

Introduction

The manner in which aircraft are manufactured, one that took almost a century to evolve, has suddenly become obsolete. No longer is the customer's single focus on pushing the limits of technology to fly ever farther, faster, and higher. In an environment plagued by downturns in defense spending and increased competition, cost has now become a primary driver. Suddenly, dramatic transformation is necessary. There is no choice; the customer can no longer afford the practices of the past.

Many have acknowledged that it will take a drastic change in approach to make this shift. Yet, they have also become increasingly aware that this change may not come easily.

Over the past several years, this industry had put into place an array of Japanese tools and practices intended to drive down costs.

Known broadly as "lean production,"¹ they have been adopted in the hope of producing savings similar to those touted by the Toyota Motor Company. However, those who have applied them have more often than not found little improvement. Very rarely have these techniques yielded anything near what they should have accomplished.

Our dealings with this industry have shown us that, despite the fact that almost every company with which we have worked has applied some of these tools and practices, each has implemented them quite differently. Their results have varied just as much. It became apparent to us that there does not exist a strong understanding of how best to implement lean production in an environment that is different from that in the Japanese automotive industry. While much is available on what should be done in this area, little is written on how these techniques should best be put into place.

Suddenly, we found ourselves in a position to help.

After spending well over a decade working with the aircraft industry in the design, testing, manufacturing, and servicing of a wide variety of military aircraft, we grew increasingly frustrated with companies' efforts to contain costs. We watched factory after factory struggle with daily problems that disrupted their operations, distracted the workforce, and drove up the cost of their products. We searched for the means to take a closer look, to learn from this industry's

hard-earned lessons, and to develop an approach for attacking this barrier.

We knew that the answer would likely be found in the results of this industry's efforts. We could see that, when viewed individually, each case could offer very little insight. However, if they could be assembled together, allowing them to be analyzed as a group, much more could be learned. Thus, while wide-ranging experimentation has not produced the results that were originally intended, these results still offer tremendous value. With the comprehensive data from these efforts—from success as well as from failure—a solid path to future successes could be developed.

Since competition had precluded most from sharing these lessons, no one company had sufficient access to gain the clear picture needed of the overall path to improvement. How could the individual pieces of this puzzle be brought together to provide the answers so critical to advancing the industry to the next level of cost performance?

It was our unique opportunity to pull together this information that paved the way for this book.

The U.S. Department of Defense set the stage for this opportunity when it made affordability a predominate consideration for its next tactical aircraft, the Joint Strike Fighter. With no other new programs in sight, competitors were faced with an urgent need to address this consideration. As they searched for the means, we brought forward our concept of consolidating

this rich field of fragmented lessons. The Joint Strike Fighter organization agreed to sponsor our study.

Much like ourselves, many across the industry saw this as a key opportunity. Seventeen of the most prestigious companies producing military and commercial aircraft, engines, and avionics enthusiastically invited us and our team of specialists to weeklong visits of their facilities. They permitted us to look at them as insiders, allowing us to roam unescorted, viewing sensitive and even proprietary information. We had been given the unprecedented degree of access that was essential to combining the lessons of an industry—the opportunity that many observers never believed we could be granted.

This book is written to tell our story.

This book is intended for those who are interested in understanding how to apply lean production in an environment other than that of the Japanese automotive industry. It is written to show why so many who have come to believe in the tools and practices of this philosophy have not yet found the path to implementing them. It demonstrates that, in an industry where serious impediments exist, the mere understanding of these techniques is not enough. Instead, we identify the core focus of this concept, and show how all of its tools and practices must work together to achieve this intent.

Breaking the Cost Barrier demonstrates that each of the major tools and practices associ-

ated with lean production is aimed at addressing one underlying factory issue: production variation. Production variation manifests itself in a number of forms, including poor quality, part shortages, underutilized equipment, and unpredictable production schedules. Its impact extends across all aspects of production, from the ordering of supplies to the assembly of the final products. Our study demonstrated that only by adopting an approach that targets this variation can large reductions in cost be achieved. In fact, after applying a specific framework to progressively address the sources of factory variation, the level of factory-wide improvement in such key metrics as manufacturing cycle time, inventory, and cycle time variation is astonishing—up to 67%, 80%, and 60%, respectively. The overall production cost savings is even more remarkable—up to 25%. Moreover, we repeatedly saw that this can be achieved with little capital investment within months of implementation.

This book shows that dramatic improvement is possible despite the existence of external constraints that cannot be changed. Adopting a focus on what can be changed—those processes internal to the organization—can lead to dramatic improvement.

Breaking the Cost Barrier provides a historical perspective of the reasons for the aircraft industry's current condition. It illustrates how such tools as Manufacturing Resource Planning (MRP II), Just-in-Time (JIT), kanban, cellular manufacturing, Statistical Process Control

(SPC), and even advanced design practices have been applied, and the specific lessons learned from this industry's experimentation in each of these areas. This book draws from specific factory cases to drive home these lessons.



The views expressed in this book are those of the authors and do not reflect the official

The results of our industry study received great praise from across this industry, academia, and the government. In fact, it was because of this overwhelming response that this book was written. While the initial report did highlight major findings, it merely served to whet the appetites of many, including ourselves. Ever since these findings were first released, the demand for further detail has steadily grown. At the same time, our continuing efforts led us to a deeper understanding of the framework that we had originally observed. This has further helped us understand the uniqueness of our knowledge base, as well as our responsibility to spread the word.

A number of highly credible organizations have embraced the conclusions of this initial study. First and foremost, the Naval Air Systems Command provided the support to make this study possible. The Department of Defense's Joint Strike Fighter program served as the sponsor of this study, and has acknowledged that "in order for the Joint Strike Fighter pro-

CHAPTER 1

An Opportunity for Advancement

It has been half a century since a team of contractor and government engineers gathered in the Muroc, California, desert to usher aviation into a new era. This group set out to do what no one was certain was possible—to break through a seemingly impenetrable wall, one that no one was sure could be crossed. On October 14, 1947, their efforts became historic when, at the controls of the Bell X-1 aircraft, pilot Chuck Yeager broke the sound barrier.

For years many had attempted this feat, but to no avail. Failure led to research, and yet again to failure, until many began to believe that this barrier truly could not be crossed. Through this, advancements were made in such key areas as transonic aerodynamics and high-speed propulsion, yet a seemingly insurmountable problem remained. As an aircraft

approached the speed of sound, it began shaking violently, ultimately losing controllability. More than one pilot was reported to have lost his aircraft—and his life—because of this.¹

If supersonic flight were ever to become a reality, this phenomenon had to be understood, and ultimately overcome. While the goal was clear, it proved to be exceedingly difficult to achieve. Traditional laboratory methods could not be used to lend assistance; wind tunnels were completely useless in duplicating this phenomenon. Flight-testing was the only way to proceed, yet it was exceedingly expensive and hazardous.

So this team of military, government, and contractor personnel joined forces in search of the answer. After numerous experiments, Yeager and this joint government-industry team had noticed that, with a traditional aircraft configuration, the nose of the aircraft began to rise as the speed of sound was approached. Shock waves forming on the horizontal tail caused the aircraft to lose its controllability. As the team worked through the problem, they discovered what would be the one remaining barrier to breaking the speed of sound:²

The big thing that came out of the whole program was that we found out, in order to control the airplane through Mach 1, we had to have a flying tail on it. That was the first time we had experimented with this flying tail on the X-1. That really was the answer to flying at supersonic speed.

... And it took the British and the French and

the Soviet Union five years to find out that little trick that we found out with the X-1. It gave us a quantum jump on the rest of the world in aerodynamics.

—Brigadier General Charles E. "Chuck" Yeager³

With this final step, a seemingly impossible hurdle forever vanished. A new window was opened, one that allowed for rapid new advancement in flight performance. Shifting from hinged elevators to a fully movable tail or "flying tail" made controllability at supersonic speeds possible. This one step changed everything; with air travel no longer relegated to subsonic speeds, aircraft could now move forward to seemingly limitless records of performance. Each generation of aircraft was better, faster, more maneuverable than the last. It appeared that nothing could halt this pace of development.

Yet, once again the aircraft industry has reached an apparently insurmountable barrier, one that must be overcome if advancement can continue its rapid pace. This time it cannot be accomplished through flight-testing, nor with a breakthrough in any of the other traditional disciplines of aircraft design. This new barrier is not one of performance; this time, it is one of cost.

The aircraft industry suffers from an apparent dichotomy in its capabilities. It continues to demonstrate an awesome ability to press the limits of technology. Its product quality is inarguably high; tremendous care is taken throughout design and production to ensure the

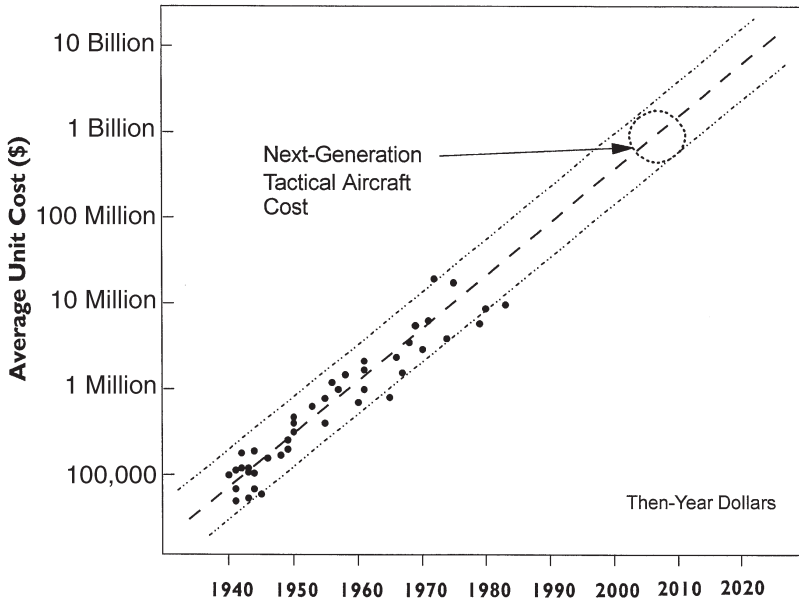


FIGURE 1.1 Cost escalation of tactical aircraft.

utmost levels of flight safety. The industry has a long history of resilience, snapping back from repeated swings in demand, from financial downturns, changes in customer focus, and wars. It has adapted well to an ever-increasing level of regulation and oversight. Yet despite its achievements, this industry has not been able to stem its dramatic rate of cost escalation.

For over a decade, industry leaders have seen that this trend cannot be sustained.⁴ Now it appears that the crisis is closer than anyone might have envisioned—even the next generation of military aircraft may not be affordable. The Defense Department will no longer pay as it has

in the past to reach the next level of performance. Increased technology is no longer enough; the customer now also demands efficiency.

The trend of cost escalation is depicted graphically in Figure 1.1, in which it can be seen that the unit price has increased dramatically for each new generation of military aircraft.⁵ It could clearly be argued that, in the long term, some sort of action will have to occur--no fighter airplane is affordable at the cost of billions of dollars. However, this industry is now finding that even the short-term trends depicted here must be altered.

Even with such a dire situation at hand, we were astonished at how many think that a rapid, dramatic reduction in the cost of manufacturing is not possible. There seems to be a pervasive belief that the barriers are too daunting, that too much is out of the control of an individual facility. It was necessary to set aside this belief in order to cross the sound barrier. The industry must again rise to the challenge; it must find a way to overcome this barrier or face dire consequences. A new approach to manufacturing must be found.

It is the premise of this book that the magnitude of these barriers has been largely overstated. This is not to say that substantial barriers do not exist; the aircraft industry, like many others, must operate within an environment that is far from optimal. Wide swings in product demand, government regulation and oversight, and a strong dependence on military

sales all affect its results. In addition, the unyielding demands for ever-increasing performance limit the trade-offs that could otherwise enhance design producibility, forcing factories to press manufacturing processes to their limits. Yet, in spite of this, we found countless examples of localized successes across this industry. By combining the lessons offered by these successes, we will show that a path to a much larger potential for savings is readily achievable, even within the constraints of this existing environment.

Our observations will be shown to boil down to a seemingly basic principle for success, one whose potential to lead to rapid, dramatic cost savings has already been demonstrated. Through the use of a simple framework for implementation, this principle can consistently enable an organization to reach these goals with a minimum of investment. We have termed this overall effect the principle of variation management.

Variation management offers a powerful new twist to manufacturing cost improvement. Unlike many other methods on which much has been written, it does not represent a single tool focused on affecting an individual aspect of production. Instead, it acts as the enabler that allows these tools to become most effective. By forming the core of a well-planned program, this principle can lead to widespread improvements within a facility, despite seemingly large obstacles. Even with only a limited understanding of this approach, improvement initia-

tives have sometimes resulted in phenomenal accomplishments.

With this framework we will show that, despite the many adverse external factors that cannot be readily changed, substantial improvement is still possible by adopting a focus on those internal processes of the organization that can be changed. The power of this approach has been repeatedly validated by real-world successes, with dramatic reductions in inventories, manufacturing cycle times, and production variability—and ultimately in production costs.

Facilities that have grasped aspects of variation management have largely become masters of their destinies, demonstrating an ability to respond to internal problems or external environmental changes much more effectively than others within the same setting. As its name suggests, this new approach is based on the premise that the waste caused by factory variation is a key driver to manufacturing costs. We found that this variation extends across all aspects of production, from the ordering of supplies to the assembly of final products. In order to deal with its day-to-day effects, factories must constantly apply tremendous resources, yet usually find themselves making little progress in reducing the underlying causes.

Using this principle, dramatic improvements to efficiency and responsiveness are possible throughout the supply chain. Suppliers are able to effectively manage the effects of widespread unforecasted demands from their cus-

tomers, minimizing or even eliminating the disruption that otherwise would impact their ability to respond. Facilities that integrate and assemble these components are able to manage their own operations more effectively, allowing them to better forecast their specific requirements such that they can more smoothly load both their own shops as well as those that supply materials. They can dramatically reduce the need for work-arounds, expediting, out-of-station work, and stock-outs that disrupt factory flow. As a result, all are able to improve their performances, gaining significantly greater productivity and efficiency.

By removing much of the guesswork in implementing improvements, organizations whose efforts have followed this framework are much less likely to stumble early in their attempts, lessening the risks of disruption to production operations. These early successes can rally the workforce, setting the stage for long-term improvement. As a result, those that use this principle are much more likely to take on new approaches, and when they do, they are much more likely to succeed.

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With the path to making such broad improvements well within reach, why do so many fail to see it? The answer may lie in how they view themselves today. We found that even in a factory marked by crisis management, one in which an inordinate amount of time is expended in developing work-arounds to day-to-day fac-

tory disruptions, many do not see a compelling reason to change. We spoke to workers and managers alike, with many explaining to us how this merely represents "the way aircraft are built." Yet, it seemed to us that the waste we found should cause concern; it clearly plays an important part in driving up manufacturing costs.

The following examples will help make this point clear:

- n A factory produces a complex product, one that requires a large number of successive manufacturing steps to be performed across a number of production shops. Even with a formal production scheduling system in place, at each shop we found expedite tags stapled to almost every order. Because of this large number of expedites, the formal scheduling system is crippled. Without any real way to prioritize these jobs, the shops are forced to respond to orders almost on a first-come-first-served basis. In essence, all jobs have been ranked as equally important. Yet, we found from those who have placed these orders that a priority to their need does exist. In fact, only a small set of the items ordered using expedite tags are needed immediately to prevent work stoppages. With the formal scheduling system rendered useless, how could workers producing these items know where to place their priorities? Furthermore, this situation leaves no way to plan production to op-

timize batch sizes, minimize machine setups, or take other measures to improve efficiency.

- n A supplier is forced to respond to severe spikes in demand from its primary customer. Despite these seemingly unreasonable expectations, the supplier must maintain on-time delivery, high quality, and competitive prices. This is especially important now; with the industry rapidly downsizing, the supplier must continue to be seen as reliable in order to maintain preferred supplier status. Recently, this customer has begun to reduce inventories in response to pressures to lower operating costs. As a result, the spikes in demand have become much more pronounced; without the customer's buffer inventories, this supplier is now subject to the full range of variation of the customer's less-than-optimal operations. With operating margins driven to record lows, how can the supplier continue to contain costs as expected and remain profitable?
- n An assembly line for a complex, very expensive product is forced to regularly "travel" a great deal of its work, redirecting operations to install parts later in the production sequence when they are not available for installation at the planned workstation. Late supplier deliveries, receipt of deficient materials, or unscheduled maintenance has made it impossible to perform these operations as originally in-

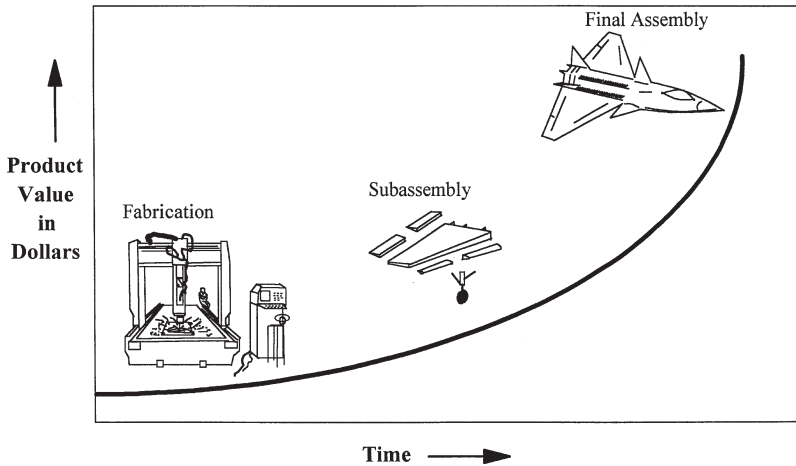


FIGURE 1.2 Increase in a product's value as it progresses down the production line.

Source: Based on a similar figure in The Manufacturing Affordability Development Program, Final Report.

tended, forcing planners to delay them until conditions improve. The factory continues to move the product down the line, however, performing operations and installing equipment not dependent on the skipped jobs. This is not without consequence; traveled tasks are often completed in a suboptimal environment. With installation access much more limited because of the product's now advanced state of assembly, standard production tooling and assembly procedures can no longer be used. Time-consuming workarounds must be applied, further disrupting operations.

These are not unusual occurrences; while

their severity may vary, we found these same types of problems in a number of facilities across this industry. Again, we must ask why an industry that is so technologically advanced cannot fix these seemingly basic problems. Perhaps it is simply that those in charge have not yet been able to understand how best to approach them. In order to answer this question we sought to understand where this industry has been focusing its attention, and why it hasn't been successful.

Current Industry Focus

One of the areas that has historically received a great deal of attention across this industry is the measurement and control of direct labor, or "touch labor." We found labor performance to standard hours (a direct measure of the efficiency of touch labor within a factory) to be the most-tracked performance metric across this industry. We also found that this industry has waged an almost obsessive war on labor idle time in an attempt to influence this aspect of production costs. Facilities are developed, equipment is purchased, and labor agreements are reached in an effort to influence this, all apparently because of a belief that a factory whose workforce remains busy all of the time must be operating at the lowest possible cost.

In fact, we found this not to be the case.

After a detailed review of data across the

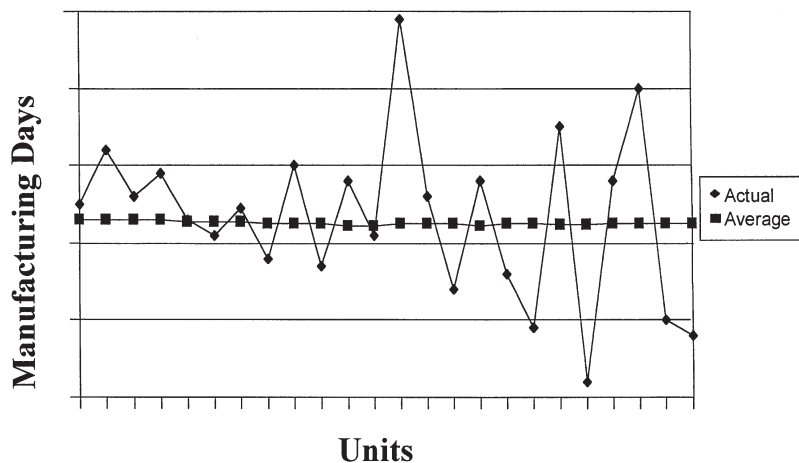


FIGURE 1.3 Variation in the amount of time required to assemble successive units.

Source: Based on a similar figure from The Manufacturing Affordability Development Program, Final Report.

different sectors of the aircraft industry, we found touch labor to consistently form only a minor overall part of the cost of production. In fact, with its entire contribution making up only 6% to 12% of the final product cost, we began to wonder if all of this attention is warranted. After all, with the considerable attention it has received over the past decades, any easy gains have likely been achieved, leaving little room for dramatic improvement. Furthermore, since touch labor is a relatively small overall contributor to production costs, any nominal improvement will not likely amount to a substantial degree of savings.⁶

Conversely, another area that this industry had begun to emphasize—the control of inventory levels within a factory—represents a large

but relatively untapped cost driver. Because the cost of carrying these inventories adds substantially to the cost of the end product, a solid effort toward inventory reduction holds the potential to result in substantial cost reduction.⁷

Yet we found that, to optimize these savings, inventory in all of its forms must be attacked. This includes all unsold products—not only those items held in warehouses, but also those items in various states of assembly residing directly in the production shops. This much less emphasized form of inventory, known as work in process (or WIP), is very important, especially since it can sometimes make up the largest contribution to the costs of a production shop.

In order to understand the importance of WIP, we must first understand that a product continuously gains value as more labor, materials, and completed components are added as it progresses down the production line; for products associated with aerospace vehicles, this can be quite substantial (notionally depicted in Figure 1.2). Because of this increased value, the monthly costs incurred by carrying this as unsold inventory may accumulate to a substantial expense. We found that by the time a product reaches the latter stages of assembly, these carrying costs can make up over 70% of the total cost of assembling the product (as depicted in the figure, inventory makes up a higher percentage of the total cost of operations late in the production sequence).

This effect also serves to help explain the

benefit of reducing manufacturing cycle times, or speeding the movement of a product through the production process. Any reduction to the time an unsold product spends at its highest state of value can have a major impact on overall production costs. Consider a \$40 million aircraft that must be held at the flight line for three weeks to correct deficiencies or complete traveled work.⁸ If we apply an annual carrying cost rate of 20%,⁹ we can approximate a cost increase of almost half a million dollars just for this one delay. If similar delays throughout production can be eliminated, delivery schedules can be shortened to yield even greater savings. We can see that, even without the ability to fully quantify the spectrum of cost contributions, this reduction in carrying costs itself justifies attention to cycle time reduction.

To this point we have rationalized that inventory reduction and manufacturing cycle time reduction represent important cost drivers. Still, we found that a narrowly targeted attack on these areas may not be sufficient to drive substantial cost reduction. Despite a steadily growing emphasis on these areas, the anticipated savings have often not been realized. In fact, this emphasis may have led a number of facilities to encounter great difficulties. In one facility, a single-minded push to cut manufacturing schedules led to the stockpiling of those items that perpetually drove critical path schedules. While we did find that cycle times were reduced, this increase in inventories may

have offset any savings, possibly even increasing overall costs. In another case, an emphasis on inventory reduction led to severe parts shortages across the facility, almost crippling production operations. From stories such as these, we began to see that something even more fundamental had to be addressed, something that these organizations had not yet begun to track.

Factory Variation: A New Focus

Further investigation of manufacturing cycle time data from factories experiencing these types of difficulties turned up a very revealing phenomenon. When we plotted the cycle times for each successive production unit (as depicted in Figure 1.3), we found there to be an inordinate degree of variation. While not clearly shown here (scales were eliminated to protect the confidentiality of the factory the data represents), the difference between the upper and lower points on this chart represents a value that is greater than 30% of the mean value. Subsequently, we found this same dramatic level of variation in cycle times at individual workstations across the production facilities.

This finding raises a number of important questions. With the degree of schedule uncertainty caused by such swings in unit-to-unit production time (as shown in the figure), how can a facility be successful in any attempt to

slash inventories? In order to manage this schedule uncertainty, buffer inventories are vital to the factory's ability to support production operations. Without the ability to forecast when parts and materials will be needed, Just-In-Time deliveries cannot be depended upon. On a more positive note, if the sources of this variation could be identified and controlled, couldn't manufacturing cycle times be dramatically reduced? After all, if one unit can be produced in the minimum time depicted here, it seems that they all could be produced in that same amount of time. As we will later show, it is only factory variation—most of which is avoidable—that prevents them all from being produced in this same amount of time.

Cycle time variation truly appears to be a new concept to this industry. While almost all of the facilities that we visited were collecting the component information, we found few to be tracking this data, and none using it as a metric to gauge their improvement. Many did not see this information as helpful, accepting the result simply as a part of the cost of doing business, much like the frequent need for traveled work and expedited materials. However, those that had been most successful in their improvement efforts quickly came to agree with us on the importance of this effect on any effort intended to drive down costs related to excess inventories and manufacturing cycle times.

From these and other observations, we began to recognize the limitations of efforts that

CHAPTER 2

The Evolution of Manufacturing in

the Aircraft Industry

The transformation of the aircraft manufacturing industry from its humble beginnings to its present stature has been nothing less than phenomenal. Early pioneers would undoubtedly marvel at the sight of the modern airplane, awed by both its tremendous capabilities as well as its growth to prominence in our society. They would likely be no less impressed by the technological advancements of the processes by which airplanes are produced. Automated machines have replaced lathes, drills, and saws to shape enormous parts to exceedingly fine tolerances.¹ Advanced composites facilities have displaced the old plywood fabrication shops, with automated

tape placement and computerized autoclaves forming high-strength, complex structures with precision and repeatability. Electronic "pick and place" machines locate transistors and other components on circuit cards with dexterity and repeatability that can't be matched by human hands. Still, despite all of this technological advancement in tooling and equipment, it might also be noted that many other practices have remained surprisingly unchanged for almost half a century.²

The manufacturing of aircraft actually did not start with a classic production line at all—in fact, this innovation was not embraced until decades after the Wrights' historic flight.³ Instead, much like the automotive industry, aircraft manufacturing has its roots in what has

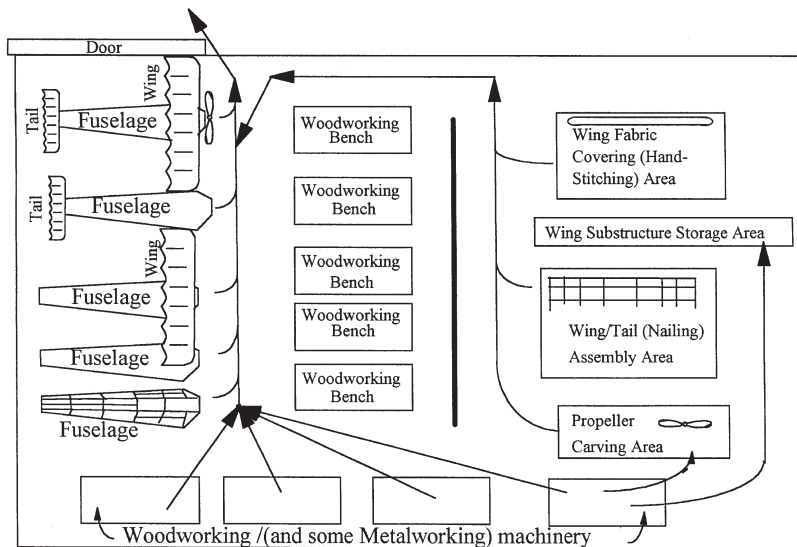


FIGURE 2.1 Typical aircraft manufacturing operation of the 1920s.

since been termed "craft production."⁴ Under this concept, the production of airplanes was highly dependent on the skills of experienced artisans. Often using little more than rudimentary woodworking tools and only the simplest assembly fixtures, a small team built entire airframes from start to finish (see Figure 2.1).⁵ Standardization was minimal; components were hand-fitted such that even similar items were unique. Without the limits imposed by standardized tooling and procedures, airplane designers often found themselves free to press the limits of existing technologies to meet the highly individualized specifications of their customers.

This approach of fashioning aircraft one at a time worked very well for a new invention that relatively few people had the money to purchase, or even the courage to climb aboard.⁶ The early airplane was seen largely as a folly—a frail, high-risk contraption appealing only to a few daring individuals wishing to experience the thrill of "slipping the surly bond of earth."⁷ With only 400 aircraft built by the entire U.S. industry in the year prior to the country's entry into World War I, the market was not sufficiently mature to support mass production.⁸ Many were individually commissioned for highly specific functions, often with customers that expected this personalized attention—and that could well afford to pay for it.⁹

Over time, manufacturers became very effective at operating in this manner. Their strong reliance on craftsmen held down the

cost of facilities and equipment, while permitting great production flexibility. While manufacturers could readily respond to the exacting demands of the customer, they were also able to maintain the type of quality workmanship that these products required.¹⁰ Even with the broad range of products offered under this make-to-order approach, only the simplest of production management and oversight systems were needed to maintain order. In fact, it is for several of these same reasons that many have clung to aspects of this approach even today.

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Only out of dire necessity did the industry begin to evolve. On the eve of World War I, this cottage industry was ill prepared to support the first massive increase in demand for its products. When the British and French entered the war, many of the early American aviation entrepreneurs saw a market forming and rushed to fill the growing need for these vehicles in Europe. They were largely unsuccessful in ramping up their production lines to meet the demand. They found that the production methods that had been so effective within a small niche-type market were much less capable within a high-rate manufacturing environment. Despite their best efforts, only a fraction of the requirement could be met, with orders instead filled from a larger overseas supply. As a result, even when the United States later entered the war, most U.S. pilots had to fly Euro-

pean aircraft. It became clear that an entirely different approach was needed.¹¹

After the war, this need for change became more and more apparent as the marketplace for airplanes continued to expand. This growth was marked by two key influences: the increasing importance of airmail services offered by the United States Postal Service, and the rekindling of America's interest in aviation by the 1927 transatlantic flight of Charles Lindbergh. Serving to advertise the technological advances made since World War I, Lindbergh's flight reawakened America's interest in aviation.¹² Because of these demonstrations of aviation's potential for peaceful purposes, Wall Street began to take a closer look at what had traditionally been considered a risky, highly speculative industry, further spurring growth.¹³

This was also a time when aircraft makers began to move away from the use of wood and fabric in favor of more advanced materials for airframe construction. New lightweight aluminum alloys and fabrication processes permitted manufacturers to form their airframes into durable, complex shapes, thus broadly expanding the horizons of the aircraft designer.¹⁴ It marked the beginning of an era that continues to this day—that of assembling aircraft by drilling and filling holes to attach aluminum skins to metallic substructures. With this shift, these vehicles came to resemble more and more closely their cousins, the automobiles. This similarity helped to make possible the cooperative efforts between the two indus-

tries that would be needed in the very near future.

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The advent of World War II set the stage for a number of key changes that would forever alter the way in which aircraft are manufactured. This event catapulted the U.S. aircraft industry to its current predominance, all in just over five short years. Prior to World War II—as late as 1939—the entire aircraft manufacturing industry was 44th in size among this nation’s industries. By the war’s peak in 1944, it had risen to become the world’s largest manufacturing industry.¹⁵ It is important to note that the automobile industry, along with several others, entered the business of aircraft production temporarily during the war, and accounted for some of this explosion. However, the regular aircraft industry produced about 90% of the airplanes used in the war.¹⁶

Most noteworthy among the changes that enabled this transformation was an accelerated shift from a dependence on skilled artisans—many of whom were now off to war—to a workforce composed of people who may have never before held a wrench. A new system took hold that could accommodate these workers, one that was also much more effective in meeting the very high production rates needed.¹⁷ After the war, many of the skilled craftsmen returned home with the intention of going back to their old jobs—only to find that their broad

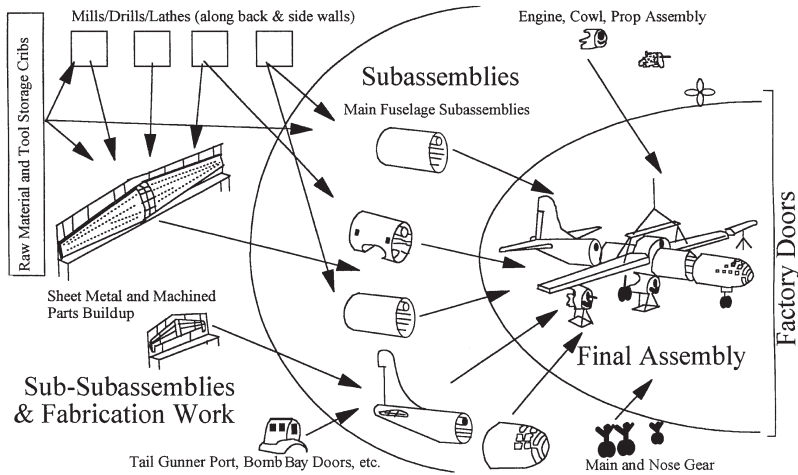


FIGURE 2.2 The BDV Aircraft Assembly Line concept.

skills were no longer the key to the production system that was now in place.

A New Era for Aircraft Production

While not usually associated with the aircraft industry, Henry Ford's philosophies have had a profound impact on the manner in which aircraft are produced. Ford's contribution came from his approach of breaking larger jobs into smaller, highly repeatable tasks.¹⁸ Building on earlier gains in parts interchangeability and assembly line production, his successes in automobile manufacturing demonstrated the advantages of moving away from craft production. It was no longer necessary to assemble products from beginning to end as a complete unit; tasks could now be broken down to such a level that workers

could repeat very narrow operations using specifically prescribed procedures. It was found that a worker assigned to relatively simple, repetitive jobs could become very efficient over time, yet still maintain or even improve the quality of the products. No longer constrained by the need to custom fit parts on assembly, the overall speed and capacity of the production line were dramatically increased.

During World War II, these innovations were broadly transplanted to the aircraft industry. Assembly and fabrication tasks were made to be more repetitive, with parts fabrication often scheduled in batches. Airframes that were once pieced together in single assembly jigs were now broken down into subassemblies and built up within separate parts of the factory. The decentralization of the assembly process resulted in a much less cramped work area; this dispersion greatly improved physical access to the airframe, allowing more workers to concurrently perform their operations. While requiring more total man-hours per day, this approach greatly reduced manufacturing cycle times, dramatically increasing production output.¹⁹

The BDV multiline production system exemplified this transformation. It was named after the companies that had first developed and implemented this system on the B-17 program—Boeing, Douglas, and Vega (a Lockheed company)—three of the aerospace giants that continued to dominate the industry until the end of the twentieth century. Rather than

adopting a straight-line approach, which was characteristic of an auto plant, this new system used a concept that minimized movement of large pieces of aircraft structure. Under this concept, assembly operations were laid out into a series of concentric semicircles, with each arranged largely based on the size of the components, as depicted in Figure 2.2. Final assembly operations were located nearest the factory doors, which were consequently surrounded by the larger subassemblies that fed into them. These were, in turn, surrounded by component fabrication areas or storerooms. This greatly reduced the factory travel distances for large aircraft components and assemblies as a function of their sizes.²⁰ This general approach continues to be used, even today.

It was not practical to assemble bombers like cars and trucks on long, moving assembly lines that went past workers who attached more and more parts to the chassis until the final product drove out the factory door because bombers were too big and complicated. They didn't have the stable chassis of a car or truck. To build a bomber around its "chassis"—the main wing spar—would have been much too awkward. Aircraft workers couldn't stand on the floor and reach into whatever part of the bomber they were working on as it passed by, the way autoworkers could. To build a B-17 or a B-29 step by step on a moving assembly line would have meant a maze of ladders and scaffolds that moved down the line with the bombers as they took shape.

—Jacob Vander Meulen, on the BDV production system²¹

Because extensive cross-pollination occurred between companies during the war years—touching almost every surviving aircraft manufacturing company—this assembly line system was largely adopted as the industry standard. Those across the industry benchmarked among themselves such functions as engineering planning and scheduling, resulting in organizations and production planning systems that were remarkably similar.²² The fact that each evolved to the same end point is logical in that they were all faced with the same situation: The high sustained demand for these products mandated such an approach. It is interesting to note, however, that despite the fact that it had been developed in an environment that was much different from that seen since, this method of producing aircraft would become the model followed by most throughout the century.

The Complexities of Factory Management

This simplification of the workers' span of responsibility did not come without a price: By dramatically increasing the number of tasks that must be managed in an environment already stressed by increased production rates and product mixes, the job of managing the facility was greatly complicated. Rigid production control methods now had to be put in place

to organize and coordinate long, variable sequences of operations. The result was a method of production that required a new mix of skills: a group of highly trained individuals to manage the overall production process, with a much larger group of more specialized workers to perform the manufacturing operations.²³

The character of aircraft manufacturing organizations changed immensely to accommodate this new operational approach. A large number of departments sprang up to handle the various aspects of this now complex business. Coordination of work became a formal process largely accomplished through bureaucratic channels. No longer could an engineer make changes to a design by simply walking out to the production shop to discuss it with the chief builder, as Wilbur or Orville could with their mechanic, Charlie Taylor. Instead, separate teams of "liaison engineers" served as the interface between the product designers and their production shops.²⁴ With the creation of other departments to buffer workers from both suppliers and customers, rigorous communication channels became essential to enable the free flow of information.²⁵

This organizational complexity led to a whole new set of problems, with production crises from the underestimating or overplanning of capacity, supplies, and raw materials becoming much more commonplace.²⁶ Yet, these problems were not unique to the aircraft industry. Even Henry Ford had experienced difficulty in managing the sprawling bureaucracy

that was spawned by his automotive production line. His counterpart at General Motors, William Durant, had similar problems. It really wasn't until later when Alfred Sloan took over GM's management that today's means of managing mass production was established.²⁷

In solving these problems, the aircraft industry suffered an additional complication in that it had not embraced these mass production approaches in their entirety. While the industry had adopted the basic tenets of mass production, it tailored the specifics to result in a hybrid approach. The multiline system represented one example where such changes were genuinely needed. In this case, the factory layout had to be adapted to suit the airplane's much greater complexity and size.²⁸ Other cases are not quite as easily rationalized, instead often lending the appearance that the industry simply could not bear to let go of the practices of its past. The most significant of these, a widespread continued reliance on craft manufacturing processes, has tremendously complicated the factory management process.

Some have argued that, because of the high-technology nature of the aircraft industry, craft production will never be entirely eliminated. As the customer continues to demand products that press performance to new limits, skill-based processes continue to be needed. While there is some merit to this argument, it is important to note that the processes requiring this level of expertise generally represent the exception rather than

the rule. We have found that the majority of the processes necessary for producing even the most sophisticated aircraft are well within the state of the art. Airframe components are often produced to much the same tolerances as are used within the automotive industry, and it is consumer electronics—rather than military aircraft—that now set the pace for this manufacturing sector. Yet, we still find that customization is widespread across the industry.

In a typical facility, this customization can be seen from the buildup of subassemblies to final assembly and acceptance testing. It is not unusual for structural components to be individually hand-trimmed on assembly in order to make them fit into place. Electronic components often fail acceptance tests, requiring extensive troubleshooting and retesting. This type of special attention is not new; even in the case of the B-29, aircraft were routinely sent straight from the factory to "modification centers" where they received tens of thousands of hours of rework.²⁹ The added degree of uncertainty associated with these activities, in both schedule variation and material needs, clearly serves to increase the complexity of the already difficult job of production management.

This tendency to rely on the skills of individuals rather than on the regimented structure of true mass production extends even to the management of the plant. Despite the existence of rigorous management controls, the experi-

ence and instincts of individuals continue to be as important as the formal system under which they must operate. This led one early production manager to lament:

The problem of scheduling aircraft fabrication is what one might call "complicated simplicity." It is not all academic or a series of numbers that can be multiplied and divided to get the answer. Much of the success of any scheduling system is due to the use of plain "horse sense" by the scheduling personnel.

—Hector MacKinnon,
production manager for Beech Aircraft, 1943³⁰

As we will further discuss in subsequent chapters, it is this continued dependence on the specialized skills of workers, schedulers, and planners that has had the greatest impact on production efficiencies. The institutionalization of work-arounds has stifled the intended operation of formal systems to manage many of the greatest sources of variation. Even more importantly, this approach has spawned an ever-increasing acceptance of variation. As a result, it seems as if no sense of urgency has been placed on refining the primary methods of factory management.

The Proliferation of Work-Arounds

During the war, multiple plants—and even industries—frequently experienced simultaneous surges in demand, often leading to severe shortages of raw materials and components.

With even one critical delay sometimes threatening to slow or even stop production operations, the aircraft industry was forced to take new measures to maintain some degree of stability. For this reason, many adopted the practice of prepositioning stockpiles of key materials.³¹ Because of the immense cost, however, it was not possible to safeguard against all material shortfalls in this manner. As a result, the industry adopted other work-around procedures to minimize the impact of delayed receipt of materials.

One of these work-arounds was the establishment of a team of "follow-up men" (who later became known as material "expeditors").³² These people were assigned the task of identifying at-risk parts or materials and pushing them through the system to mitigate disruption to the awaiting assembly line. Because of the criticality of their mission, they were given great latitude in sidestepping established policies and procedures to achieve their goals. The result was impressive: Expeditors were highly successful in minimizing the impact of scarce materials on production operations, thereby preventing major delays in delivering the aircraft to support the war effort.³³

Following the war, many manufacturers continued their dependence on these approaches. Proven as a hedge against untrustworthy material and component suppliers during this time of crisis, they became widely accepted. Thus, these same practices were adapted for use dur-

ing peacetime operations. Along with buffer inventories, expeditors had become factories' insurance that production would continue to flow despite sometimes severe disruptions.³⁴

We have found that these methods have not been as effective as many seem to believe. Despite the supposed insurance they offer, shortages continue to plague production operations. Even with hundreds of expeditors and mountains of inventory, the single largest problem cited by many of these factories continues to be a chronic shortage of parts.

In fact, it is often because of these work-arounds that this problem continues to be so pronounced. In their haste, we found that expeditors routinely circumvent formal purchasing and inventory control systems, leaving a substantial portion of material receipts and deliveries undocumented. Without all matériel transactions captured, inventory records are corrupted. The ability of these organizations to cost-effectively manage production operations without accurate inventory information was called into question even as early as 1944:

Existing inventory records at most airframe companies are probably far from accurate and in some instances are recognized as being so inaccurate that they are seldom used for control purposes. Yet without accurate and timely inventory data no satisfactory materials control is possible. Without these data, also, total inventories must be kept large in order to avoid shortages in the plant.

—1944 Harvard University study³⁵

At the end of the war, this Harvard University study highlighted the cost impact that these types of behaviors could pose during the postwar drawdown. Others agreed with these findings, calling for substantial changes and cautioning that only through a much more rigorous approach to production could the industry efficiently make the transition to a peacetime environment.³⁶ Yet, despite the comprehensive findings of such a prestigious organization, many of these concerns seem to have gone unheeded for almost half a century.

Attempts to Control Manufacturing Inefficiencies

After the war, a new focus quickly drew attention away from these shop floor inefficiencies. A strong interest in new high-performance airplanes took hold. Jet engines, revolutionary new wing designs, and the subsequent leap to supersonic flight led to renewed demand for military aircraft and the creation of entirely new lines of passenger-carrying aircraft. Performance became paramount; cost was not a driving concern.³⁷ With this stimulation of long-term industry growth, along with some degree of industry consolidation, the pain that the aircraft manufacturers would feel as a result of a postwar contraction was not as severe as once thought.³⁸

Throughout much of this century, this strategy continued to be highly successful. After all,

it was this technological focus that offered an immediate competitive edge in both the commercial and military marketplaces. It allowed aerospace manufacturers to offer unique features that would differentiate their products from those of their competitors. Both commercial and military customers wanted the latest advances as quickly as possible and they were willing to pay for it.³⁹ Unfortunately, this focus led to the continued growth of manufacturing inefficiency. As one company executive observed in retrospect, "As business got better, efficiency got worse."⁴⁰

This is not to say that manufacturing improvements were never attempted. There were cases where aerospace companies made valiant, successful efforts, sometimes in response to customer demands, other times simply in order to remain viable. Yet, these efforts tended to be aimed at achieving some preset goal; once attained, the efforts subsided. Many times these improvements lacked key provisions to prevent other problems from surfacing. As a result, many improvements were either short-lived or highly localized.

One published example of this phenomenon surrounded the Boeing Company in the late 1960s. The company was near bankruptcy and desperately needed to make improvements in order to slash operating costs. Production methods were far from optimal, and a downturn in demand for its products squeezed margins such that inefficiencies could no longer go on unaddressed. In response, the company pulled

out all stops. After a detailed assessment, it took strong action to reduce its inventory stocks. Excess tooling and machinery were sold off, improved work practices were implemented, and tighter inspections were instituted. Furthermore, production flow through the factory was scrutinized and streamlined such that production schedules could be compressed.⁴¹ Overall, these initiatives yielded sufficient improvement to save the company.⁴²

Still, these actions did not completely eliminate waste. For instance, because suppliers were not made a direct part of the overall approach, their late deliveries led to part shortages that continued to plague the assembly line.⁴³ Despite a large degree of improvement, the use of work-arounds and inventory buffers continued to be important in permitting delivery schedules to be met.

It wasn't until decades later that a concerted effort to control these areas of manufacturing inefficiency began to spark the aircraft industry. Pressed to reduce operating expenses to accommodate shrinking customer budgets, manufacturers embraced a new round of tools and practices in the 1980s. Once again, lessons from the automotive industry served as the foundation for this movement. Yet, unlike what was seen in the past, these ideas did not originate at Ford or GM—this time they came from Toyota.

CC

After World War II, the Toyota Motor Company

began to experiment with its own concept of manufacturing, one that started with an understanding of the tenets of mass production, but adapted to work within the scope of its own environment. Toyota could not directly adopt the approaches used by the U.S. automotive giants if for no other reason than that there was a much lower demand for its products (at the time, this company produced far fewer automobiles in a decade than were shipped from Ford's Rouge plant in a single day). To compound the situation, the company had little access to investment capital, and had been recently pressured into an agreement with its trade unions that virtually guaranteed lifelong employment to the workforce. As a result, any solution would have to leverage the flexibility of this workforce to extract the highest degree of productivity from the company's limited facilities and equipment.⁴⁴

Through trial and error, Eiji Toyoda and his production designer, Taiichi Ohno, proved out a number of innovative solutions to their problem. An emphasis on creating an environment of workforce flexibility and empowerment was central to their strategy; only with this could the company get the most from workers who would be tied to the company for many decades.⁴⁵ With the workforce trained for multiple disciplines, it would no longer be necessary for workers to remain idle between tasks. While waiting for a piece of production machinery, workers could now move to another station. Equipment was moved closer, quick setup

fixtures were developed, and new procedures were put into place to facilitate workers' efforts. Toyoda and Ohno demonstrated that, by emphasizing workforce and equipment flexibility, the company could achieve astounding gains even without the efficiencies of scale of its competitors.⁴⁶

This approach allowed Toyota to dramatically reduce the production cycle times and inventory levels needed to do business. With methods and procedures now in place to permit the fabrication of parts in very small batch sizes, work in process (WIP) inventories were reduced. Since Ohno focused on the elimination of activities that added no real value to the final product, a strong emphasis was placed on minimizing production rework. Using such methods as Statistical Process Control, processes were routinely monitored to keep them operating within the limits needed to maintain product quality. Continuous improvement, or kaizen, was adopted, where workers were asked to chase down the root cause of problems and identify means to improvement. Ultimately by driving down lot sizes and rework, buffers to schedules and inventories were dramatically reduced.⁴⁷

Rather than focusing solely on the manufacturing efforts of its own plants, Toyota took additional measures to ensure the quality and timely delivery from its suppliers. As was noted earlier, external disruption would impact its operations just the same as if it had occurred within one of the company's own work-

