[48] largely contains generic descriptions, and the few references to specific policies relate to outdated initiatives from previous administrations. For example, both the *Programa de Apoyo para la Mejora Tecnológica de la Industria de Alta Tecnología* (PROIAT)[49] and the *Instrumentos de Comercio Exterior* section[50] have not been updated since 2015. Additionally, the *Programa para la Productividad y Competitividad Industrial* (PPCI)[51] ended in 2020. As for the aerospace industry specifically, the most recent formal document made available by the federal government dates back to 2017 (Secretaría de Economía, 2017).

Nevertheless, the interviewees put some emphasis on the relative capacity for resilience and unilateral development of clusters: "clusters have a life of their own" (field research, 2021). This ability, however, seems to be aligned with different competitive factors and strategies. Martínez-Romero (2011) highlights differences among the clusters: the inland companies felt more supported by being in a cluster than the border firms. Additionally, Martínez-Romero (2013) indicates that the inland firms receive better R&D funding and better support for staff training. These outcomes continue in some ways reflect earlier industrial strategies based mainly on maquiladoras in border regions, with a focus on capacity-building in inland regions. But even with better outcomes for inland companies, productive and technological upgrade capabilities are not viewed as considerably better (field research, 2021; Martínez-Romero, 2011, 2013; Vázquez & Bocanegra, 2018).

- **Argentina**

The history of the Argentine aeronautics industry is intertwined with the trajectory of its main company, currently called Fábrica Argentina de Aviones (FAdeA). Founded in 1927 as Fábrica Militar de Aviones (FMA), a state company, it was the first aircraft manufacturer in Latin America. Between the 1930s and 1960s, the company made

48. https://www.gob.mx/se/es/archivo/acciones_y_programas. Accessed on 11/04/2021.
49. https://bit.ly/3EKCZZL. Accessed on 11/04/2021.
50. https://bit.ly/3ELFyL3. Accessed on 11/04/2021.
51. https://bit.ly/3bLG6ny. Accessed on 11/04/2021.

progress not only on the manufacture of foreign aircraft models but also on developing its own aircraft. In the late 1940s, it was one of the first aerospace companies in the world to develop jet-powered fighter aircraft, albeit only experimentally.

From the mid-1960s the FMA's activities declined, with development restricted to a few models. In 1995, control of the firm was privatized, and the concession was acquired by US company Lockheed Martin, which transformed its Argentine subsidiary into an MRO center (de Moraes, 2011; Fajardo, 2018). During the same period, in 1991, the Argentine government closed the Instituto de Investigaciones Aeronáuticas y Espaciales (IIAE), negatively impacting the development of the country's aerospace industry (Gala & Porto, 2020).

In 2009, the FMA's control was renationalized (and renamed FAdeA), and since then, it has aimed to resume the production of the IA-63 Pampa jet trainer aircraft, as well as develop a new light military training aircraft, the IA-100. Recently, it began manufacturing structural components for the KC-390 military transport aircraft for Brazilian company Embraer, in addition to strengthening its role as the main MRO center for FAA aircraft. In short, the FAdeA seeks to recover from its decline over the last few decades, but it plays a limited role in the global supply chains, given that throughout its history, it has been dedicated primarily to meeting the needs of the Argentine Air Force (FAA).

It is also worth mentioning the private company Cicaré SA, created in 1972, which is the only local manufacturer of helicopters in Latin America. The company develops its own projects for light duty helicopters, used for both civil and military purposes, and most of its production is exported to other countries.[52]

- **Chile**

The Chilean aerospace industry is essentially concentrated in a single company, which is the state-owned Empresa Nacional de Aeronáutica de Chile (ENAER) created in 1984 from the maintenance department of the Chilean Air Force (FACh). In the 1980s, it began producing two aircraft under license; a basic military trainer (the T-35 Pillán) exported to several countries, and a jet trainer and light attack aircraft (T-36 Halcón). The company specialized in the production of components and aerostructures exported to large OEMs, becoming one of Embraer's risk partners in some projects (ENAER, 2021; Ferreira, 2009).

ENAER also provides MRO services for aircraft (military and, secondarily, civil) and engines, complying with international certification requirements. It also performs mid-life update (MLU) services of sophisticated military aircraft. Despite maintaining significant competence, ENAER has participated little in the global supply chain, as it focuses primarily on the FACh's needs. In addition to ENAER, there are a few local and foreign aircraft maintenance and aeronautical training companies, primarily serving the local market (field research, 2021).

- **Costa Rica**

Costa Rica's manufacturing industry is well known for its recent growth in high-tech and knowledge-intensive products, including microelectronics, electromechanics, precision mechanics, and medical devices. In 2016, 78% of the country's export value came from these types of products (The Business Year, 2018). In an attempt to explore the related capabilities of those sectors, the Costa Rica Aerospace Cluster (CRAC) was established over the last decade.

52. http://www.cicare.com.ar/. Accessed on 11/19/2021.1.

The cluster comprises 27 companies with productive capacities in electromechanical technology for various critical and non-critical systems, software development and testing, and experience in MRO services (CRAC, 2021). The companies' productive capacities could be employed to take advantage of technology trend opportunities, especially those involving ICT and smart factories. However, the small number of companies with certifications required in the sector weighs against the cluster. Only two companies have an AS9100 certification, and only one has the NADCAP certification.

Also, to the companies vary in size depending on the controlling capital. SMEs are predominantly national companies and largely orbit around large multinational companies, which have great export capacity (field research, 2021). This structure is associated with a pattern of development established through free trade zones (FTZ) and, in a way, mimics the industrial structure observed in Mexico.

- **Upgrading firms in latecomer countries**

Developing countries use different strategies to grow their aerospace industries. Product complexity, the need for certifications, and the reliability of the relationships mean countries with little experience in the sector frequently approach it by performing MRO service activities and/or by joining upstream stages of the value chain (even by producing components used in other industries).

Opportunities in MRO may be associated with three specific issues, namely: the size of the global market, regional demand, and the region's competitive capacity. The MRO market was estimated to be worth US$54 billion in 2020, forecasting an average growth rate of 6% through 2026.[53] Also, the competition in the market is from OEMs, airlines, the airlines' third-party suppliers, and independent suppliers. Operating capabilities in different MRO activities, however, may differ among competitors. The range of MRO activities can be seen in Table 21. It is divided among engines, components, line, and airframe (heavy maintenance, avionics, and retrofits/conversions).

Engine repair has the greatest market share, as expected due to their value-added and inspection control. This type of maintenance is usually specialized, but in other segments, MRO companies often operate in an array of maintenance areas or establish partnerships with other companies that offer complementary services in a nearby geographic location.

Table 20.
MRO Service Activities.

TYPE OF MRO	DESCRIPTION OF ACTIVITY	FORECAST MARKET SHARE (2020-2025)*	GEOGRAPHIC SENSITIVITY
Engine overhaul	This ranges from routine service checks to complete engine repair.	46%	Global, low cost, specialized locations
Components overhaul	This usually involves the overhaul of all parts not classified as heavy maintenance. The work ranges from landing gear to fuselage overhauls.	20%	Global, low cost, specialized locations

53. Estimates for the MRO market have some discrepancies, so we averaged the four market surveys. The surveys are available at: https://bit.ly/3H6DSxN (Mordor Intelligence), https://bit.ly/3C4mnKP (GM Insights), https://bit.ly/3D5vU5t (Statista) and https://bit.ly/31PxQkY (GV Research). Accessed 11/10/2021.

Line maintenance	Involves 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.	19%	Local, limited man-hours, in airport hubs
Heavy maintenance	This usually involves the disassembly of major components of the aircraft for detailed inspection and repairs.	15%	Global / Regional, low cost, specialized locations
Avionics	MRO organizations in this category specialize mainly in the overhaul of the aircraft avionics and associated components.		Global, low cost, specialized locations
Retrofits and conversions	This sector is responsible for major and minor design retrofits of interiors and the conversion of passenger aircrafts to freighter aircrafts.		Global, low cost, specialized locations

Source: adapted from Bamber et al (2016). Note: (*) Mordor Intelligence (https://bit.ly/3H6DSxN).

In recent years, OEMs have dominated a significant portion of the market as they have moved towards incorporating after-sales service revenues. Even so, the market for independent suppliers is expected to be about 60% of the entire market in 2027.[54] The main growth drivers for MRO activities are linked to the rising demand for low-cost carriers, required maintenance for the in-service and aging fleet, stringent airworthiness regulations and policies, and the digitalization of aircraft MRO services (Mordor, 2021).

The expected increase in the share of single-aisle and regional aircraft tends to increase the need for MRO structures in key traffic flow areas, as it is expensive to fly planes long distances for maintenance and requires just a few man-hours. However, high costs and the need for qualified labor are important drivers for certain MRO services – such as components and systems maintenance – with greater workloads. Moreover, line maintenance is usually needed in nearby locations serving the regional needs of airlines, and therefore, they are usually local.

Some observations about LAC countries are worth exploring here.

Ecuador has several notable companies involved in MRO activities, including Diaf[55] (an enterprise of the Ecuadorian Air Force), Mantomain[56] (a nationally-held company), and Atlas Copco[57] (a Swedish-held company). The two nationally-held companies mentioned above hold important certifications for aircraft and component maintenance, even from the Federal Aviation Administration (USA). They provide MRO services to various civil aviation companies, even US companies. Diaf had revenue of US$10 million in 2018 and US$6 million in 2019.[58]

Colombia also stands out as a potential major MRO hub, given the country's

54. Embraer is an example of the importance of independent suppliers. Despite having seven of its own MRO centers, the company has relationships with independent suppliers in Argentina (Austral), China (Staeco and HNA Technik), Singapore (SAI Engineering and Jet Aviation), the Netherlands (LOT AMS), South Africa (Lanseria), Kenya (Kenya Airways), and even in Rio de Janeiro (TAP).
55. https://diaf.gob.ec/. Accessed on 11/10/2021.
56. http://www.mantomain.com/. Accessed on 11/10/2021.
57. https://www.atlascopco.com/es-ec/itba/industry-solutions/aerospace. Accessed on 11/10/2021.
58. https://diaf.gob.ec/wp-content/uploads/2021/06/INFORME-DNA1-0063-2020.pdf. Accessed on 11/10/2021.

economic growth trajectory and its recent positioning in service exports. Companies like CIAC, ACC Colombia, Aeroman, Central Aerospace, Indaer Aviation, Safran, and SGS have been establishing their presence in this market, capitalizing on the growth opportunities in domestic civil aviation.[59]

GE Celma, in Brazil, is also of interest. The company has for more than 70 years provided maintenance services for aeronautical engines. It was purchased in 1996 by General Electric (GE) and today it is the main MRO facility for engines manufactured by GE. It employs around 2,000 people and had revenue of around US$2 billion in 2020 (Field Research, 2021).[60]

Costa Rican company Coopesa has more than 50 years of experience in MRO services for aircraft and helicopters, holding maintenance certifications from multiple control agencies around the world, including those of the US (FAA) and Europe (EASA).[61] The company is a self-managed cooperative with strong government support and has an important human resources training partnership with the *Instituto de Formación Aeronáutica* (IFA),[62] a recognized regional school for training technical staff (Field Research, 2021). The company employs roughly 1,000 people and operates in all MRO activities except engine maintenance, being certified to provide services to aircraft from the 3 largest prime contractors (Boeing, Airbus and Embraer).

The largest aircraft maintenance center in Latin America, Aeroman, is in El Salvador. Established in 1983, it now employs 3,000 people and has the capacity to perform MRO on 35 aircraft simultaneously, offering MRO services also to the three largest prime contractors.[63] According to a statement published by the Salvadoran government, its MRO services costs are 40% lower than in the US and Mexico to.[64]

59. https://www.mordorintelligence.com/industry-reports/colombia-commercial-aircraft-mro-market/companies#:~:-text=Colombia%20Commercial%20Aircraft%20MRO%20Top,Safran%20SA. Accessed on 16/04/2025.
60. Revenue was between US$2.5 billion and US$3billions in 2019.
61. https://coopesa.com/. Accessed on 11/11/2021.
62. https://www.ifacr.com/. Accessed on 11/11/2021.
63. https://www.thecentralamericangroup.com/largest-aircraft-maintenance-center-in-latin-america/. Accessed on 11/10/2021.
64. https://www.thecentralamericangroup.com/aerospace-development-in-el-salvador/. Accessed on 11/10/2021.

10. OPPORTUNITY PRIORITIZATION

We present in Table 21 a group of possible strategies that could be implemented by countries and companies – depending on the company's internal capabilities, the country's environment, and the industry's opportunities and threats. The rationale is explained afterward, and along with each rationale, a chart is provided showing the competitiveness factors, opportunities, and threats associated with both the priority and the countries/companies.

Table 21.
Prioritization by countries/companies.

PRIORITIES IN PUBLIC POLICIES	DESCRIPTION	COUNTRIES / COMPANIES
Expanding company scale and technological capabilities	Industrial and financial scale besides technological capabilities are important assets for competitiveness in the final product market	Brazil: Embraer Argentina: FAdeA Chile: ENAER
Improving productivity in assembly operations	Expand specialized, fully certified local suppliers with advanced product and process capabilities and with sufficient logistics abilities.	Brazil, Mexico: improve technological capabilities / certification and standards. Costa Rica: increase the number of firms with certifications and standards
Product upgrading	Move from producing upstream components and/or spare parts to more complex and higher value-added components, increasing capabilities in downstream stages of the value chain.	Brazil: main actors are national companies with R&D/engineering capabilities and industrial scale Mexico: main actors are foreign companies

Exploring R&D/ engineering capabilities	Adopt a business model that makes it possible to provide R&D services with greater value-added. Also, explore the acquired capacity in R&D, engineering, and design, gradually building competencies in manufacturing, diversifying into new products and/or improving existing products.	Brazil
Establish and/or upgrade post-sales services	Build capabilities to deliver MRO services for simple, routine on-site maintenance Upgrading from basic MRO services to more complex MRO services that absorb global demand	Latecomer countries (El Salvador, Costa Rica, Colombia, Ecuador, Chile, for example).

Source: Prepared by the authors.

- **EXPANDING COMPANY SCALE AND TECHNOLOGICAL CAPABILITIES**

As shown, competition patterns in the aircraft segment center around large aerospace companies. Both industrial and financial scale therefore are important assets for competitiveness in the final product market. In the case of Embraer, the company's main competitors in 2020 had revenue of US$61 billion (Airbus), US$58 billion (Boeing) and US$6.5 billion (Bombardier Aviation), while Embraer's revenue stood at around US$3.8 billion.

The importance of military programs, dependence on public funding for aircraft exports,[65] possible market limitations given the long product lifecycle, and engineering and R&D uncertainties require constant government relationship with sectoral agents. It appears that much of the competitiveness in aircraft production stems from the support provided to major local companies by the government. In Embraer's case, for instance, public policy support is even more relevant, as the company needs to compete in the international market with companies from the largest and most developed economies in the world, all while remaining located in an emerging country with structural and financial limitations.

Scale is also for a significant factor of competitiveness for the Argentine and Chilean companies, even though they are companies with smaller productive and technological capacities than Embraer. These examples are put forward because of their historical competence and in the understanding that they could be their countries' best bet, especially given their relationships with the military and their productive and engineering competencies (with demonstrated capabilities in providing subparts for Embraer projects).

Regarding competitiveness, Embraer plays a prominent role in the science and technology environment in Brazil and abroad. Its products enable the company to have a certain amount of political and economic clout. The company has been exploring and creating conditions in major trends (risk-sharing partnerships, ICT, and smart factories), but threats related to new materials and energy are issues that weigh on the company's growth prospects.

FAdeA and ENAER can take advantage of the productive and technological capacities they have achieved during the course of their historical development. They

65. For example, almost 30% of Embraer's funding for aircraft exports comes from the Brazilian development bank BNDES (Field Research, 2021).

should also move forward in strengthening their relationships with Embraer and other major aircraft manufacturers, offering components or getting involved in RSP, as in the projects already carried out. The small scale of these companies, however, poses threats as far as the manufacturing environment (ICT and smart factories), new materials, and fuel technologies.

Chart 2.
Competitiveness factors, opportunities, and threats.

	BRAZIL (EMBRAER)	ARGENTINA (FADEA) AND CHILE (ENAER)
COMPETITIVENESS FACTOR		
Low-cost production		
S&T capabilities		
Political / economic power		
Logistic		
Location (close to Prime contractor)	Not applicable	Embraer
Demand		
Opportunities	Risk-sharing partnerships (RSP)	Risk-sharing partnerships (RSP)
	ICT	
	Smart Factories	
Threats	Energy	ICT Smart factories Energy
	New materials	New materials

Source: Prepared by the authors.

IMPROVING PRODUCTIVITY IN ASSEMBLY OPERATIONS

Despite a certain established capacity for parts assembly or manufacture of simple components, some Latin American companies barely have the required certifications to become suppliers of global aircraft firms and have limited capability to perform complex tasks (Department of Commerce, 2021; field research, 2021; Martínez-Romero, 2013). In these cases, the pattern is one of a captive relationship (Gereffi *et al.*, 2005), yet with a reasonable opportunity for escape from by improving supplier capabilities and acquiring certifications.

Still, the countries' strategies seem to be somewhat different. The Brazilian and Mexican industries have a history with established supplier companies. In these countries, major challenges must come from technological threats like ICT and smart factories, for instance and, thus, efforts must be made to incorporate these new technologies; on average, in addition to managerial limitations, the industries are smaller and have little access to financial markets or industrial knowledge. Costa Rica's case is the opposite: It has developed manufacturing capacities in ICT and smart factories through its experience with other industrial sectors, enabling it to explore trend opportunities to position itself strategically (COVID-19 pandemic/economy, geopolitics), but the country does not have an industrial history in the aerospace industry, meaning it will need to make strenuous efforts to acquire the necessary certification standards. It will therefore be difficult for Costa Rican companies to act as suppliers to the big players, meaning the RSP trend is certainly a threat. Even in training of human resources, the plan has been to focus on more general scientific fields, but some sector-specific focus will be needed (field research, 2021).

These factors are presented in Chart 3, which appears to indicate that while the nearshoring movement in response to the COVID-19 pandemic, economy, and geopolitics offers opportunity for all countries, manufacturing and product technology trends may impact countries differently. Competitiveness factors also vary, which may impact growth opportunities.

Chart 3.
Competitiveness factors, opportunities, and threats, by country.

	BRAZIL	MEXICO	COSTA RICA
COMPETITIVENESS FACTOR			
Low-cost production			
S&T capabilities			
Political / economic power			
Logistics			
Location (close to prime contractor)			
Demand			
Opportunities	Pandemic/Economy		Pandemic/ Economy
	Geopolitics		Geopolitics
			Smart factories
			ICT
Threats	Smart factories		RSP
	ICT		

Source: Prepared by the authors.

- ## PRODUCT UPGRADING

To move from producing upstream components and/or spare parts to more complex and higher value-added components, capacity must be increased in the downstream stages of the value chain. Prioritization must be both company-specific and country-specific.

In specialized manufacturing structures, product upgrading may be easier thanks to the vertical evolution within the systems offered (e.g., avionics, interiors, airframes, or engines). In companies with broad productive or technological scope, technological and market roadmap strategies can point to the most promising areas.

The countries' different structure patterns point to the companies that should be the focus. In Mexico, productive improvement processes should be focused on increasing the productive capacities of multinational companies, with the aim of onshoring the production of components and systems performed in other production units. In Brazil, the focus should be on the capacities already acquired in the productive structures of national companies, while also aiming at expanding production scale. For both cases, product upgrading in chemistry processes (thermal and hydro forming, surface treatments, nitro-carburized materials and nitrocarburizing) and metallurgical processes (special composites and processes, metal treatments and metal raw materials, aerospace molding, and special tooling) may be specific opportunities.

Lastly, despite the varying competitiveness factors, the countries' productive bases may have similar opportunities and threats. The threats are of course a matter of debate, as trends can also turn out to be opportunities. Our observation, however, is that, in general, neither of these countries have companies prepared to face these technological trends. Therefore, if the production structure is not changed, these trends will amount to a risk for as far as the product upgrading process.

Chart 4.
Competitiveness factors, opportunities, and threats, by country.

	BRAZIL	MEXICO
COMPETITIVENESS FACTOR		
Low-cost production		
S&T capabilities		
Political / economic power		
Logistic		
Location (close to Prime contractor)		
Demand		
Opportunities	Pandemic/Economy Geopolitics	
Threats	Smart factories ICT RSP New materials	

Source: Prepared by the authors.

EXPLORING R&D/ENGINEERING CAPABILITIES

It is important to exploit the acquired capacity in R&D, engineering and design of subsystems, systems, and final products, gradually building competencies for manufacturing parts, components, subsystems, and advanced systems. A sizeable group of Brazilian companies have experience in R&D/engineering activities. Most of these companies, however, are SMEs, which undermines the strategic diversification for productive activities, as scale is important (a relevant threat).

An interesting case study is that of Akaer.[66] The company was founded in the 1990s by former Embraer employees to provide engineering services, and it contributed to the first Embraer jet, the ERJ-145. Since the 2000s, the company has been working on engineering projects for the domestic and foreign market, and its client portfolio includes companies from every continent.[67] Akaer's success is linked to its business model, which is unique in the market,[68] of offering a predefined list of services.

66. https://www.akaer.com.br/. Accessed on 11/12/2021.
67. https://www.akaer.com.br/portfolio/nossos-clientes/. Accessed on 11/12/2021.
68. The typical engineering contract is the job shopper, where the OEM buys work-hours from engineers and keeps project management internal.

This provides predictability, as the price and scope are defined *ex ante*, giving the contractor security and reducing project risk (precisely due to project detailing). A practical problem is that most companies do not have structured market and R&D information or a clearly defined scope. Defining scope and price is complex so the acquired capacity is an important asset for the company's competitiveness. The company forecasts US$33 million in revenue for 2021.

Chart 5.
Competitiveness factors, opportunities, and threats.

	BRAZIL
COMPETITIVENESS FACTOR	
Low-cost production	
S&T capabilities	
Political / economic power	
Logistic	
Location (close to Prime contractor)	
Demand	
Opportunities	Pandemic/Economy
	Geopolitics ICT
Threats	Economic scale

Source: Prepared by the authors.

- ### LAUNCHING AND/OR UPGRADING POST-SALES SERVICES

Two strategies may be important for the aerospace industry's latecomer countries: (i) building capacity to deliver MRO services for simple, routine, on-site maintenance, and (ii) upgrading from basic to more complex MRO services that absorb global demand. Both strategies can rely on labor cost competitiveness, but proximity to demand and logistics (in specific countries, mainly American Central countries) may also be relevant competitiveness factors. Economic and geopolitical reasons may offer opportunities, and likewise for the current servitization trend.

Chart 6.
Competitiveness factors, opportunities, and threats.

	LATECOMER COUNTRIES
Low-cost production	
S&T capabilities	
Political / economic power	
Logistic	mainly Central American countries
Location (close to Prime contractor)	
Demand	mainly Central American countries
Opportunities	Pandemic/Economy
	Geopolitics Servitization
Threats	-

Source: Prepared by the authors.

11.
KEY POINTS

Science, technology, and innovation (STI) are crucial elements to be leveraged for the development of the aerospace industry. Thus, STI should be the central target of policies for this sector. In this section, we present the key elements for each strategy aimed at boosting STI, which is based on education and technical support. Then in the next section, we discuss country-specific policy options.

• EDUCATION: HUMAN RESOURCES AND TRAINING REQUIREMENTS

Human resources training is a *sine qua non* for sustained development of the aerospace industry. Adequate courses at the technical, undergraduate, and graduate levels are needed to ensure the availability of the skilled labor the industry needs. **The school curricula should be designed to meet the needs of the industry and its related service sector**. Moreover, **the curricula should incorporate training on technological trends to anticipate the needs of the industry in future years**.

This requires training in the areas of application typical to the aerospace industry, along with constant monitoring of scientific improvements and emergence of new technologies to ensure the changes can be promptly incorporated into the training at all levels. The task will benefit from continuous interaction with public authorities (e.g., the Ministry of Education) and private companies active in the industry, as well as universities, teaching institutes, and research institutes.

We recommend creating working groups involving representatives from the government, industry, and education sectors that meet regularly to define the structure and development of training at different levels. These working groups should be an integral part of the government's education development strategy to effectively ensure a supply of skilled human resources capable of supporting the industry's development on par with global standards.

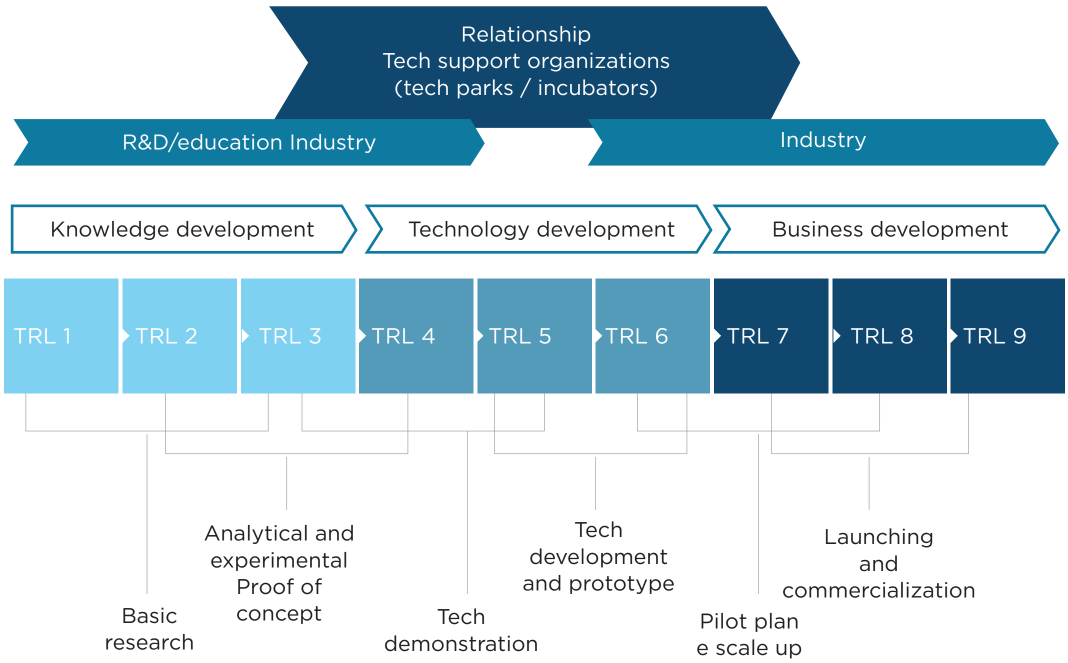
The strategy should be tailored to the maturity of the education system and industry. Countries with an already well-established industry should consider establishing private-public partnerships to develop the education system further. In countries where the industry is less established, stronger state intervention may be necessary,[69] together with incentives for the private sector.

- ### SCIENCE AND TECHNOLOGY (S&T) SUPPORT

S&T support should be linked to industry development. Indeed, S&T support becomes more important as countries and companies increase their capacity to offer more complex products and services. Industry characteristics and different levels of technological maturity contribute to delineating possible actions with respect to the different phases of production and innovation, as well as the different agents participating in these phases.

The Technology Readiness Level (TRL) is an interesting method for rating specific projects and tasks with respect to their time to market. TRL was developed by NASA and is currently used to measure technological feasibility in different industries. It has also been adopted by the European Commission to classify projects to be financed by public research and innovation funds. There are nine TRLs (see Figure 22), each corresponding to different stages of S&T development, and each stage requires different skills and capabilities.

Figure 22.
TRL and agents.



Source: Prepared by the authors.

69. For example, the establishment of the Instituto Tecnológico de Aeronáutica (ITA) at the begining of Brazil's aerospace industry (Caliari and Ferreira, 2022), and the Universidad Aeronautica en Queretaro (UNAQ) when forming the Queretaro Aerospace Cluster. To this day, both remain public universities.

Each project is evaluated against a series of parameters set for each technology level and is then assigned to a TRL. The classification ranges from activities involving basic research and knowledge development (TRL 1 to 3) to more applied technological activities (TRL 4 to 6) and culminates in the deployment of new products and bringing them to market (TRL 7 to 9).

Projects akin to basic research are more related to scientific research centers and postgraduate human resources training programs. As they do not have proven economic viability yet, they require public support for their development. In these cases, public funding agencies and national science and technology councils play a fundamental role in developing and disseminating knowledge.

As technological feasibility becomes clearer and the project moves to more applied phases, it becomes increasingly important for public and private organizations to take joint action on providing support structures for companies. In these phases, incubators and technology parks play an important role in successfully developing new technology solutions. In these environments, it is crucial to establish a specific management structure that fosters the relationship between industry and academic institutions.

Therefore, within this scope, it is necessary to highlight the importance of

a. **Providing a solid foundation for the aerospace S&T environment's funding and strategic organization.** It is important to create and/or maintain specific structures to foster and support the S&T community;

b. **Establishing a technology support environment by promoting the relationship between industry and academia.** Creating programs that foster public-private relationships is important, including joint development of products and technologies through joint financing and academic training in the industry, among other things.

12. POLICY RECOMMENDATIONS

These country-specific policy recommendations are based on the discussion on prioritizing found in Section 10. Table 22 gives country-specific recommendations tailored to the state of the aerospace industry in each country, along with a number, indicating the order of priority.

In the following section, we suggest a series of policies to be discussed according to the proposed prioritization. In addition, given the relevance of the critical points presented earlier, the general recommendations regarding the state of the country's aerospace industry should be considered key for supporting the innovation system and the effectiveness of specific policies.

Table 22.
Policy recommendations.

DESCRIPTION	BRAZIL	MEXICO	ARGENTINA AND CHILE	COSTA RICA	LATECOMER COUNTRIES
Expanding company scale and technology capabilities	1 . Strengthen loan programs for trade and growth (scale, diversification and internationalization) . Public procurement (technology orders and offsets)		1 . Improve local companies' ability to provide products/ services . Public procurement (technology orders and offsets)		
Improving productivity in assembly operations	3 . Improve the capacity of local SMEs to provide products/services for Embraer and leading foreign companies	2 . Improve local SMEs' capacity to provide products/ services to foreign companies		1 . Improve SMEs' capacity to provide products/ services to foreign companies . Meet aerospace production technical needs	
Product upgrades	4 . Incentivize national companies to provide new products/services	1 . Attract foreign companies . Support product/service upgrading			
Exploring R&D/ engineering capabilities	2 . Define specific missions (technological platforms) . Public procurement (offsets)				
Establishing and/or upgrading post-sales services				2 . Maintenance certifications . Partnership with regional aerospace countries/ companies	1 . Maintenance certifications . Partnership with regional aerospace countries/ companies

Source: Prepared by the authors.

• BRAZIL

The Brazilian aerospace industry was developed by Embraer. Over time, engineering and R&D capabilities developed by the company generated spillovers by labor turnover among sector companies, building supplier relationships, and fostering innovation. However, another group of companies with low value-added activities and little participation in GVC has emerged. This industrial heterogeneity requires different policy initiatives to strengthen the Brazilian aerospace value chain.

1. Building companies' scale and technical capabilities

The leading company, Embraer, operates in the highest value-added stages of the aerospace industry (development, manufacturing, and post-sales services). Given its importance, **public policies need to include and prioritize Embraer**.

Despite its position as a global leader, Embraer has reported lower revenues than its main competitors. In 2019, ranked 21 among the world's largest aerospace (final products) and defense companies. Hence, one of **the main public policy objectives must be to help expand the scale of Embraer's business**. The policies may focus on bolstering the company using three main strategies: **(i) expansion of existing businesses** (in both conventional projects – e.g., turboprop commercial aircraft – and innovative ones – e.g., the development of hybrid-propelled aircraft); **(ii) diversification** into related sectors through new competitive advantages (dynamic projects with better economic prospects, such as the newly formed e-VTOL segment); and **(iii) internationalization**, as well as expanding production scale.

Financial support for aircraft exports is crucial for Embraer's competitiveness. In this case, existing instruments should be maintained and, if possible, improved. Furthermore, specific instruments should be created for financing and guaranteeing military aircraft exports, coupled with the technical and diplomatic support of the Brazilian government, given the unique characteristics of these operations.

Public procurement, especially technology orders and offsets, are essential for incorporating cutting-edge innovation. These policies, especially those implemented by the military, must be used as instruments to improve Embraer's technological capabilities, for both military and civil products.

2. Exploring R&D/engineering capabilities

A small but significant group of national companies has engineering and/or R&D capabilities. These companies provide solutions and services to Embraer and other Prime Contractors and tier 1 companies globally. **The recommendation regarding these companies is to improve their technological capabilities and scale up their production.** Specifically, two recommendations seem to be relevant.

The first one is using **public procurement for innovation and taking these companies into account in offset agreements, mainly through technology transfer policies**. Additionally, **they can participate in technology orders and as solution-providers for Embraer**. The success of these companies in projects such as the FX-2 (offset) and KC-390 (technology order) illustrate the Ministry of Defense's relevance in consolidating this productive structure. However, in this regard, controlling the structure and enforcing goals should be stipulated in the contract, given the possible asymmetry of power between the transferring company and the national company receiving the technology.

Nevertheless, given the synergy in the country's innovation environment, **a coordinated policy defining a technology platform could be an important option worth pursuing**. The technology platform should be related to a different set of key technology competencies shared by different families of products and applications. It is the result of knowledge and experience accumulated in the search for new knowledge and the culling of obsolete knowledge. It produces results and drives a mature and dynamic innovation system (companies, research institutes, and universities) that undergoes constant restructuring in response to market changes.[70] Coordination among public agents must be systematized with the participation of other agents within the innovation system by establishing S&T funding programs that provide subsidies for both basic and applied research (low-medium TRL), as well as prioritizing university-industry interaction.

3. Improving product assembly and/or component production

For the SMEs that operate at lower value-added stages and supply components mainly to Embraer, **industrial processes must be improved to head off threats from technology trends (ICT and smart factories)**. Funding programs to improve industrial process productivity – aside from labor training – are important and can be fostered by strengthening the relationship between government agencies (federal, state, and municipal), industrial associations, technological parks, research institutions, and universities.

Complementary to this, efforts to **provide advisory services in the areas of standards and certifications** (NADCAP and AS9100 certifications) must be intensified. One example of this is the successful ongoing program funded by the federal government (Export Promotion Agency, APEX) and organized by the technological park of São José dos Campos with the support of consulting firms to provide advisory services for obtaining NADCAP certification. So far, 13 companies have obtained NADCAP certification through these services.

4. Product upgrading

The small size of Brazilian companies may create obstacles when it comes to supplying products to the international market. Therefore, **lawmakers should consider implementing policies aimed at providing funding for manufacturing and product development**. Furthermore, **export promotion policies could facilitate access to new markets for companies that do achieve greater value-added products.** Guaranteeing lines of credit for product exports when the private market cannot finance market expansion and sending delegations to congresses and fairs are important parts of supporting product upgrade and participation in the GVC. For example, company delegations to fairs can be promoted through industrial associations, government agencies (APEX), and technology parks. This could represent an important strategy for marketing products/services and establishing professional connections.

70. As examples, the European Union has the Clean Sky technology platform program, which develops six projects called "demonstrators of integrated technologies" (green rotorcraft, green regional aircraft, smart fixed-wing aircraft, eco-design, sustainable and green engines, and systems for green operations). For the US, technology platforms are common in the aerospace sector for both civil and military applications, with the National Aeronautics and Space Administration (NASA) supporting the former, and the Defense Advanced Research Projects Agency (DARPA), an agency under the Department of Defense (DoD), supporting the latter.

GENERAL RECOMMENDATIONS

Existing policies to improve education and science and technology capabilities should be continued and furthered. **The maturity of some institutions makes it possible for them to seek out international relationships for jointly developing competences**, but critical aspects of technology trends and specific aerospace knowledge must be continually monitored to update educational curricula.

• MEXICO

The Mexican aerospace industry is composed of five major clusters, all with different backgrounds and orientations. Geographic location and development strategy define the characteristics of these clusters. Nevertheless, a shared feature of their industrial structures is facilities run by transnational multi-plant firms with few connections or networks within the region. External links to the parent corporation and other plants elsewhere predominate.

The industry has achieved some resilience at the regional level, through regional associations, industrial federation, and support from local governments. Nevertheless, there is currently no centrally coordinated plan for the long-term development of the industry. The aerospace industry has not been included by the federal government in its economic development strategy. Therefore, the first recommendation is **to resume federal coordination aimed at developing the aerospace industry**.

1. Product upgrading

Provide incentives foreign companies with incentives to increase product complexity in the country. Specific programs should be established to increase the technology content of the products manufactured by foreign companies in Mexico and upgrade GVC participation. Toward this, federal and local governments must coordinate to provide grants, loans, and guarantees. Improving the innovation system and infrastructure (general recommendations) is essential. In general, public support during economic crisis (a common criticism by the industry during the pandemic), greater support for education (human resources), and support for science and technology are key factors.

Provide benefits to attract new foreign companies and seize opportunities from GVC reconfiguration. Mexico should take advantage of the value chain reconfiguration to attract new foreign companies that are emerging as global players in specific segments of the GVCs. Likewise, public coordination (federal and local) is crucial to establishing the legal and technical conditions necessary to attract firms and develop the products necessary for the emerging technologies. Benefits such as tax exemptions and loans for productive, engineering, and R&D activities could be crucial, along with improving innovation systems and infrastructure.

These recommendations also apply to Mexican companies that play a significant role in the value chain.

2. Improving product assembly and/or component production

The manufacturing capacities of Mexican companies that tend to be small and poorly connected to the aerospace value chain should be improved. **The federal government renew its focus on specific programs for SMEs aimed at enhancing the industry's**

technology and productivity. Due to the characteristics specific to the Mexican clusters (their resilience and independence), such programs can be better developed in coordination with regional stakeholders (local government and cluster associations) that understand the region's peculiarities.

Provide advisory services on standards and certifications. Certifications such as NADCAP and AS9100 are required in order to supply the leading companies in the industry with products and services. Coordinated action by the government, industrial associations, and technology parks is important to help companies improve their quality and acquire these certifications.

GENERAL RECOMMENDATIONS

Efforts should be made to improve the capabilities of the Mexican innovation system. This can be achieved by (i) increasing the course offerings at different educational levels (technical, undergraduate, and graduate); (ii) designing curricula that meet industry standards and reflect technology trends; and (iii) increasing the scale and scope of S&T institutes. A strategic plan must be devised (industrial, scientific, and technological) to reinforce the connections among the different agents of the innovation system and establish stable relationships among them.

Besides these specific recommendations, we emphasize **the need to connect financial institutions to productive demand**. Productive investment in Mexico mainly comes from capital, with little involvement by development banks and multilateral institutions. It is crucial for these organizations to participate more effectively in supporting the innovation system in general, and companies in particular, in order to further the development of the aerospace value chain.

● ARGENTINA AND CHILE

Argentina and Chile's aerospace industries are centered on their respective leading companies, FAdeA and ENAER. Both companies are state-owned and were established to meet the demands of their militaries. They have focused on producing military aircraft, most of which were licensed or adapted from foreign projects. These companies have also offered MRO services for a wide range of military aircrafts.

As a result of these efforts, they have developed decent production capacity, not only in aerostructures but also in engineering (in this case, the capability to adapt foreign projects or even upgrade military aircraft). Based on these skills, these two companies have made entry to the aerospace GVC, albeit in a limited way. Both have become first-tier aerostructure suppliers, especially through risk-sharing partnerships with Embraer.

It there seems **the competitiveness of the aerospace industry in Argentina and Chile necessarily involves improving and promoting their leading companies**, given that both have significant accumulated competences.

1. Expanding Company Scale and Technological Capabilities

Building competitive advantages necessarily involves training in three areas: technological-productive, managerial, and commercial. First, expansion in the technological-productive area should focus on building capacity to carry out projects and production of metallic and composite aerostructures. Second, companies must also continue, at a slow but study pace, the development, production, and modernization of aircraft, which may increase their capacities in higher value-added activities. For this, companies need **investment of public resources in both engineering (human resources and software) and modernization and expansion of production structures**.

Governments should also upgrade the managerial structure of their respective state-owned companies, to implement **corporate governance that incorporates the most advanced management techniques in order to achieve greater business efficiency, which will subsequently attract private resources (with the possibility of privatization in the future), all while enhancing public policies**. Companies must also seek greater commercial competence, seeking out business opportunities and directing activities toward a more active insertion in global value chains, in both the military and commercial sectors.

Public procurement – especially technology orders and offsets – is an important instrument both for the technological capability of companies and insertion in the GVC. Offset policies are especially significant, as they may involve the development and production of components and subsystems for the aircraft to be acquired, as in the case of FAdeA's participation in the aerostructures for Embraer's KC-390. Offsets can also be used to exchange final products, such as the light training aircraft ENAER T-35 Pillán, acquired by the Spanish Air Force in exchange for the sale of light fighter aircraft to the Chilean Air Force.

GENERAL RECOMMENDATIONS

In addition to policies focused on leading companies, **efforts must be made to improve the capabilities of the innovation system in Argentina and Chile**. This action should (i) improve and expand the supply of technical and higher education; in the latter, especially in engineering areas, to meet the needs of the industry and incorporate technology trends; and (ii) increase investment in S&T institutes and universities, establishing areas specializing in engineering, aerostructures, and new materials. Finally, strategic planning (scientific, technological, and industrial) must involve the main agents of the innovation system: In this case, leading companies, the military, research institutes, and universities.

• COSTA RICA

Costa Rica does not have an aerospace industrial park, but it does have a group of firms with manufacturing capacities enabling them to explore technology trends in the sector in it. A group of companies has sought to build capacity in the industry, and the Costa Rican NGO Costa Rica Aerospace Cluster (CRAC) was created for this purpose. Market-enabling policies should be implemented to help the private sector restructure its productive activities to make the most of existing comparative advantages and to promote connectedness policies to reduce the costs of linking domestic GVC activities to foreign value chain partners.

The government should play a central role in defining sector development objectives along with CRAC and the recently approved Costa Rican Space Agency,[71] a public agency under the Ministry of Science and Technology.

1. Improving productivity in assembly operations

Provide advisory services on standards and certifications: Only three Costa Rican companies hold international certifications (two companies with AS9100, one company with NADCAP), which limits the country's participation in the aerospace industry. CRAC could emerge as the coordinator of this work. Such actions could send important market signals and attract foreign suppliers.

Equally important is the attention to SMEs. Costa Rica's productive structure is similar to that of Mexico. Therefore, **offering support to increase production must be an important strategy if these companies are to attain sustainable growth**. CRAC could be a central stakeholder, aligned with the government's development objectives and supported by development banks.

2. Upgrade of post-sales services

The existence of a technical training center (IFA) and a consolidated company (Coopesa) is an important competitive factor for post-sales services. In this sense, **enhancing the role played by these agents and promoting instruments to improve market capacities are crucial in improving post-sales service results**, and upgrading MRO services.

As specific strategies, **maintenance certifications can help attract global demand**, with FAA (USA) and EASA (Europe) certifications being the most important ones. Coopesa's strong ties to the government can improve its skills and budget. Further, **international partnerships are also useful for attracting demand**. Geographically-close countries whose sectors are more developed, such as Mexico, can be important allies. The CRAC could collaborate with Coopesa to facilitate these relationships.

GENERAL RECOMMENDATIONS

Decisive efforts must be made to improve the Costa Rican innovation system. This should involve strengthening the sector's innovation environment, with an **emphasis on undergraduate and graduate courses, and science and technology institutes** (such as the recently approved Guanacaste Space Center, a unit of the Costa Rican space agency). To improve manufacturing capabilities in key technologies, the country must promote vertical integration in aerospace science. This must be coordinated by public entities, with the Ministry of Education and the Ministry of Science and Technology playing the central roles.

In the short term, attracting foreign professionals (work visas) and offering international educations through specific programs (even virtually) may be temporary but important measures to address national education deficiencies.

71. https://www.thecentralamericangroup.com/costa-rican-space-agency-has-been-created/. Accessed on 12/13/2021.

- ## LATECOMER COUNTRIES

Latecomer countries can exploit labor competitiveness by entering the value chain at lower value-added stages. MRO services provision is a relevant strategy. **However, given their nascent infrastructure, public policy must be more general, coordinated by public agencies**, and in particular, with the support of development banks and industrial associations.

1. Upgrading post-sales services

The complexity of the service depends on the maturity of the company and the country. If no services are yet offered, it is recommended to start with offering basic services for local and regional demand (line maintenance/heavy maintenance). Development of technical capabilities can lead to providing more complex services. With more mature structures, a certain opportunity may attract specialized service structures for leading companies (engines and avionics).

In all cases, general recommendations should be made after **taking into consideration the companies' funding**. Government and development banks can meet the financing needs when the private sector does not.

Moreover, **maintenance certifications are needed to attract global demand**, with FAA (USA) and EASA (Europe) being the most important certifications. **International partnerships may also be important for attracting demand**, and geographically close countries with higher levels of sector development, such as Mexico and Brazil, can be important allies.

GENERAL RECOMMENDATIONS

Technical training for employees is needed in order to provide specialized services. It is therefore crucial **to establish or strengthen technical training centers**. It is important to train employees in the areas of the aerospace industry and constantly monitor, include, and improve the courses by incorporating new technologies. **Interaction between public and private agents is important, but in the case of nascent industries, the government (usually represented by the Ministry of Education) may be supported by multilateral institutions and ally countries**. In the short term, attracting foreign professionals (work visas) and providing international education through specific programs (even virtually) may be temporary measures that can compensate for domestic education deficiencies.

In addition, **adequate transportation infrastructure must be provided**. As the provision of services is often carried out on the aircraft itself, MRO services must have adequate infrastructure at airports. The facilities must be prepared to receive aircraft consistent with the services to be provided. Additionally, local suppliers must be provided with sufficient infrastructure in the form of other modes of transport delivering products and receiving inputs.

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Appendix

Table A.1.
Classification of products in the stages of the aerospace industry value chain

VC STAGE	HS PRODUCT CATEGORY	HS CODE	DESCRIPTION
Final products	Balloons	880100	Balloons and dirigibles, gliders, hang gliders and other non-powered aircraft.
	Helicopters	880211	Helicopters; of an unladen weight not exceeding 2000kg
		880212	Helicopters; of an unladen weight exceeding 2000kg
	Airplanes	880220	Airplanes and other aircraft; of an unladen weight not exceeding 2000kg
		880230	Airplanes and other aircraft; of an unladen weight exceeding 2000kg but not exceeding 15,000kg
		880240	Airplanes and other aircraft; of an unladen weight exceeding 15,000kg
	Spacecraft	880260	Spacecraft; (including satellites) and suborbital and spacecraft launch vehicles
Sub-assemblies	Landing gear	880320	Aircraft and spacecraft; under-carriages and parts thereof
	Aircraft parts & assemblies (generic)	880330	Aircraft and spacecraft; parts of airplanes or helicopters n.e.c. in heading no. 8803
	Propellers & rotors	880310	Aircraft and spacecraft; propellers and rotors and parts thereof
	Other parts	880390	Aircraft and spacecraft; parts thereof n.e.c. in chapter 88
	Main Engine (propulsion)	841111	Turbo jets; of a thrust not exceeding 25kN
		841112	Turbo jets; of a thrust exceeding 25kN
		841121	Turbo-propellers; of a power not exceeding 1100kW
		841122	Turbo-propellers; of a power exceeding 1100kW
	Other engines (other on-board engines)	840710	Engines; for aircraft. spark-ignition reciprocating or rotary internal combustion piston engines
		841210	Engines; reaction engines. other than turbo jets
	Launching gear	880510	Aircraft launching gear. deck-arrestor or similar gear and parts thereof
	Ground trainers	880521	Ground flying trainers and parts thereof; air combat simulators and parts thereof
		880529	Ground flying trainers and parts thereof; other than air combat simulators and parts thereof
	Interior	940110	Seats; of a kind used for aircraft
Components	Main engine	841191	Turbines; turbojets and turbo propeller parts
	Other engines	840910	Engines; aircraft engine parts (spark-ignition reciprocating or rotary internal combustion piston engines)
	Landing gear	401130	Rubber; new pneumatic tires. of a kind used on aircraft
		401213	Retreaded tires; of a kind used on aircraft
	Electronic instruments	901420	Navigational instruments and appliances; for aeronautical or space navigation (excluding compasses)

Source: Prepared by the authors based on Bamber and Gereffi (2013), Bamber et al. (2016) and Caliari et al (2021).

Table A.2.
IPC classes related to the aerospace industry included in this study

IPC CODE	DESCRIPTION
B64B	Lighter-than-air aircraft
B64C	Airplanes; helicopters
B64D	Equipment for fitting in or to aircraft; flying suits; parachutes; arrangements or mounting of power plants or propulsion transmissions in aircraft
B64F	Ground or aircraft-carrier-deck installations specially adapted for use in connection with aircraft; designing. manufacturing. assembling. cleaning. maintaining or repairing aircraft. not otherwise provided for; handling. transporting. testing or inspecting aircraft components. not otherwise provided for
B64G	Cosmonautics; vehicles or equipment therefor
G01W 1/08	Aircraft for meteorological use
G05D 1/00	Control of position. course or attitude of aircraft
A62C 3/08	Fire prevention. containment or extinguishing specially adapted for particular objects or places in aircraft
G01C	Measuring course or position of aircraft
A47C	Seats for aircraft
G09B	Teaching the control of aircraft
E06B	Windows for aircraft
G01C 21/24	Measuring course or position for cosmonautics
F02K	Jet-propulsion plants

Source: Prepared by the authors.

Table A.3.
Embraer main clients

MAIN CLIENTS (COMMERCIAL AIRJETS)	Backlog (E-jet family)
SkyWest	Azul
Republic	AerCap
Envoy Air	AirCastle
Mesa	AirPeace
JetBlue	
KLM Cityhopper	
Azul	
Aeromexico	
J-Air	
Air France HOP	
Horizon Air.	

Source: Embraer.

Table A.4.
Embraer productive sites

PRODUCTIVE SITES			
BRAZIL	MEXICO	EUA	PORTUGAL
São José dos Campos (SP)	Chihuahua	Melbourne	Évora
		Jacksonville	Alverca
		Titusville	

Source: Embraer.

Table A.5.
Classification of activities, Aerospace industry

PROPOSED RECLASSIFICATION	PRIMARY CLASSIFICATION
PRIME CONTRACTOR	OEM (ORIGINAL EQUIPMENT MANUFACTURER)
R&D/Engineering	Research and Development
	Engineering services
	Computational Fluid Dynamics
	Integration Services
Systems	Avionics
	Electronic systems
	Software development
	Navigation systems and equipment
	Communication Systems
	Electrical supplies, wiring
	Engine and Equipment Systems
	Environmental system
	Fuel system
	Landing Gear System
	Mechanical System
	Ground support equipment
	Flight simulators, trainers
Manufacturing	Mounting
	Tooling
	Aircraft Devices and Parts
	Structures
	Press Shop
	Machining
	Compounds
	Special process
	Interior and Interior design

Defense and space system	Advanced Defense Systems
	Missiles and Weapons
	Space systems and equipment
Basic Materials	Adhesives and coatings
	Industrial Chemicals and Supplements
	Painting
	Raw material sources
Specialized services	In-flight data acquisition and analysis
	Geoprocessing, Remote Sensing
	Surveillance
	Tests and Certification
	Industrial Metrology
	Documentation
	Logistics
	Technical Support
	Training
	Consulting
MRO	Inspection
Flight services	Air Traffic
	Airport services
Others	Transparency
	Other

Source: Prepared by the authors with initial classification from Brazilian Aerospace Cluster.

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