United States Government Accountability Office

Report to Congressional Requesters

March 2024

COMMERCIAL AVIATION MANUFACTURING

Supply Chain Challenges and Actions to Address Them

GAO-24-106493

March 2024

COMMERCIAL AVIATION MANUFACTURING

Supply Chain Challenges and Actions to Address Them

GAO Highlights

Highlights of GAO-24-106493, a report to congressional requesters

Why GAO Did This Study

Aviation manufacturing is a major economic driver in the United States, with the largest trade balance (exports minus imports) among all U.S. manufacturing sectors. A global network of manufacturers and suppliers provides the aircraft and components that airlines in the United States rely on to support their operations. Aircraft manufacturers and their suppliers have faced headwinds in recent years, including steep declines in orders for new aircraft and supply chain disruptions brought on by the COVID-19 pandemic in 2020. As airlines respond to the rebound in demand for air travel that began in 2021, aviation manufacturers' ability to provide new aircraft and parts is key to airlines' efforts to maintain and grow their operations.

GAO was asked to examine challenges facing the aviation manufacturing supply chain. This report describes (1) what is known about demand for and production of new aircraft and parts since 2020, (2) factors affecting manufacturers' production of new aircraft and parts and actions to mitigate these factors, and (3) how airlines have been affected by the availability of new aircraft and parts to support their operations.

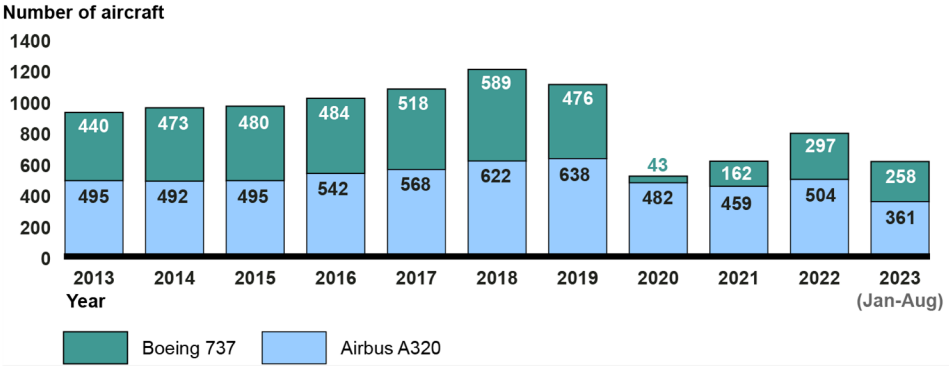
GAO analyzed data on new aircraft orders and deliveries from Boeing and Airbus along with data on aircraft production from Aviation Week Network for 2013 through 2023. GAO interviewed a non-generalizable sample of 38 stakeholders—including manufacturers and airlines—who were selected to achieve a range of perspectives.

View GAO-24-106493. For more information, contact Heather Krause at (202) 512-2834 or krauseh@gao.gov.

What GAO Found

Orders for new commercial aircraft have rebounded since they declined in 2020. However, the two main manufacturers of commercial aircraft—Boeing and Airbus—have faced challenges in increasing production of their most popular models—the Boeing 737 and Airbus A320—to meet demand. Steps Boeing and FAA are taking to ensure safety after a January 2024 in-flight failure of a section of the fuselage have also affected Boeing's production levels early in 2024. Additionally, of the 15 companies GAO interviewed that supply components to Boeing and Airbus, nine said that they have likewise had difficulty filling orders with the rebound in demand following the COVID-19 pandemic.

Estimated Number of Boeing 737 and Airbus A320 Aircraft Produced, 2013–2023



Source: GAO analysis of Aviation Week Network data. | GAO-24-106493

Manufacturers attributed these production challenges to workforce and material shortages and are working to mitigate them. Fifteen of the 17 manufacturers GAO spoke to said they or their suppliers have had difficulty hiring enough skilled workers to enable them to satisfy the demand for their products. Six manufacturers said that difficulty hiring sufficient workers may be related to difficult or hazardous working conditions that some of these jobs entail, such as the use of toxic chemicals. Some manufacturers reported offering financial incentives and working with local schools to build interest in aviation careers to address their workforce needs. Further, fifteen manufacturers said that they or their suppliers have had difficulty procuring materials needed to complete their orders. Material shortages included a broad range of items, such as engines and semiconductors as well as raw materials like aluminum. To address these material shortages, manufacturers said they have increased monitoring of suppliers and established additional sources for some supplies.

Airlines reported making changes to scheduled flights and developing ways to safely extend the life of some parts, among other actions, due to the difficulty obtaining new aircraft or the parts needed to maintain their current fleet. Seven of the eight airlines GAO spoke with reported delays of new aircraft they had expected to receive in 2023, and all eight airlines said they have had trouble obtaining a broad range of parts needed to maintain their fleets. Parts in short supply included small hardware like nuts and bolts as well as specialized items like cockpit windows and engine components.

Contents

Abbreviations

BLS	Bureau of Labor Statistics
CHIPS	Creating Helpful Incentives to Produce Semiconductors
DOT	Department of Transportation
FAA	Federal Aviation Administration
IATA	International Air Transport Association

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
441 G St. N.W.
Washington, DC 20548

March 6, 2024

The Honorable Sam Graves
Chairman
Committee on Transportation and Infrastructure
House of Representatives

The Honorable Garret Graves
Chairman
Subcommittee on Aviation
Committee on Transportation and Infrastructure
House of Representatives

The U.S. commercial airline industry is supported by a global network of manufacturers and suppliers that provide the aircraft and components integral to maintaining mobility for passengers and cargo. In addition to its role in supporting air transportation, aviation manufacturing is a major economic driver in the United States. The U.S. aerospace sector, which includes aviation manufacturing, has the highest trade balance (the value of goods exported minus the value of goods imported) and the second highest level of exports among all manufacturing sectors.[1]

The aviation manufacturing industry has faced severe headwinds in recent years, including in 2019 when 120 orders for Boeing's 737 MAX aircraft were cancelled or changed following the Federal Aviation Administration's (FAA) grounding of the plane after two fatal accidents.[2] In January 2024, after the in-flight failure of a fuselage section, FAA issued an emergency airworthiness directive prohibiting the operation of some Boeing 737 MAX-9 aircraft until the aircraft were inspected and

[1]According to the Department of Commerce's International Trade Administration, in 2019, the U.S. aerospace sector had a trade balance of $77.6 billion, with total exports valued at $148 billion.

[2]On March 13, 2019, FAA issued an emergency order prohibiting the operation of the Boeing 737 MAX-8 and MAX-9 by U.S. certificated operators in response to the crashes of Lion Air Flight 610 in Indonesia on October 29, 2018, and Ethiopian Airlines Flight 302 on March 10, 2019. FAA rescinded the emergency order on November 18, 2020, which enabled operation of the aircraft after satisfaction of certain requirements for return to service.

corrective actions performed.[3] FAA's latest action comes on the heels of challenges the industry faced during the COVID-19 pandemic including travel restrictions, steep declines in demand for new aircraft, and supply chain disruptions.[4] As airlines respond to the rebound in demand for air travel that began in 2021, aviation manufacturers' ability to provide new aircraft and parts for safe operations is key to airlines' efforts to maintain or increase their operations.

Within the Department of Transportation (DOT), FAA has oversight of the aviation industry, including regulating the safety of aircraft and replacement parts that are manufactured for use in commercial aircraft. You asked us to examine challenges facing the aviation manufacturing supply chain. This report describes:

1. what is known about the demand for and production of new aircraft and parts since 2020;
2. selected manufacturers' perspectives on factors affecting production of new aircraft and parts as well as current and potential actions to mitigate these factors; and
3. how the availability of new aircraft and parts has affected airlines' operations.

To address the first objective, we analyzed Boeing and Airbus financial filings and data on aircraft orders, production, and deliveries. We focused our work on Boeing and Airbus and their suppliers because they are currently the main manufacturers of commercial aircraft, as we discuss later in the report. We also analyzed data developed by Aviation Week Network to estimate new aircraft production rates.[5] Based on our review of these data to identify errors and discussions with Aviation Week

[3]On January 5, 2024, a door plug (used to fill the space in the fuselage left by an unused exit) failed mid-flight on a Boeing 737 MAX-9, causing a rapid depressurization in the aircraft cabin. According to the National Transportation Safety Board, this incident resulted in minor injuries to seven passengers and one flight attendant. See National Transportation Safety Board, Aviation Investigation Preliminary Report: DCA24MA063, (Washington, D.C.: Feb. 6, 2024). FAA subsequently issued an emergency airworthiness directive prohibiting flight of some 737 MAX-9 aircraft until corrective actions could be performed.

[4]For additional discussion of the impacts of the 2019 737 MAX grounding and COVID-19 on the aviation manufacturing industry, see GAO, *COVID-19 PANDEMIC: Observations on the Ongoing Recovery of the Aviation Industry*, GAO-22-104429 (Washington, D.C.: Oct. 21, 2021).

[5]Aviation Week Network is an industry publication providing reporting, data, and analysis on the commercial aviation, aerospace, and defense sectors.

Network, Boeing, and Airbus about the data, we found these data to be sufficiently reliable for the purpose of providing contextual information about changes in aircraft orders, deliveries, and production over time. In addition, we interviewed or received written responses from representatives of a non-generalizable sample of 17 aviation manufacturers (further discussed below) to learn about the state of demand for and production of new aircraft and parts since 2020.

To address the second objective, we interviewed or received written responses from representatives of a non-generalizable selection of aviation manufacturing stakeholders between February and November of 2023. These stakeholders included three industry associations, three industry analysts, and 17 aviation manufacturers. Among manufacturers, we interviewed Boeing and Airbus, all four major commercial aircraft engine manufacturers,[6] and 11 other manufacturers of component parts and suppliers of raw materials whom we selected to achieve a range of perspectives based on the type of component produced. We selected the 11 other manufacturers based on referrals from other stakeholders and random selection from among the manufacturers that supply components and materials to Boeing and Airbus.[7] We analyzed the responses of the manufacturers to identify common factors affecting manufacturing, actions taken to address these factors, and opportunities for FAA to help address these factors. Additional information on this analysis and the stakeholders we interviewed is included in appendix I. We also conducted a site visit to the Seattle, Washington, area to tour manufacturer facilities. We chose that location due to the concentration of aviation manufacturers in the area. We conducted the majority of our audit work before the January 2024 in-flight failure of a 737 MAX-9 door panel and subsequent actions FAA and Boeing reported taking in response. We did not assess what effects those actions may have on the demand for or production of new aircraft and parts or on airlines' operations.

[6]We interviewed or received written responses from engine manufacturers Pratt & Whitney, Rolls Royce, GE, and Safran. GE and Safran manufacture aircraft engines in a joint venture under the umbrella CFM International.

[7]We selected manufacturers from lists of recent Boeing and Airbus suppliers developed by S&P Capital IQ, a market intelligence firm. Based on our review of S&P Capital IQ's methodology, we found these lists sufficiently reliable for the purpose of identifying a universe of manufacturers from which to make our selections. We randomly selected manufacturers using a tiered methodology to ensure that our selection included a variety of company types, including variety in the type of components or materials supplied and variety of company sizes.

In addition, we analyzed data relevant to factors identified by stakeholders as affecting production from the Bureau of Labor Statistics (BLS) on changes in (1) aviation manufacturing employment, (2) wages and salaries of aviation manufacturing workers, and (3) material supply costs. Based on our review of BLS documentation, we determined these data were sufficiently reliable for the purpose of providing contextual information about labor and material costs in the aviation manufacturing industry. We reviewed FAA and DOT documents relevant to the aviation manufacturing supply chain, such as those related to standards for additive manufacturing. We interviewed FAA and DOT officials regarding actions these agencies have taken and opportunities for further action identified by stakeholders to address the supply chain challenges discussed in this report.

To address the third objective, we reviewed industry reports, airline financial filings, and market forecasts. We also analyzed information provided by airlines and maintenance providers on delays in obtaining new aircraft and parts. Based on our review of this information for errors and on our discussions with company representatives, we found this information sufficiently reliable for the purpose of providing contextual information about delays selected airlines experienced obtaining new aircraft and parts and about the effect of those delays on their operations. In addition, between February and November 2023 we interviewed representatives of a non-generalizable selection of four industry associations representing airlines, airports, and maintenance providers; one industry analyst; eight commercial passenger and cargo airlines; and three maintenance providers. We selected industry associations and the industry analyst based on prior GAO work and recommendations from other stakeholders. We selected maintenance providers based on recommendations from other stakeholders as well as random selection from an industry directory.[8] We selected airlines from DOT's 2022 list of 18 major U.S. commercial airlines to achieve a range of airline services and operating models, including both cargo and passenger airlines,

[8]Aircraft maintenance and repair services are commonly referred to as maintenance, repair, and overhaul (or "MRO"). In this report, we refer to companies providing these services as maintenance providers.

regional airlines, and low-cost airlines.[9] We analyzed the responses of airlines and maintenance providers to identify common themes. Additional information on this analysis and the stakeholders we interviewed is included in appendix I.

We conducted this performance audit from January 2023 to March 2024 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

[9]Department of Transportation, A*irline Quarterly Financial Review; Third Quarter 2022: Majors* (Washington, D.C.: 2022). DOT's Office of Aviation Analysis reviews air carrier financial data to group airlines according to operating revenue. DOT defines "major" airlines as those with annual operating revenues exceeding $1 billion. For quarter 3 of 2022, the eight airlines we selected account for about 36 percent of all U.S. revenue air miles (miles flown while transporting passengers or cargo in exchange for payment) and 40 percent of U.S. revenue air miles by the 18 major airlines.

Background

Aviation Manufacturing Supply Chain

Thousands of manufacturers and raw material suppliers make up the global aviation manufacturing supply chain.[10] The United States is a net exporter of aerospace products, and most U.S. imports of aviation products come from five countries: France, Canada, Japan, Germany, and the United Kingdom.[11] Companies involved in the aviation manufacturing supply chain include aircraft manufacturers, component manufacturers, and raw materials suppliers, as described below.[12]

As we and others have previously reported, supply chains can be vulnerable if they depend on small numbers of suppliers.[13] In 2002, the Commission on the Future of the United States Aerospace Industry reported that consolidation in the aerospace industry beginning in the mid-1990s had resulted in a reduction of the number of U.S.-based aerospace firms, as companies sought to maximize resources.[14] Compounding this, aviation manufacturing has high barriers to entry, which may limit the number of companies able to compete in the industry. For example, as DOT's Office of Inspector General reported in 2022, developing and testing aviation components—including the process of

[10]The aviation manufacturing supply chain is often discussed together with the defense industrial base—jointly referred to as the aerospace and defense industry—because of the frequent overlap in companies that supply the commercial airline industry and defense agencies. For example, Boeing and Airbus both produce military aircraft in addition to commercial aircraft.

[11]Department of Transportation Office of Inspector General, *DOT's Tracking of Aviation Imports and Potential Impacts of Disruptions*, AV2023009 (Washington, D.C.: Dec. 19, 2022). This analysis of aviation imports excludes products associated with drones.

[12]Throughout this report, we refer to aircraft manufacturers, component manufacturers, and raw materials suppliers generally as "manufacturers," but we differentiate when referring to a specific type of manufacturer. We use the terms "component" and "part" interchangeably.

[13]See, for example, GAO, *Supply Chain Resilience: Agencies Are Taking Steps to Expand Diplomatic Engagement and Coordinate with International Partners,* GAO-23-105534 (Washington, D.C.: Feb. 2, 2023) and Department of Transportation Office of Inspector General, *DOT's Tracking of Aviation Imports*.

[14]Commission on the Future of the United Stated Aerospace Industry, *Final Report* (Arlington, VA: Nov. 2002). The commission was established by section 1092 of the Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001 to, among other things, assess the future importance of the U.S. aerospace industry for the economic and national security of the United States. Pub. L. No. 106-398, § 1092, 114 Stat. 1654, 1654A-300 (2000).

obtaining FAA's safety approval—can cost more than $1 million and take several years to complete.[15]

Aircraft manufacturers: Boeing and Airbus each manufacture narrow and wide-body aircraft, including several different families of aircraft with varying specifications. Narrow-body aircraft generally have a single aisle and are used to transport fewer passengers or smaller amounts of cargo over relatively shorter distances. In comparison, wide-body aircraft are larger, frequently have twin aisles, and are used to transport larger numbers of passengers or larger amounts of cargo over greater distances. Within each aircraft family, manufacturers typically offer different models and configurations that vary in size and other specifications. Boeing, an American company, produces narrow-body aircraft such as the 737 family and wide-body aircraft such as the 787 family.[16] Boeing has major production facilities in Washington state and South Carolina. Airbus, headquartered in the Netherlands and France, produces narrow-body aircraft such as the A320 family and wide-body aircraft such as the A350.[17] Airbus has production facilities throughout Europe as well as in Alabama in the United States.

Component manufacturers and raw materials suppliers: Boeing and Airbus depend on many different manufacturers, located in the United States and globally, to supply components for the final aircraft. For example, according to Boeing, approximately 700 suppliers support production of its 737 aircraft, which are each composed of about 2 million separate parts. These companies range in size and type from those producing a wide variety of aircraft components with thousands of employees to highly specialized firms with fewer than 100 employees. In addition to supplying parts for new aircraft, component manufacturers supply parts and materials needed for the maintenance and repair of existing aircraft fleets. Examples of the different types of components and

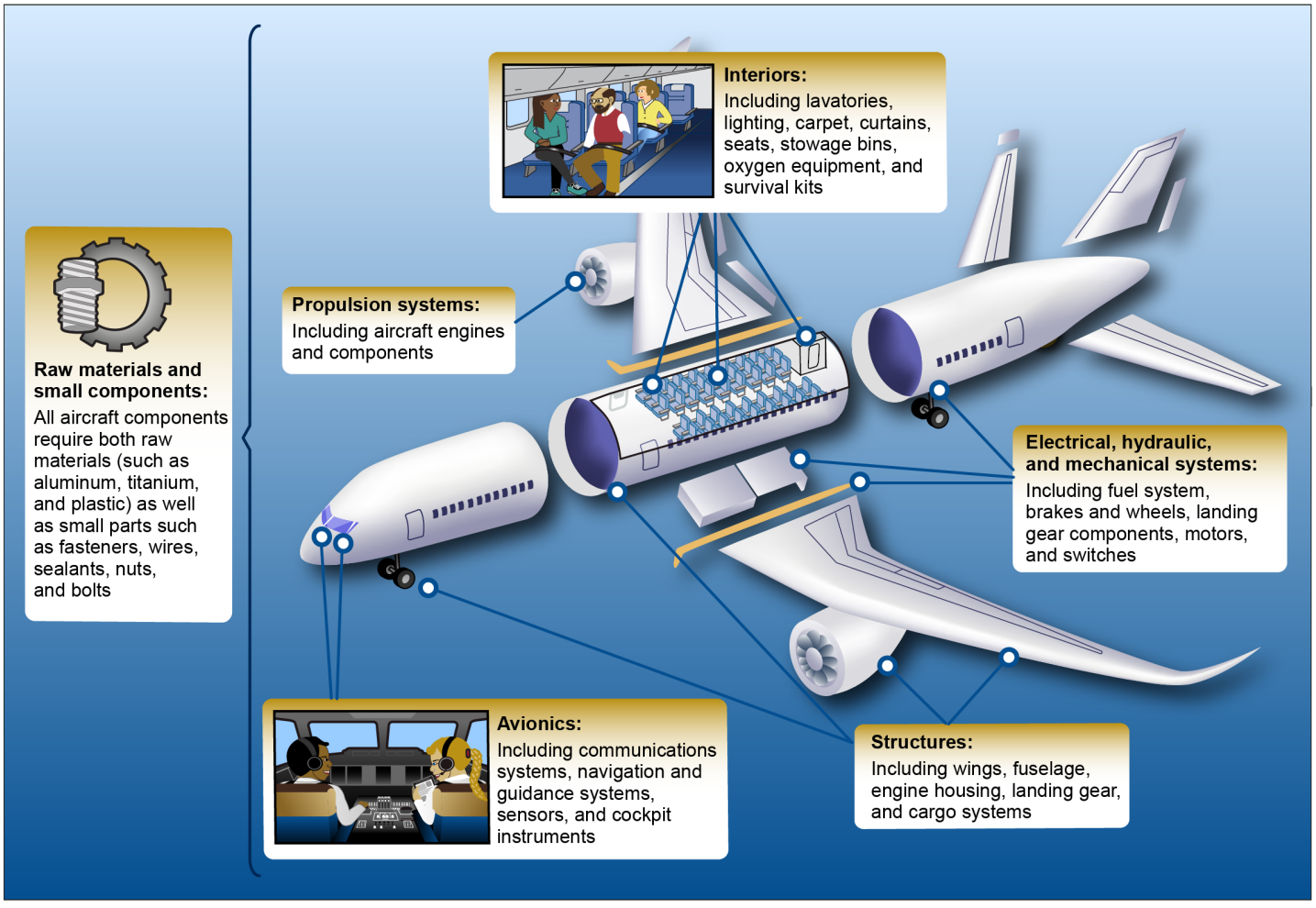
[15]Department of Transportation, Office of Inspector General, *DOT's Tracking of Aviation Imports*.

[16]Within the 737 family of aircraft, Boeing currently produces the 737 MAX, of which it offers several configurations including the 737-7, 737-8, 737-9, and 737-10. These configurations vary in length, the amount of space for cargo and passengers, and range of the aircraft. Within the 787 family, Boeing currently produces the 787-8, 787-9, and 787-10, which also vary in length, space, and range.

[17]Within the A320 family of aircraft, Airbus currently produces the A319, A320, and A321—varying in length, space, and range—and offers a choice of engines. For instance, Airbus offers the A320neo, with neo denoting use of the "new engine option."

materials needed to build and maintain commercial aircraft are illustrated in figure 1.

Figure 1: Examples of Commercial Aircraft Components



Source: GAO summary of Boeing and Airbus information, GAO (illustrations), and Anshuman/stock.adobe.com. | GAO-24-106493

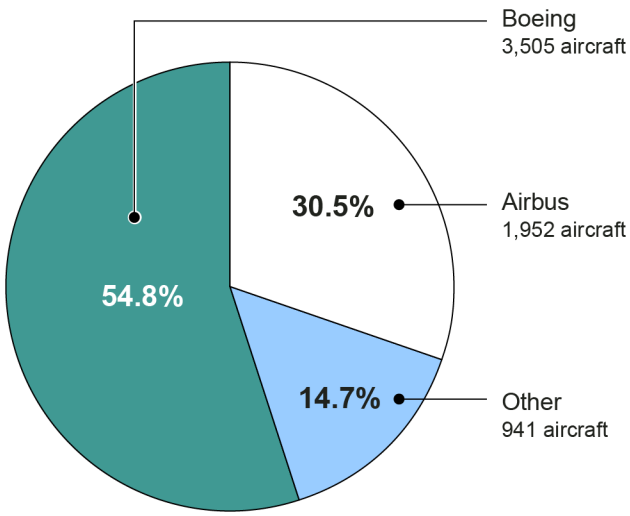
Manufacturing lead times: New aircraft and major components such as engines typically require long amounts of time between the customer's order and when the product can be delivered (referred to as "lead time"). They must be ordered far in advance so that manufacturers can acquire the parts and materials needed for final assembly. Boeing representatives told us the company can assemble a 737 in a matter of days once it has all the needed supplies at the final assembly facility, but it orders

materials and components from suppliers months or years in advance of when they are needed.

Commercial Airline Fleet

More than 85 percent of the current in-service aircraft among the 18 major U.S. passenger and cargo airlines were manufactured by Boeing or Airbus, as shown in figure 2. Of the 18 major airlines, the three regional passenger airlines generally operate smaller aircraft manufactured by Embraer and Bombardier.

Figure 2: In-Service Aircraft Fleet for Major U.S. Airlines, by Manufacturer, as of September 2023



Source: GAO analysis of Cirium data. | GAO-24-106493

Note: "Other" includes Embraer, Bombardier, Cessna, Dassault Aviation, and ATR Aircraft.

Aircraft Maintenance

Airline fleets require periodic maintenance and repair, which may be conducted by the airlines or a third-party maintenance provider. FAA regulations direct airlines to ensure that all in-service aircraft receive regularly scheduled inspections and maintenance, such as engine overhauls and replacement of certain parts, and that aircraft receive any unscheduled repairs needed to adhere to minimum equipment standards.[18] According to airline financial data, in 2022, the 18 major U.S.

[18]*See, e.g.,* 14 C.F.R. §§ 121.363, 135.413; *see also* FAA, Advisory Circular 120-16G: Air Carrier Maintenance Programs, Jan. 4, 2016.

airlines spent more than 12 percent of their total operating budgets on maintenance, nearly $16 billion.[19]

Federal Role in Supporting the Aviation Supply Chain

Federal agencies are not responsible for ensuring that the aviation manufacturing supply chain produces sufficient parts and aircraft to meet customer demand. However, federal policymakers sometimes take actions to support an industry—including the aviation manufacturing industry—based on the industry's importance to national and economic security. Although the scope of this report is limited to aviation manufacturing, we have included examples of federal actions applicable to manufacturing more broadly to provide additional context on the breadth of possible actions to address manufacturing challenges.

One example of such federal action is title III of the Defense Production Act. This act allows federal agencies to provide domestic firms with financial incentives to invest in production capabilities, so as to ensure that the domestic industrial and technological base can meet national defense needs.[20] A recent use of this provision is the Department of Defense's agreement with Spirit AeroSystems, a manufacturer of structural components for commercial and defense aircraft.[21] According to press releases from the Department of Defense and Spirit AeroSystems, the agreement provides funds for the company to upgrade its Kansas facility to improve domestic capacity to meet defense needs and to help maintain critical skills in the defense industrial base.

Additionally, the Consolidated Appropriations Act, 2023 included a provision for DOT to establish a task force to identify and assess risks to the United States's aerospace supply chains and identify best practices and recommendations to mitigate those risks.[22] DOT established the

[19]Data on maintenance spending are submitted by airlines to DOT through DOT Form 41. These data are maintained by DOT's Bureau of Transportation Statistics. We obtained these data from Cirium, a private contractor that provides online access to U.S. airline financial, operational, and passenger data with a query-based user interface.

[20]*See* generally 50 U.S.C. §§ 4531–34.

[21]Department of Defense, *DOD Announces $135 Million in Defense Production Act Title 3 COVID-19 Actions,* June 10, 2020.

[22]Consolidated Appropriations Act, 2023, Pub. L. No. 117-328, div. Q, § 106, 136 Stat. 4459, 5255–57 (2022).

Aerospace Supply Chain Resiliency Task Force in December 2023 and held an initial meeting of the task force in January 2024.[23]

FAA's Oversight of Aviation Manufacturing and Aircraft Maintenance

Aviation Manufacturing

FAA certifies the design and production of aircraft and aircraft parts to certain regulatory standards. FAA issues production approvals to manufacturers, authorizing the production of parts used for new aircraft and maintenance, repair, and modification. According to agency officials, FAA does not directly oversee the entities supplying materials and components to manufacturers. Rather, manufacturers with production approvals are responsible for ensuring their suppliers adhere to design requirements for each type of aircraft or part, and FAA oversees the process by which manufacturers exercise this control. As part of this oversight, the FAA Aircraft Certification Service conducts supplier control audits to determine if the production approval holders have effective controls in place to ensure the supplied parts meet the FAA-approved design. In some cases, companies may be production approval holders for some parts—and therefore subject to FAA oversight regarding those parts—while they act as suppliers to other companies that hold production approvals for other parts.

As we and the DOT Office of Inspector General have recently reported, FAA is in the process of evaluating and implementing changes to its certification process to address investigative findings and legislative changes following the 2019 grounding of the Boeing 737 MAX.[24]

[23]The statute, which was enacted December 29, 2022, required that the Secretary of Transportation establish the task force not later than 90 days after enactment and that the task force "convene for an initial meeting not later than 120 days after the date of enactment." Pub. L. No. 117-328, div. Q, § 106, 136 Stat. at 5255–56.

[24]Independent reviews of FAA's certification process—under which the 737 MAX was certified—identified areas of weakness in FAA's certification process requiring FAA actions to improve. For example, recommendations to FAA include examining and clarifying the role of manufacturers in the certification process. The Aircraft Certification, Safety, and Accountability Act, enacted in December 2020, also requires FAA to make certain changes to how it carries out and oversees its certification processes. Pub. L. No. 116-260, div. V. 134 Stat. 2309 (2020). For additional information, see Department of Transportation Office of Inspector General, *FAA Has Completed 737 MAX Return to Service Efforts, but Opportunities Exist to Improve the Agency's Risk Assessments and Certification Processes,* AV2023025 (Washington, D.C.: April 26, 2023) and GAO, *Aircraft Certification: Comparison of U.S. and European Processes for Approving New Designs of Commercial Transport Airplanes*, GAO-22-104480 (Washington, D.C.: June 30, 2022).

Additionally, after the January 2024 in-flight door plug failure, FAA initiated an investigation of Boeing's production system to ensure that all aircraft components conform to the approved design and are safe for operation.[25] In addition to this investigation and other actions, FAA announced plans to increase its presence at Boeing assembly facilities to improve monitoring and stated that it had obtained commitment from Boeing that the current 737 MAX production rate will not increase until FAA completes its review of Boeing's production system.[26]

Aircraft Maintenance

FAA requires that commercial passenger and cargo aircraft be maintained in accordance with specific standards for airworthiness established for each type of aircraft. For example, FAA regulations require that (1) airline maintenance programs ensure that in-service aircraft are airworthy and properly maintained, (2) maintenance and modification of in-service aircraft has been performed according to FAA's maintenance manual, and (3) airlines provide for competent personnel and adequate facilities and equipment to perform such maintenance and modification.[27]

[25]FAA initiated the investigation to examine compliance with 14 C.F.R. § 21.146, which requires that production certificate holders ensure each completed, certificated product or article conforms to its approved design and is in a condition safe for operation when presented for airworthiness approval.

[26]As a result of this incident, FAA issued an emergency airworthiness directive on January 6, 2024, prohibiting further flight of affected Boeing 737-9 MAX airplanes until the airplane is inspected and all applicable corrective actions have been performed using an FAA-approved method. On January 24, 2024, FAA approved an inspection process to be performed for each of the grounded aircraft prior to returning to service. Federal Aviation Administration, *FAA Halts Boeing MAX Production Expansion to Improve Quality Controls, Also Lays Out Extensive Inspection and Maintenance Process to Allow Boeing 737-9 MAX Aircraft to Return to Service*, (Washington, D.C.: Jan. 24, 2024).

[27]14 C.F.R. §§ 121.367, 135.425.

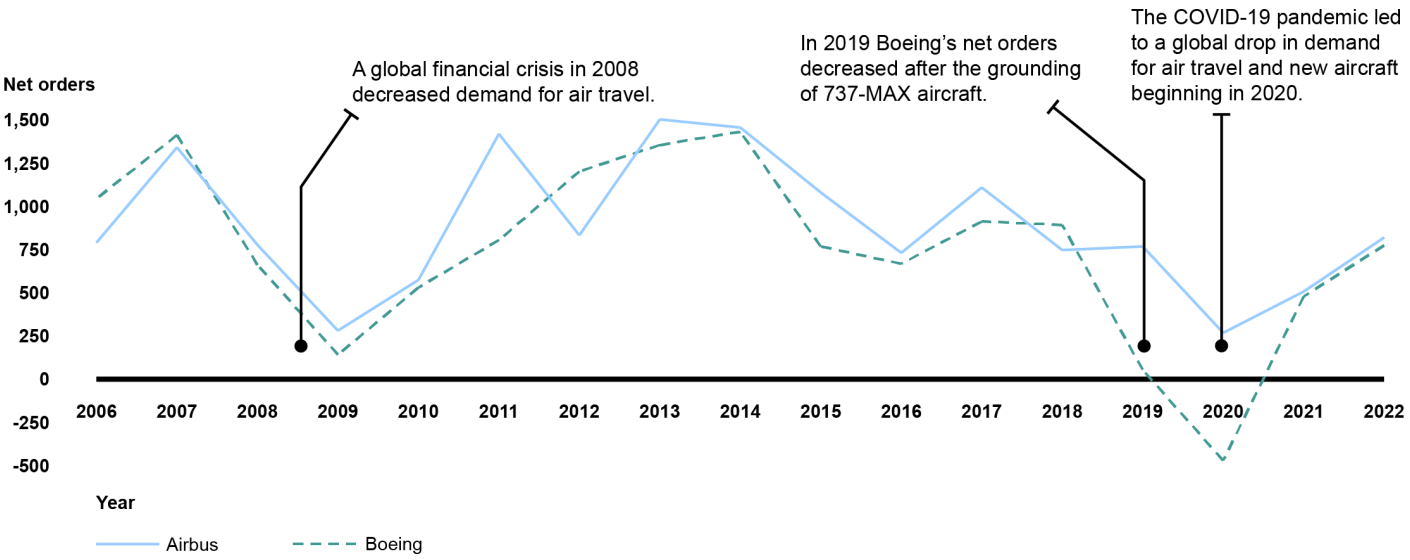
New Aircraft Demand Has Increased Since 2020, Outpacing Production of Aircraft and Needed Parts

Demand for New Aircraft Has Recovered from the COVID-19 Pandemic Slump

Since 2020, the number of new aircraft ordered (i.e., demand) from Boeing and Airbus has increased, and in 2022 demand was similar to 2018 levels. Figure 3 shows Boeing and Airbus net orders for commercial aircraft. Net orders is a metric that reflects demand for new aircraft by measuring the number of aircraft ordered each year minus the number of order cancellations. In 2022, Boeing and Airbus had net orders of 774 and 820, respectively, up from the recent low points in 2020.

Demand for new aircraft is affected by a variety of factors, including fluctuations in demand for passenger and cargo air transportation. In turn, the demand for air transportation tends to fluctuate in relation to the state of the economy as well as to political, international, and health-related events. Figure 3 illustrates how some of these past events have been correlated with decreased demand for new Boeing and Airbus aircraft.

Figure 3: Boeing and Airbus Net Commercial Aircraft Orders, 2006–2022



Source: GAO analysis of Federal Aviation Administration information and Boeing and Airbus data. | GAO-24-106493

Notes: Net orders are calculated by subtracting order cancellations in each year from total orders received that year. Negative orders can occur when the number of cancellations of orders made in prior years is greater than the number of new orders in that year.

On March 13, 2019, FAA issued an emergency order prohibiting the operation of Boeing 737 MAX series aircraft by U.S. certificated operators in response to the crashes of Lion Air Flight 610 in Indonesia on October 29, 2018, and Ethiopian Airlines Flight 302 on March 10, 2019. FAA rescinded the emergency order on November 18, 2020, which enabled operation of the aircraft after satisfaction of certain requirements for return to service.

Aircraft manufacturers also accumulate customer commitments that span several years—like an order placed in 2018 for aircraft delivery in 2023—which they refer to as their order backlog. Airbus reported an order backlog of more than 7,000 aircraft in 2018, and that number has largely remained unchanged through September 2023. Similarly, Boeing reported an order backlog of nearly 5,900 aircraft in 2018 and a little over 5,600 aircraft in 2023. In its 2018 annual report, Boeing reported that the backlog of nearly 5,900 aircraft would take about 7 years to clear based on production levels at the time. Thus, even if there were no new orders in a given year, Boeing and Airbus would need to maintain production to meet prior commitments to customers.

Aircraft and Component Manufacturers Have Had Difficulty Keeping up with Customer Demand

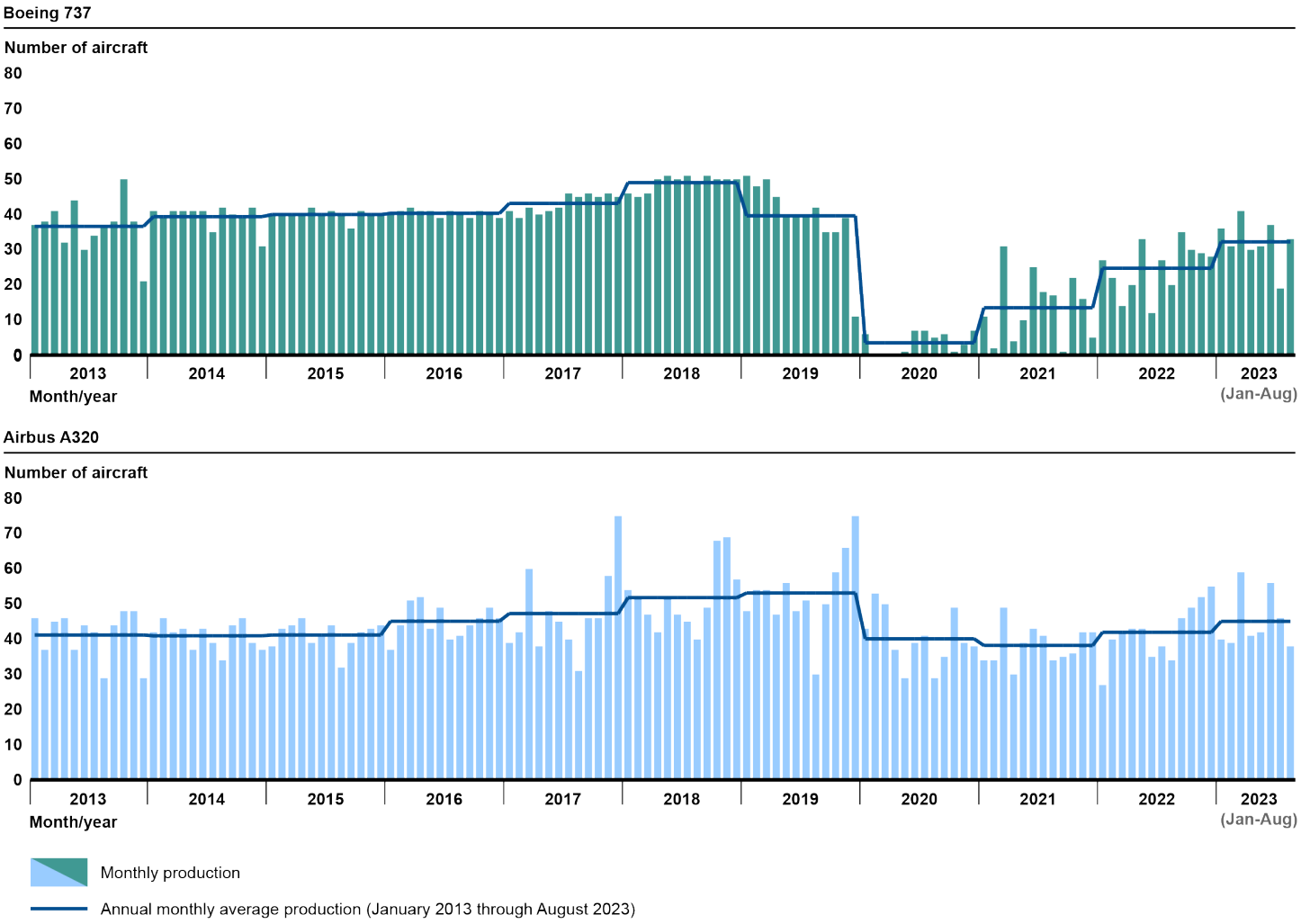
Aircraft Manufacturers

Boeing and Airbus have faced challenges meeting their production targets since demand for new aircraft returned in 2021, according to representatives of these companies. Representatives from both companies told us it has been challenging to increase and stabilize their monthly production rates for these aircraft at the pace needed to meet demand. Boeing representatives told us in the first half of 2023 that the company was working to increase production of the 737 MAX from 31 to 38 aircraft per month but had found it difficult to consistently meet 31 per month. In the third quarter of 2023, Boeing reported that it planned to transition to producing 38 of its 737 aircraft per month by year-end. Similarly, in its 2023 semiannual report, Airbus reported a goal of producing 75 A320 aircraft per month in 2026 even though it reported difficulty increasing production toward that goal. In comparison, in its 2021 annual report, Airbus stated a goal of increasing production of the A320 to a rate of 64 per month by the second quarter of 2023.

According to Aviation Week Network—an industry publication—average monthly production rates for the Boeing 737 and the Airbus A320 have increased since the low-demand period in 2020 but have not surpassed pre-COVID-19 and 2019 737 MAX grounding levels (see fig. 4).[28] For example, Boeing's average monthly production of the 737 is estimated to have increased from 25 in 2022 to 32 in the period from January through August 2023. Similarly, Airbus's average monthly production of the A320 is estimated to have increased from 42 in 2022 to 45 in the period from January through August 2023.

[28]Aviation Week Network collects data from a variety of sources on the manufacturing date for each aircraft produced by Boeing and Airbus—as well as those produced by other manufacturers—and uses the data to estimate production rate. Boeing and Airbus do not publicly report data on aircraft production rates. Aviation Week Network data are subject to revision and should be interpreted as estimates.

Figure 4: Estimated Production of Boeing 737 and Airbus A320 Aircraft, January 2013–August 2023



Source: GAO analysis of Aviation Week Network data. | GAO-24-106493

Notes: Aviation Week Network estimates the production date based on information from a variety of industry sources on, for example, the date an aircraft was rolled out of the manufacturing facility or the date of the first flight. Boeing and Airbus do not publicly report data on aircraft production rates. Aviation Week Network data are subject to revision and should be interpreted as estimates.

Data for 2023 include January through August.

Boeing and Airbus data on the number of finished aircraft delivered to airlines and other customers align with company statements about the difficulty in stabilizing production levels. Aircraft deliveries are not a perfect measure of production capacity because deliveries may be delayed for a variety of reasons, including customer preferences or

regulatory concerns. Nevertheless, total aircraft deliveries in 2022 were lower than pre-pandemic and pre-737 MAX grounding levels. In the first half of 2023, Boeing and Airbus reported delivering 266 and 316 aircraft, respectively, putting them on a path to delivering a similar number of aircraft in 2023 as in 2022. In the third quarter of 2023, Airbus reported delivering 172 aircraft, bringing the total deliveries during the first 9 months of 2023 to 488. Airbus reported that it was aiming to deliver around 720 aircraft by the end of 2023, more than its 2022 deliveries but lower than the 2019 level. However, in the third quarter of 2023, Boeing reported that it expected to deliver fewer 737 aircraft in 2023 than forecasted. Boeing reported delivering 105 aircraft in the third quarter of 2023, bringing the total deliveries during the first 9 months of 2023 to 371.

In the near term, Boeing's production levels for 737 aircraft have been affected by the actions Boeing and FAA announced in response to the January door plug failure, which preliminary information suggests may have been caused by manufacturing quality issues.[29] For instance, in its January 2024 call with investors about 4th quarter 2023 earnings, Boeing announced that in January 2024 it had paused production of the 737 for one day to focus staff on safety and quality. Further, according to FAA, Boeing has committed to not increasing the 737 MAX production rate until FAA completes its ongoing investigation to assess Boeing's compliance with manufacturing requirements. FAA has stated that its inspections of grounded 737 MAX-9 aircraft showed that the quality system issues at Boeing were unacceptable and require further scrutiny.[30] Additionally, the National Transportation Safety Board has an investigation underway to determine the cause of the door plug failure.

Component Manufacturers and Raw Material Suppliers

Nine of the 15 component manufacturers and raw material suppliers we interviewed told us that they have had difficulty filling orders for customers or that they have been unable to fill all orders in recent years. These manufacturers and suppliers provide parts and materials to Boeing and Airbus, airlines, and maintenance providers, among others. For example,

[29]The National Transportation Safety Board's preliminary investigation report states that their examination of the aircraft involved indicates that four bolts intended to prevent movement of the door plug were missing prior to the accident. National Transportation Safety Board, Aviation Investigation Preliminary Report: Accident Number DCA24MA063, February 6, 2024.

[30]Michael Whitaker, Administrator, Federal Aviation Administration, *The State of American Aviation and The Federal Aviation Administration*, testimony before the U.S. House of Representatives Committee on Transportation and Infrastructure, Subcommittee on Aviation, 118th Cong., 2nd sess., February 6, 2024.

one manufacturer of mechanical assemblies stated that in 2023—for the first time ever—it missed a delivery to an aircraft manufacturer customer. That same company stated that its production is still 40 percent below pre-COVID-19 levels, despite its efforts to ramp up production to meet demand.

On the other hand, six of the 15 component manufacturers and raw material suppliers we interviewed told us that they have been able to meet customer demand as of 2023. For example, one manufacturer of internal control systems told us that in 2023 the company has met all scheduled deliveries to its aircraft manufacturer customers. That same manufacturer said it had been able to meet demand largely due to certain aircraft production levels that are lower than they were before the COVID-19 pandemic.

However, because component and material production rates are closely tied to the number of new aircraft being produced, three of these companies stated they may have difficulty meeting demand if new aircraft production rates increase. For example, one manufacturer of structural assemblies stated that it will need to invest in increased production capacity to meet the future production levels aircraft manufacturers have targeted. That same manufacturer stated that, given the volatility in the market, the company will have to decide whether aircraft production rate increases are stable enough for the company to feel comfortable making investments in capacity to meet future targets.

Selected Manufacturers Said Difficulty Hiring and Material Shortages Have Affected Production, and Described Actions to Mitigate Challenges

Manufacturers Reported Difficulties Hiring Enough Sufficiently Skilled Workers and Identified Responsive Actions

Fifteen of the 17 manufacturers we spoke with stated that the difficulty that they or their suppliers have had in hiring enough sufficiently skilled workers has affected their ability to increase production and meet current demand. For example, one manufacturer of raw materials stated that its inability to hire enough skilled workers in one U.S. location has made it difficult for the company to justify moving forward with new projects that would require a large workforce increase. Similarly, one manufacturer said it has been trying to fill thousands of vacancies across its global operations to increase production capacity, including at one U.S. facility, but has been unable to hire workers at the rate they planned. Two of the 17 manufacturers, however, stated that their labor force has been sufficient to meet current demand.

Aviation manufacturing employment remained lower in 2023 than before the COVID-19 pandemic. As we reported in 2022, and as the DOT Office of Inspector General confirmed more recently, the aviation manufacturing industry experienced unprecedented upheaval and lost many employees during the COVID-19 pandemic through layoffs, retirements, and decisions to leave the industry.[31] Six manufacturers we spoke with stated that COVID-19 relief legislation helped them or their suppliers mitigate the loss of workers through the period of low demand during the pandemic.

[31]See GAO-22-105397, GAO-22-104429, and Department of Transportation, Office of Inspector General, *DOT Has Effectively Managed the Aviation Manufacturing Jobs Protection Program and Should Capture Lessons Learned from Its Oversight Efforts,* Report No. AV2023045 (Washington, D.C.: Sept. 19, 2023).

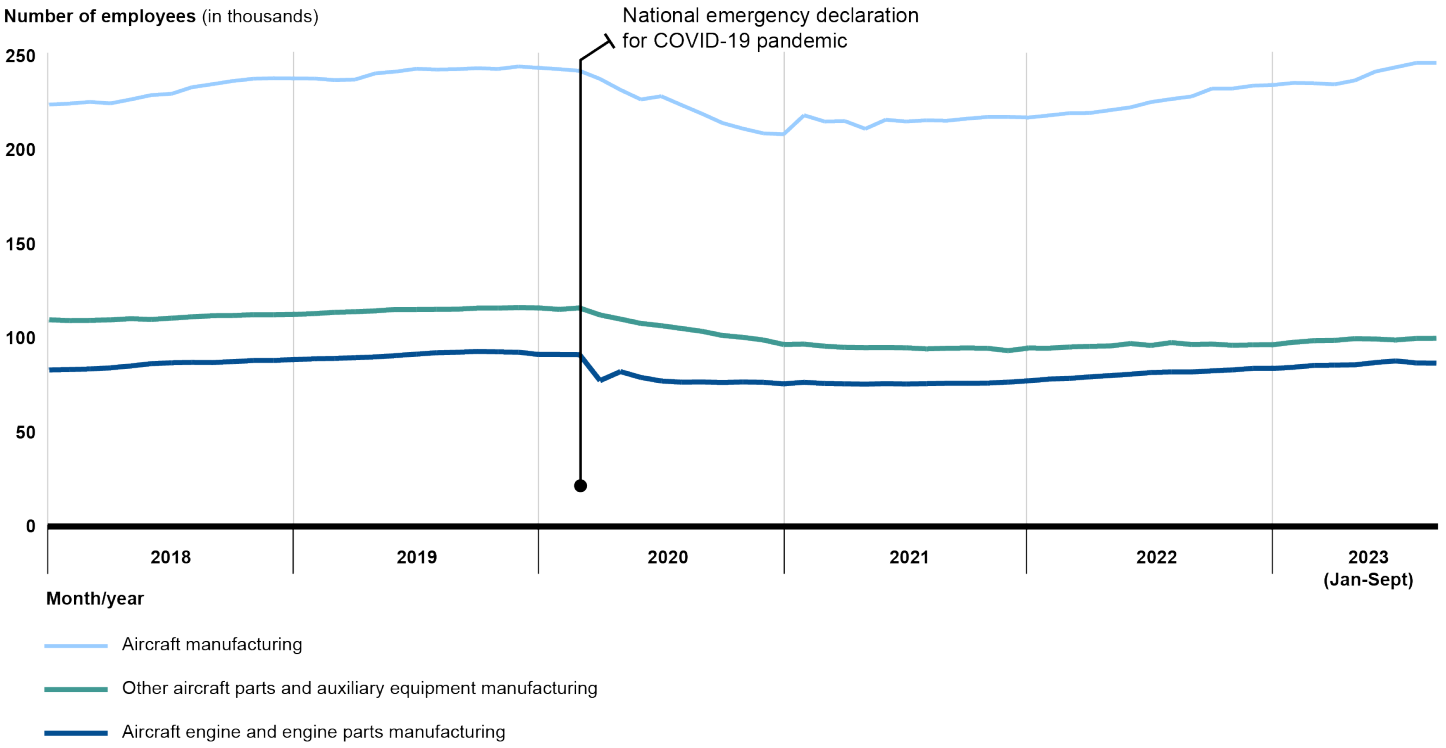
These programs included the Aviation Manufacturing Jobs Protection Program and Paycheck Protection Program.[32]

According to our analysis of BLS employment estimates, employment across several aviation manufacturing occupations has changed to varying degrees since the pandemic, as shown in figure 5.[33] While employment in all three of BLS's aviation manufacturing-related categories declined beginning in April 2020, only the aircraft manufacturing category had recovered to pre-COVID-19 levels, which it reached in July 2023.

[32]The DOT Office of Inspector General reported that the Aviation Manufacturing Jobs Protection Program awarded more than $664 million and had agreements with 584 companies to provide funds to either pay employee wages, salaries, and benefits or rehire furloughed personnel. That figure represented program obligations as of April 30, 2023. According to DOT officials, some companies did not incur sufficient allowable labor costs and therefore did not receive the full amounts originally awarded. According to these officials, as of September 30, 2023, the awards were updated to provide 583 recipients a total of more than $652 million through the Aviation Manufacturing Jobs Protection Program.

[33]BLS employment estimates for September 2023 are preliminary and subject to revision as of October 2023.

Figure 5: Estimated Aviation Manufacturing Employment, January 2018–September 2023



Source: GAO analysis of Bureau of Labor Statistics data and Centers for Disease Control information. | GAO-24-106493

Manufacturers we interviewed attributed the difficulties in hiring enough sufficiently skilled labor to three factors: (1) competition for workers, (2) the lack of skilled and experienced labor, and (3) labor cost increases.

- **Competition for workers**. Nine manufacturers told us they have found it difficult to compete within and outside the industry to hire workers. Six of the 17 manufacturers told us their difficulty finding workers may be related to difficult or hazardous working environments. For example, one manufacturer stated that one of its U.S. suppliers for nickel plating has been unable to hire enough workers because its processes involve toxic chemicals. Another manufacturer noted that it can be difficult for aerospace companies to compete because some employees now expect to be able to work from home. In a March 2023 report, the Council of Economic Advisers noted that throughout 2022, U.S. employment vacancy rates were

high and unemployment rates were low, indicating that labor demand was high relative to labor supply.[34]

- **Lack of skilled and experienced labor supply.** In addition to too few workers, eight of the 17 manufacturers we spoke with said that many workers lack the skills and experience needed for aviation manufacturing. For example, one manufacturer of raw materials stated that many of its experienced workers were laid off during the period of low demand, and the company is now having to hire and train workers without any previous manufacturing experience. Three manufacturers told us that having workers who are less skilled or experienced can result in reduced production because of inconsistencies in quality and components that do not meet required specifications. For instance, one manufacturer that supplies components to Boeing and Airbus stated that, in recent years, a higher percentage of components from its suppliers have not been made to specification, which the manufacturer attributed to a less experienced workforce. As a result, the manufacturer has needed to take time to correct the quality issue or return unusable components to the supplier, reducing their capacity to supply the finished structural components to Boeing and Airbus. In addition, according to a May 2023 workforce study on the aerospace and defense industry conducted by PwC for the Aerospace Industries Association, large numbers of retirement-aged employees with specialized skills, long tenures, and deep institutional knowledge may be preparing to leave the workforce, potentially exacerbating the lack of needed skills and experience in the competitive labor market.[35]
- **Labor cost increases.** Four of the 17 manufacturers we spoke to cited the increased cost of labor as a factor affecting their or their suppliers' ability to hire workers. For example, one manufacturer said labor cost increases reduce the number of workers they can afford to hire. Based on our analysis of BLS data on employment costs, wages and salaries for private industry workers in U.S. aircraft manufacturing increased, on average, 11 percent from September 2019 to

[34]Council of Economic Advisers, *The Annual Report of the Council of Economic Advisers,* (Washington, D.C.: Mar. 20, 2023). BLS uses the ratios of unemployed people per job opening to measure whether the labor market is tight or slack. When the ratios are less than 1.0, the labor market is tight, as job openings outnumber the unemployed. According to BLS's May 2023 *Monthly Labor Review*, throughout 2022, the ratio has been in a narrow range of 0.5 to 0.6, which reflected the historically high levels of job openings and the decline in unemployment.

[35]PwC, *On the Radar: Evolving Workforce and Aerospace and Defense Firm Needs* (May 2023).

September 2023.[36] This increase in wages and salaries has not kept pace with inflation; that is, this 11 percent increase is lower than overall inflation during the same period, indicating real wages have decreased. During the same period, the larger manufacturing sector has also seen an increase in wages and salaries that has not kept pace with inflation.

Nine of the manufacturers we spoke with described a range of actions they are taking to address these workforce challenges, including workforce development and worker incentives.

- **Workforce development.** Four manufacturers stated that they are working with local stakeholders, such as high schools and community colleges, to build interest in the aviation industry and to increase the supply of skilled labor in the future. For example, one aircraft manufacturer established a program with local high schools that provides students the opportunity to work as apprentices for the company, gaining needed manufacturing experience. This program has become one of their direct hiring sources, according to company representatives. However, two manufacturers noted that these types of programs take a long time to produce results in the workforce. For example, one large manufacturer estimated that the programs it participates in only produce 15 to 20 workers per year in contrast to the thousands of workers the company hopes to hire.
- **Worker incentives.** Three manufacturers stated that they have offered financial incentives, such as signing bonuses, to attract workers in the competitive environment. For example, one manufacturer of mechanical assemblies stated that to attract workers, the company has offered a $5,000 signing bonus and a $5,000 referral bonus (meaning an employee that refers a new applicant who is hired would receive a bonus). However, despite these incentives, that manufacturer (which has hundreds of employees) stated it has had more than 25 positions open for more than a year as of May 2023. Another manufacturer told us it offers tuition reimbursement to staff who want to go back to school as an incentive to work at the company.

Seven of the 17 manufacturers we spoke with said that expanding FAA programs for aviation workforce development to include manufacturing

[36]We analyzed BLS Employment Cost Index estimates. Employment Cost Index estimates are derived from national surveys of establishments in the U.S. economy, not including workers overseas, who may be present in the aviation manufacturing supply chain.

could help address manufacturing labor shortages.[37] FAA has had several efforts related to increasing the supply of pilots and aviation mechanics, including (1) conducting research focused on understanding and encouraging youth and women's involvement in aviation careers and (2) providing grants aimed at supporting the education and recruitment of the next generation of pilots and aviation maintenance workers. According to FAA officials, while FAA does not currently have any programs that focus specifically on the aviation manufacturing supply chain workforce, an expansion of programs to include this focus would be consistent with the agency's workforce goals. An FAA reauthorization bill passed in the House of Representatives in July 2023 and one pending in the Senate as of February 2024 propose this type of expansion to FAA workforce programs.[38] If enacted, this legislation would provide for the expansion of FAA's workforce grant programs to support the education and recruitment of aviation manufacturing workers and the development of the aviation manufacturing workforce.

[37]FAA established aviation workforce development grant programs under the FAA Reauthorization Act of 2018, Pub. L. No. 115-254, § 625, 132 Stat. 3186, 3405–07. The authorization for these programs expired at the end of fiscal year 2023. The House of Representatives passed a bill that would extend this authorization through fiscal year 2026. *See* Securing Growth and Robust Leadership in American Aviation Act, H.R. 3935, 118th Cong. § 301 (2023). A bill introduced in the Senate in 2023 would extend this authorization through fiscal year 2028. *See* FAA Reauthorization Act of 2023, S. 1939, 118th Cong. § 501 (2023).

[38]*See* Securing Growth and Robust Leadership in American Aviation Act, H.R. 3935, 118th Cong. § 302 (2023); see also FAA Reauthorization Act of 2023, S. 1939, 118th Cong. § 501 (2023).

Manufacturers Reported Difficulties Procuring Raw Materials and Components and Described Actions to Help Address Shortages

Fifteen of the 17 manufacturers we spoke with stated that the difficulty that they or their suppliers had in procuring raw materials or components affected their ability to meet demand. These manufacturers reported shortages or delays in obtaining a broad range of items, ranging from castings and forgings[39] to engines and semiconductors (see sidebar for an example of federal government action to increase the supply of semiconductors).[40] According to our interviews, the supply chain of these aviation products is complex and dispersed globally, and shortages are not limited to a particular source.

CHIPS Act of 2022

Enacted in August 2022, the act established and appropriated $39 billion to a Creating Helpful Incentives to Produce Semiconductors (CHIPS) for America Fund to bolster semiconductor manufacturing capacity in the United States by providing financial incentives for building, expanding, and equipping domestic fabrication facilities. The act also appropriated $11 billion for activities such as semiconductor research and development by the National Institute of Standards and Technology. The act also appropriated funds for three additional efforts that seek to bolster U.S. semiconductor capabilities through a national network of research and development, workforce development, and international cooperation.

Source: CHIPS Act of 2022, Pub. L. No. 117-167, div. A, § 102, 136 Stat. 1372, 1372–78 and Congressional Research Service, *Frequently Asked Questions: CHIPS Act of 2022 Provisions and Implementation*, R47523 (Washington, D.C.: April 25, 2023). | GAO-24-106493

As noted by manufacturers we spoke to, shortages early in the supply chain may lead to shortages of components and finished aircraft later in the supply chain. For example, shortages of raw material—such as stainless steel, aluminum, and titanium—could lead to shortages of the components those materials are used for, such as engine and landing gear components. In turn, shortages of those components could lead to the delay of final assemblies, such as aircraft engines, finished aircraft, and other end products delivered to airlines and maintenance providers.

Further, shortages of aircraft components mean that manufacturers must prioritize how limited supplies will be allocated: to aircraft manufacturers for assembly of new aircraft or to airlines for maintenance of existing fleets. Either approach can reduce the number of aircraft available for airline operations.

[39]Castings and forgings refer to products made through casting and forging manufacturing processes. Casting is the process in which metal is heated to liquid state and poured into a mold to create a component shape. Forging is the process in which force is applied to metal to change the shape while in a solid state to create a component shape.

[40]In July 2022, we reported that a global shortage of semiconductors—also called microchips or chips and used to manufacture a wide variety of products including aircraft and aircraft parts—began in 2020 and continued into 2022. See GAO, *Semiconductor Supply Chain: Policy Considerations from Selected Experts for Reducing Risks and Mitigating Shortages,* GAO-22-105923 (Washington, D.C.: July 26, 2022).

Critical Minerals National Strategy

In June 2019, the Department of Commerce issued a national strategy to address vulnerabilities within the critical minerals supply chain, which spans from securing of raw materials to end uses in both civilian and defense applications. Specifically, this strategy aims to accomplish goals including:

- identifying new sources of critical minerals;
- enhancing activity at all levels of the supply chain, including exploration, mining, concentration, separation, alloying, recycling, and reprocessing;
- stimulating private sector investment and growth of domestic downstream value-added processing and manufacturing;
- ensuring that miners, producers, and land managers have access to the most advanced mapping data; and
- outlining a path to streamline leasing and permitting processes in a safe and environmentally responsible manner.

Source: Department of Commerce, A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals (June 2019). | GAO-24-106493

Selected manufacturers identified geopolitical risks and sole source suppliers as factors contributing to supply and material shortages.

- **Geopolitical risks.** Eleven manufacturers we spoke with attributed raw material shortages to a reliance on foreign sources vulnerable to risks such as natural disasters and government actions.[41] For example, certain raw materials are produced only in particular regions, which may be affected by international sanctions, regional pandemics, or shifting trade relationships. According to the DOT Office of Inspector General, supply chain experts identified U.S. environmental regulations as often limiting the mining and processing of raw materials required for aviation manufacturing.[42] Consequently, manufacturers may depend on foreign sources to procure raw materials, which are used in a variety of aerospace applications. See sidebar for additional information on federal government action on raw materials, specifically critical minerals.
- **Sole source suppliers**. In some cases, only one supplier may be qualified to supply a material, whereas in others a company may choose to only contract with one supplier. Manufacturers dependent on just one source for certain supplies could be particularly challenged if that source were compromised or unable to meet production demands from all customers. For example, one manufacturer told us that in 2023 it was unable to get a component critical to its production because the sole source supplier had to close its facility due to fire damage. In another example, an internal control systems manufacturer told us that its supplier decided to stop production of heater units because the product was no longer profitable. In some cases, manufacturers decide to use a single source for a critical component or material because they believe the risk of sole sourcing is small. For example, one manufacturer told us it uses a sole source supplier for a highly technical system because it is the only source for that technology. Based on the large size and financial health of the supplier, the manufacturer feels it is unlikely the supplier would go out of business or otherwise cease production.

In addition to the challenges of sourcing needed materials, nine of the manufacturers we interviewed said costs have risen for many aerospace

[41]We have previously reported on risks to the supply chain of such raw materials. GAO, *Critical Minerals: Building on Federal Efforts to Advance Recovery and Substitution Could Help Address Supply Risks*, GAO-22-104824 (Washington, D.C.: June 16, 2022).

[42]Department of Transportation Office of Inspector General, *DOT's Tracking of Aviation Imports*.

products including raw materials and other supplies. Although increased costs do not directly affect these manufacturers' production capability, the costs can affect their financial health, and, ultimately, their ability to remain in business.

Aerospace Product Prices

Based on our analysis of Bureau of Labor Statistics data on the Producer Price Index, the cost of aerospace manufacturing products in the U.S. increased, on average, by approximately 12 percent from September 2019 to September 2023. For comparison, during the same period, the cost of motor vehicle manufacturing products increased, on average, by approximately 10 percent. The extent of the increase differs for different products during this period. For example, from September 2019 to September 2023, the cost of aircraft fasteners increased, on average, by 84 percent while the cost of aircraft engine parts and accessories increased, on average, by about 8 percent.

Source: GAO analysis of Bureau of Labor Statistics Producer Price Index Industry Data. | GAO-24-106493

Note: Bureau of Labor Statistics Producer Price Index Industry Data for June through September 2023 are preliminary and subject to revision as of October 2023. These data consist of the output of the aerospace and motor vehicle manufacturing sectors in the United States, not the global supply chain for aircraft manufacturing.

Manufacturers told us that they are taking actions to address shortages of supplies and mitigate disruptions to manufacturing. The most common step manufacturers reported taking relates to supply chain management, including monitoring and—in some cases—supporting the financial and operational health of their suppliers. For example, in October 2023 Boeing entered into an agreement with one of its suppliers to provide funding to increase production capacity. Boeing reported that this agreement will increase stability in its production system and help deliver on its commitments to customers. Table 1 describes the actions manufacturers said they are taking to address supply challenges.

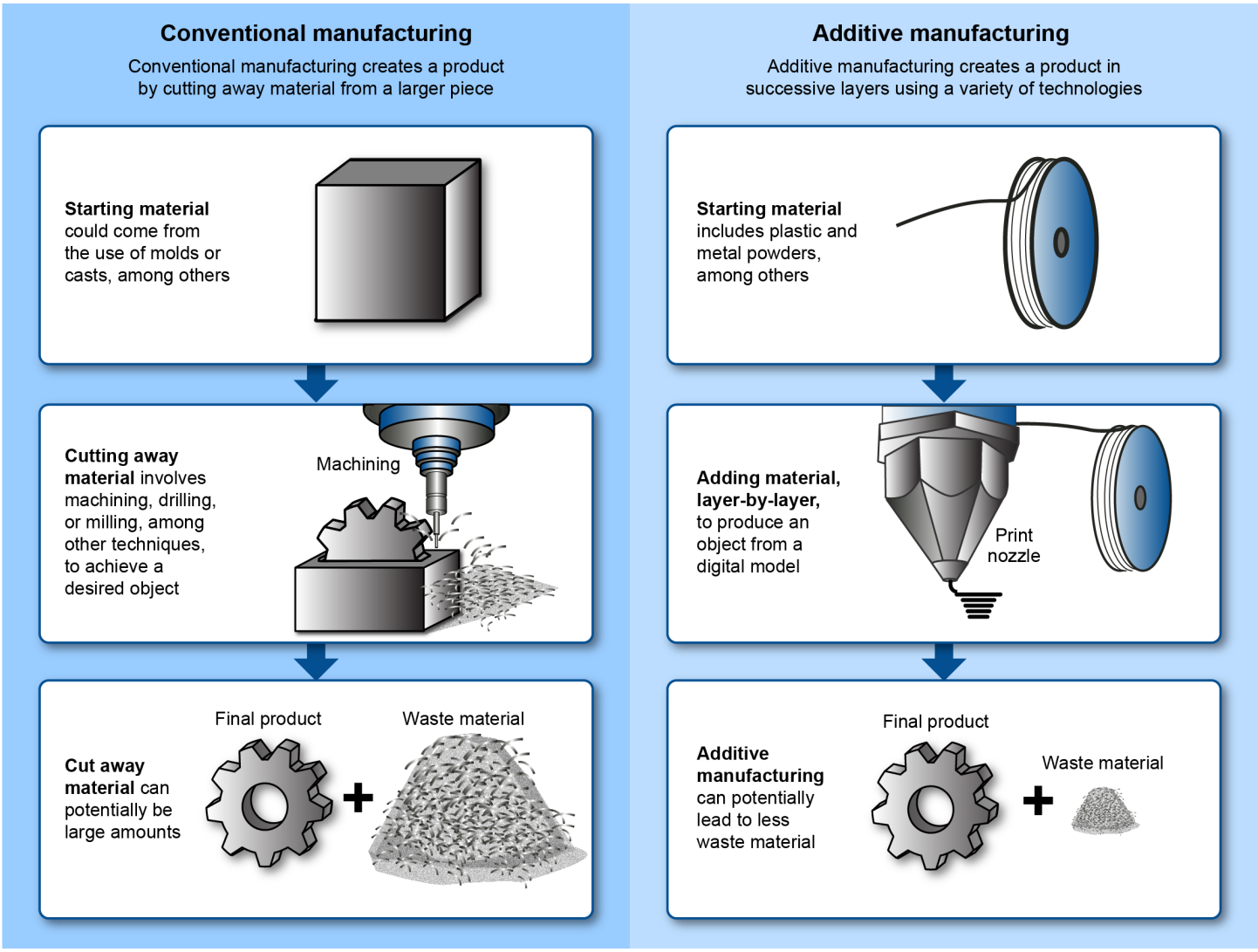
Table 1: Actions Selected Aviation Manufacturers Said They Are Taking to Address Supply Challenges

Action	Description
Began or enhanced supply chain management	Sixteen manufacturers told us they have either begun or enhanced existing efforts to manage their supply chain, including monitoring and supporting the financial and operational health of their suppliers. For example, one manufacturer maintains staff on site with suppliers to assist with operational improvements, and another helps smaller manufacturers procure raw materials by leveraging its buying power.
Established dual or alternative sources	Twelve manufacturers told us they have begun to establish additional sources to avoid the risks associated with having a single source for critical supplies.
Increased inventory	Eleven manufacturers told us they have begun increasing their inventory of needed supplies, moving away from a just-in-time supply strategy, to reduce the impact of increased lead times.
Developed in-house production	Seven manufacturers told us they have developed internal capacity to produce needed materials and components to reduce the risk of shortages. For example, one raw material manufacturer said it developed a proprietary process to produce its own high-purity aluminum from regular aluminum.

Source: GAO analysis of interviews with manufacturers. | GAO-24-106493

Four of the manufacturers we spoke with said that DOT and FAA could help address supply challenges by establishing clearer guidance and standards for the certification of alternative manufacturing processes. According to three of these manufacturers, alternative manufacturing processes such as additive manufacturing could allow them to produce some components in short supply more quickly or with less raw material as compared with conventional manufacturing processes (see fig. 6). In turn, the ability to use more efficient processes could help address manufacturing shortages. These manufacturers said that the process for confirming that these new techniques meet FAA and manufacturer safety standards is lengthy and unclear, due partly to the newness of the technology. According to one manufacturer that uses additive processes, additive manufacturing was developed about 30 years ago, and certain aspects of the technology are still in development. The manufacturer added that other technologies used in aerospace—such as machining—have been in use for 100 years or more. That same manufacturer said that the aerospace industry has been slow to accept additive manufacturing in part because the technology is not fully matured and standards for ensuring additively manufactured parts meet safety standards are not universal.

Figure 6: Conceptual Comparison between Conventional and Additive Manufacturing



Source: GAO (analysis and illustration). | GAO-24-106493

Note: For additional information on additive manufacturing, see GAO, *Defense Additive Manufacturing: DOD Needs to Systematically Track Department-wide 3D Printing Efforts*, GAO-16-56 (Washington, D.C.: Oct. 14, 2015).

According to FAA officials, the agency generally does not establish regulations specific to an individual manufacturing process. Rather, FAA establishes safety standards for aircraft parts, and manufacturers must demonstrate that their processes produce products that adhere to those

standards. Recently, FAA established some guidance for use of additive manufacturing and, according to officials, continues to explore ways to further develop industry standards for this technology. The guidance, issued in June 2023, describes how engine part manufacturers could demonstrate compliance with established regulations for aircraft engine parts produced using a specific additive manufacturing process.[43] FAA officials stated that, in addition to publishing guidance, the agency develops project-specific standards and issue papers for applicants wanting to use this technology. The four manufacturers that discussed this issue with us expressed a need for additional guidance beyond what FAA has already issued. For example, one company stated that it contributed to the development of FAA's recent guidance and saw a need for FAA to continue to work with industry on similar guidance for other technologies.

Additionally, the Consolidated Appropriations Act, 2023 directed the Aerospace Supply Chain Resiliency Task Force to explore new solutions to resolve supply chain issues and evaluate the potential for the introduction and integration of advanced technology. Beyond these current efforts, recent proposed legislation includes provisions for FAA to implement a research and development program for advancing aviation manufacturing, including improving the efficiency of certification processes for additively manufactured aviation products and components.[44]

Delays in Availability of New Aircraft and Parts Have Led Airlines to Make Operational Changes

Selected Airlines Reported Delays in Obtaining New Aircraft and Reliable Parts

Though airlines in general increased orders for new aircraft in 2021 and 2022 as compared with 2019 and 2020, Boeing and Airbus have been unable to deliver many of these aircraft on schedule. All eight of the airlines we spoke to reported difficulty obtaining new aircraft or the parts

[43]Federal Aviation Administration, *Powder Bed Fusion Additive Manufacturing Process for Aircraft Engine Parts*, Advisory Circular 33.15-3 (June 23, 2023).

[44]*See* Securing Growth and Robust Leadership in American Aviation Act, H.R. 3935, 118th Cong. § 1143 (2023).

needed to maintain their current fleet, which they attributed to delays and shortages in the aviation manufacturing supply chain since 2020. Regarding new aircraft, seven of the eight airlines we interviewed stated that manufacturers had delayed delivery of new aircraft that the airlines had expected to receive in 2023. For example, one passenger airline stated that it will receive 11 fewer new aircraft than scheduled in 2023, representing about 3 percent of the aircraft the airline has ordered overall according to aircraft manufacturer data. The eighth airline said it coordinated with its aircraft manufacturer to delay aircraft deliveries in 2021 and 2022 because it would not have been in a position to use the new aircraft given pilot shortages.

In addition to those airlines we interviewed, four other major U.S. airlines reported experiencing delays in obtaining new aircraft. According to these airlines' annual and quarterly reports in 2022 and 2023, three of the airlines were notified by manufacturers that aircraft expected for delivery in 2023 would be delayed to 2024 and beyond. Also in its 2022 annual report, a fourth airline noted outstanding orders for nearly 50 aircraft that had yet to be delivered in 2022 as scheduled. Looking forward, actions FAA and Boeing are taking in response to safety concerns stemming from the January 2024 in-flight incident on a 737 MAX-9 could further impact deliveries of new aircraft. In January 2024 investor calls, representatives of some airlines expressed concern that manufacturing supply chain challenges would continue to delay deliveries of new aircraft in 2024.

All eight airlines told us that—since 2020—they have also had trouble obtaining a broad range of parts needed to maintain their existing fleets, including the following examples:

- Two airlines stated that in 2023 they have experienced delays in obtaining cockpit windows from the only supplier for the aircraft model that those airlines operate. A third airline reported delays in obtaining cockpit windows for other types of aircraft.
- One airline told us that their maintenance providers are having trouble obtaining general hardware such as nuts, bolts, and wire clamps.
- One airline reported that manufacturers are strategically reserving components to enable companies to prioritize supplying parts for new aircraft or parts for maintenance as needed. As a result, the airline is unable to obtain parts in advance of conducting maintenance. Rather, needed parts must be ordered after the aircraft has been taken out of service which adds to the amount of time needed to complete maintenance.

Further, the International Air Transport Association (IATA)—a global association of airlines—told us that airlines are concerned about how components are being distributed by manufacturers for installation on new aircraft versus for maintenance of in-service fleets.[45] IATA stated that aircraft manufacturers have not disclosed their methodology for making these decisions to airlines. According to Boeing representatives, the company works closely with customers and suppliers to address part shortages and help ensure airlines can maintain operations.

Four airlines discussed experiencing challenges since 2020 with the quality and availability of aircraft engines and engine parts, in particular. For example, one airline told us that since the onset of the COVID-19 pandemic, only 20 to 30 percent of core engine parts they received from the engine manufacturer have been useable. The airline estimated that about 80 to 90 percent of parts were usable prior to the pandemic. The airline told us that, as a result, there have been fewer available parts to maintain engines, which in turn has increased the time required for engine maintenance. Like some of the manufacturers we interviewed, the airline attributed these quality issues to inexperienced personnel replacing experienced workers who were laid off or left the workforce during the pandemic.

Additionally, recent challenges with the reliability of some new engines have further increased demand for both engine repair components and mechanic labor.[46] For example, one airline told us that, since November 2022, it has had between one and four aircraft consistently out of service

[45]The International Air Transport Association is a trade association and standards-setting body representing about 300 airlines located around the world.

[46]Aircraft engine manufacturers have recently experienced challenges with production, including contaminants affecting the reliability of some components. For example, FAA issued several airworthiness directives in 2023 requiring additional inspections and maintenance for a variety of aircraft engines. In the latter half of 2023, two major engine manufacturers recalled large numbers of engines to inspect them for possibly contaminated powdered coatings. Additionally, in 2023, FAA and the European Union Aviation Safety Agency (the regulatory agency for aviation in the European Union) have identified instances of unapproved engine parts being sold for use in commercial aircraft by a parts distributor located in the United Kingdom. As a result of these incidents, regulators have recommended that airlines and maintenance providers conduct additional inspections of relevant engines and parts. FAA provides guidance on how suppliers and maintenance providers can prevent unapproved parts from being installed on aircraft. See Federal Aviation Administration, *Detecting and Reporting Suspected Unapproved Parts*, Advisory Circular 21-29D (July 12, 2016). In February 2024, aviation industry stakeholders including airlines and manufacturers announced the formation of a coalition with the goal of preventing unauthorized parts from entering the aviation supply chain and of strengthening supply chain integrity.

because of engine repair delays. According to the airline, the maintenance provider attributed these delays to shortages of both repair parts and mechanic labor.[47] Corroborating the experiences of those we interviewed, industry reports have also noted that the combination of slower production rates, technical performance issues of new engine models, and labor shortages have led to increased lead times for engine maintenance.[48]

The timeliness of maintenance and repair services in general has suffered because of delays in obtaining parts, according to airlines and maintenance providers. Representatives of all three maintenance providers we interviewed stated that they have experienced an increase in lead times for parts since 2020. For example, one representative stated that lead times for some parts have increased from 120 to about 400 days, resulting in average turnaround time for repairs growing from 21 to 30 days. Similarly, one airline stated that—due to a lack of parts as well as mechanics to perform the work—the time it takes to get an aircraft back from maintenance has increased.[49] The airline said that the median time required for maintenance peaked at 36 days in 2022, as compared with 23 days prior to 2020. As of December 2023, the airline said they continue to experience these delays.

Industry sources have reported similar dynamics in the industry more broadly. For example, a 2023 survey on the aviation maintenance market found that supply chain concerns were rated as top disruptors for the aircraft maintenance industry. Supply chain concerns were expressed by respondents across all industry segments—including airlines, maintenance providers, and manufacturers—and across all maintenance categories, including airframes, engines, and components.[50]

[47]In May 2023 we reported on challenges for airlines and maintenance providers in meeting the demand for both pilots and mechanics. GAO, *Aviation Workforce: Current and Future Availability of Airline Pilots and Aircraft Mechanics,* GAO-23-105571 (Washington, D.C.: May 2023).

[48]See, for example, Aviation Week Network, *State of the Engine MRO Aftermarket in 2023*, July 14, 2023, and Oliver Wyman, *Global Fleet and MRO Market Forecast 2023-2033*, 2023.

[49]For additional information on the availability of aircraft mechanics, see GAO-23-105571.

[50]Oliver Wyman, *MRO Levels Off: Post-Pandemic Supply Chain and Talent Challenges*, 2023.

Seven of the airlines we spoke to reported improvement in some supply chain delays as of mid-2023, though challenges have continued. For example, one airline reported that shortages have narrowed to a smaller range of parts since 2022 but that delays in critical parts are causing larger effects. According to data provided by another airline, lead times for one wheel and brake components supplier increased from 38 days in 2019 to a peak of 146 days in 2022, but as of December 2023, lead times for this supplier were about 49 days. The eighth airline reported that they have not seen significant improvement as of November 2023.

Delays Led to Changes in Flight Schedules and Supply Chain and Maintenance Practices

Four airlines told us that they made changes to scheduled flights in 2023 because of delays in obtaining either new aircraft or parts. For example, one passenger airline told us they operated about 5000 fewer flights than planned from January through October 2023 (a reduction of more than 3 percent of the airline's flights over the same period) because of delays in obtaining new aircraft.

In addition to changing flight operations for existing routes, three of these airlines stated that they had delayed or cancelled planned expansion of operations because of delays in obtaining new aircraft or parts. Airlines for America—an association of U.S.-based airlines—stated that reduced access to aircraft may cause airlines to delay the opening of new routes if they do not have enough of the right types of aircraft to serve all the markets they would like. Beyond the experience of U.S. airlines, IATA told us that maintenance delays have resulted in flight delays and reductions in scheduled flights for airlines around the world because airlines are having difficulty maintaining enough aircraft to provide service.

Two other airlines, however, stated that while they had experienced supply chain delays, those delays had not affected the number of flights they operated because they were instead limited by pilot and other workforce shortages.[51] Additionally, the two cargo airlines we spoke with reported that a recent reduction in cargo demand has helped them more easily manage the limited supply of new aircraft and parts.

To minimize the chance of further disruptions to their operations, airlines reported taking steps to manage their supply of new aircraft and parts more strategically, including the following.

[51]For additional information on the availability of airline pilots, see GAO-23-105571.

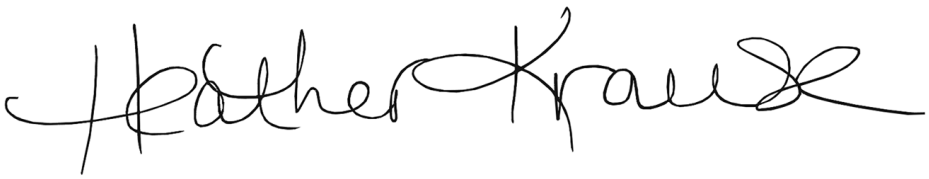
- **Enhancing supply chain management.** Like manufacturers, all eight airlines reported that they are more actively managing their supply chain to help address delays. One example noted was increasing the frequency of meetings with suppliers to monthly or quarterly instead of once per year. IATA representatives told us they believe the relationships between aircraft manufacturers and airlines are likely to influence manufacturer decisions about allocating parts among clients during a parts shortage. IATA told us some airlines have been negotiating new orders and maintenance agreements to better position themselves for favorable treatment by manufacturers.
- **Extending the life of aircraft components.** Four airlines told us about options they have identified for safely extending the life of some parts. For example, one airline reported increasing the frequency of inspections for some components that would normally be scheduled for replacement. According to the airline, increasing the inspection frequency allows them to safely extend the life of the component within the manufacturer's guidelines. Another airline reported repairing damaged cockpit windows that it previously would have replaced because of a shortage of new windows. IATA representatives also stated that airlines are increasingly repairing components instead of replacing them and taking advantage of used serviceable materials—parts from an out-of-service aircraft—when available.
- **Increasing spare parts inventories.** Three airlines told us that they are increasing their inventory of spare parts to ensure they have parts for needed repairs. For example, one airline told us that since 2021 it has tried to hold at least a year's worth of certain spare parts to meet its maintenance needs because it did not anticipate lead times improving soon.

Agency Comments

We provided a draft of this report to the Department of Transportation (DOT), Boeing, and Airbus for review and comment. DOT and Boeing provided technical comments, which we incorporated as appropriate. Airbus had no comments on the report.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Transportation, and other interested parties. In addition, the report is available at no charge on the GAO website at https://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-2834 or krauseh@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix II.



Heather Krause
Managing Director, Physical Infrastructure

Appendix I: Stakeholders Interviewed

We interviewed or received written responses from a broad range of stakeholders (see table 2) to better understand the factors affecting production of new aircraft and components, the ability of airlines to obtain new aircraft and components, and the impact of any delays on airline operations. We analyzed stakeholder responses to identify common themes that arose. Two analysts independently coded stakeholder responses, and then reconciled differences in coding through discussion.

Throughout the report, we note the number of relevant stakeholders with similar responses. Because we selected a non-generalizable sample of stakeholders, their responses should not be used to make inferences about a population. However, we believe that the variety of stakeholders represented provides a good basis for describing the range of experiences and opinions stakeholders have had regarding the aviation manufacturing supply chain.

Table 2: Stakeholder Categories and Organizations Represented, Alphabetical within Category

Stakeholder category	Organization
Aircraft Manufacturers	**Airbus:** Headquartered in the Netherlands and France, Airbus manufactures aircraft for commercial and defense applications.
	Boeing: Headquartered in Virginia, Boeing manufactures aircraft for commercial and defense applications.
Other Manufacturers	**AMT:** A subsidiary of Senior Aerospace, AMT is headquartered in Washington state and manufactures structural parts for commercial aircraft.
	Arconic: Headquartered in Pennsylvania, Arconic manufactures aluminum products.
	Collins Aerospace: A subsidiary of RTX Corporation, Collins Aerospace is headquartered in North Carolina and manufacturers systems including avionics, interiors, and power and controls.
	CTT Systems AB: Headquartered in Sweden, CTT Systems AB manufactures aircraft humidifiers and dehumidifiers.
	Damar Aerosystems: A subsidiary of Senior Aerospace, Damar Aerosystems is headquartered in Washington state and manufactures precision machined parts and assemblies for the commercial aerospace and defense industries.
	General Electric Aerospace: Headquartered in Ohio, General Electric Aerospace manufactures integrated systems, such as avionics, and aircraft engines, including engines produced by CFM International (a joint venture between Safran and General Electric).
	Honeywell: Headquartered in North Carolina, Honeywell's aerospace business manufactures avionics, auxiliary power units, and other electronic components.
	Nabtesco Aerospace, Inc.: A subsidiary of Nabtesco Corporation, Nabtesco Aerospace, Inc. is headquartered in Washington state and manufactures mechanical systems.
	Novelis: A subsidiary of Hindalco Industries Limited, Novelis is headquartered in Georgia and manufactures aluminum products.
	Pratt & Whitney: A subsidiary of RTX Corporation, Pratt & Whitney is headquartered in Connecticut and manufactures aircraft engines.

Stakeholder category	Organization
	Rolls Royce: Headquartered in the United Kingdom, Rolls Royce's aerospace business manufactures aircraft engines.
	Saab: Headquartered in Sweden, Saab's aerospace business manufactures communication systems, aerostructures, and other electronic components.
	Safran: Headquartered in France, Safran manufactures auxiliary power units, electronic components, and several other components, including aircraft engines through CFM International (a joint venture between Safran and General Electric).
	Stratasys: Headquartered in Minnesota and Israel, Stratasys manufactures additive manufacturing technologies and products.
	TMX Aerospace: A subsidiary of Thyssenkrup Aerospace, TMX Aerospace is headquartered in Washington state and is a service provider for aluminum and titanium products.
Airlines	**American Airlines:** A U.S.-based airline offering international and domestic passenger service.
	FedEx Express: A U.S.-based airline offering international and domestic cargo service.
	Frontier Airlines: A U.S.-based airline offering international and domestic passenger service.
	Hawaiian Airlines: A U.S.-based airline offering passenger service to Hawaii from the U.S. mainland and international destinations.
	JetBlue: A U.S.-based airline offering international and domestic passenger service.
	Republic Airways: A U.S.-based airline offering regional passenger service.
	SkyWest Airlines: A U.S.-based airline offering regional passenger service.
	UPS: a U.S.-based airline offering international and domestic cargo service.
Maintenance Providers	**Collins Aerospace:** A subsidiary of RTX Corporation, Collins Aerospace provides spare parts and overhaul and repair services for systems, including avionics, interiors, and power and controls.
	Honeywell Aerospace: Honeywell's aerospace business provides spare parts, repair, overhaul, and maintenance services for avionics, auxiliary power units, and other electronic components.
	Jet Landing Systems: Jet Landing Systems provides maintenance services for aircraft landing systems.
Others	**Aerodynamic Advisory:** An aerospace-industry consulting firm.
	Aeronautical Repair Station Association: A trade association representing international civil aviation maintenance providers.
	Aerospace Industries Association: A trade association representing aerospace manufacturers, suppliers, and service providers.
	Airlines For America: A trade association representing major U.S. passenger and cargo airlines.
	Airports Council International: A trade association representing airports around the world.
	Aviation Suppliers Association: A trade association representing companies that distribute aviation parts.
	International Air Transport Association: A trade association and standard-setting organization representing about 300 airlines worldwide.
	Modification and Replacement Parts Association: A trade association representing manufacturers of FAA-approved aftermarket aircraft parts.
	Morgan Stanley: A firm providing economic analysis on a variety of industries, including aerospace manufacturing.
	Oliver Wyman: A management consulting firm providing analysis on a variety of industries, including commercial aviation, aerospace manufacturing, and aviation maintenance.

Source: GAO. | GAO-24-106493

Appendix II: GAO Contact and Staff Acknowledgments

GAO Contact

Heather Krause, (202) 512-2834 or krauseh@gao.gov

Staff Acknowledgments

In addition to the contact named above, Heather Halliwell (Assistant Director), Katie Hamer (Analyst-in-Charge), Kevin Gonzalez (Analyst), Paul Aussendorf, Melissa Bodeau, Lydie Loth, Dan Luo, Malika Rice, Pamela Snedden, Mike Soressi, Andrew Stavisky, and Jake Whitson made key contributions to this report.

GAO's Mission

The Government Accountability Office, the audit, evaluation, and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people. GAO examines the use of public funds; evaluates federal programs and policies; and provides analyses, recommendations, and other assistance to help Congress make informed oversight, policy, and funding decisions. GAO's commitment to good government is reflected in its core values of accountability, integrity, and reliability.

Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through our website. Each weekday afternoon, GAO posts on its website newly released reports, testimony, and correspondence. You can also subscribe to GAO's email updates to receive notification of newly posted products.

Order by Phone

The price of each GAO publication reflects GAO's actual cost of production and distribution and depends on the number of pages in the publication and whether the publication is printed in color or black and white. Pricing and ordering information is posted on GAO's website, https://www.gao.gov/ordering.htm.

Place orders by calling (202) 512-6000, toll free (866) 801-7077, or TDD (202) 512-2537.

Orders may be paid for using American Express, Discover Card, MasterCard, Visa, check, or money order. Call for additional information.

Connect with GAO

Connect with GAO on Facebook, Flickr, Twitter, and YouTube.
Subscribe to our RSS Feeds or Email Updates. Listen to our Podcasts.
Visit GAO on the web at https://www.gao.gov.

To Report Fraud, Waste, and Abuse in Federal Programs

Contact FraudNet:

Website: https://www.gao.gov/about/what-gao-does/fraudnet

Automated answering system: (800) 424-5454 or (202) 512-7700

Congressional Relations

A. Nicole Clowers, Managing Director, ClowersA@gao.gov, (202) 512-4400, U.S. Government Accountability Office, 441 G Street NW, Room 7125, Washington, DC 20548

Public Affairs

Chuck Young, Managing Director, youngc1@gao.gov, (202) 512-4800
U.S. Government Accountability Office, 441 G Street NW, Room 7149
Washington, DC 20548

Strategic Planning and External Liaison

Stephen J. Sanford, Managing Director, spel@gao.gov, (202) 512-4707
U.S. Government Accountability Office, 441 G Street NW, Room 7814,
Washington, DC 20548