The Boeing 767: From Concept to Production (A)

In August 1981, eleven months before the first scheduled delivery of Boeing's new airplane, the 767, Dean Thornton, the program's vice president-general manager, faced a critical decision. For several years, Boeing had lobbied the Federal Aviation Administration (FAA) for permission to build wide-bodied aircraft with two-, rather than three-person cockpits. Permission had been granted late in July. Unfortunately, the 767 had originally been designed with a three-person cockpit, and 30 of those planes were already in various stages of production.

Thornton knew that the planes had to be converted to models with two-person cockpits. But what was the best way to proceed? Should the changes be made in-line, inserting new cockpits into the 30 planes without removing them from the flow of production, or off-line, building the 30 planes with three-person cockpits as originally planned and then retrofitting them with two-person cockpits in a separate rework area? Either way, Thornton knew that a decision had to be made quickly. Promised delivery dates were sacred at Boeing, and the changes in cockpit design might well impose substantial delays.

The Airframe[1] Industry

Commercial aircraft manufacturing was an industry of vast scale and complexity. A typical 767 contained 3.1 million individual parts; federal regulations required that many be documented and traceable. There were 85 miles of wiring alone. Manufacturers employed thousands of scientists and engineers to develop new technologies and production systems, and also to attack design problems. Facilities were on a similarly grand scale. Boeing assembled the 747, its largest commercial airplane, in the world's largest building—62 acres under a single roof—with a work force of 28,600 people.

Few companies were able to marshal such massive resources. In 1981 the industry had only three major players: the American manufacturers, Boeing and McDonnell Douglas, and the European consortium, Airbus. A fourth manufacturer, Lockheed, left the commercial airplane industry in 1981 after its wide-bodied jet, the L-1011, had incurred losses of $2.5 billion. Boeing and McDonnell Douglas were competitors of longstanding; Airbus, on the other hand, made its commercial debut in May 1974. It was not generally regarded as a serious competitive threat until 1978, the date of its first large sale to a U.S. airline. By 1981, Airbus had sold 300 planes to 41 airlines, and had options for 200

[1] An airframe is an airplane without engines. Technically, Boeing competed in the airframe industry. In this case, however, the terms airframe, airplane, and aircraft are used interchangeably.

Associates for Case Development Janet Simpson and Lee Field and Professor David A. Garvin prepared this case as the basis for class discussion rather than to illustrate either effective or ineffective handling of an administrative situation.

more. It received direct financing and subsidies from the French, Spanish, German, and British governments.

Airframe manufacturing was a business of enormous risks, for in no other industry was so much capital deployed with so much uncertainty. Launching a new plane meant up-front development costs of $1.5-2 billion, lead times of up to four years from go-ahead to first delivery, and the qualification and management of thousands of subcontractors.

Projects of this scale could put a company's entire net worth on the line. For that reason, industry executives were sometimes characterized as "gamblers," sporting participants in a high-stakes game. Side bets—actual wagers between manufacturers and airlines regarding airplane performance, features, or delivery dates—occasionally accompanied purchase negotiations. The odds against a successful new product were large. According to one industry expert, in the past thirty years only two new plane programs, the Boeing 707 and 727, actually made money.[2] (According to Boeing, the 737 and 747 programs have also been profitable.) If a new program were successful, however, the potential returns were enormous. A successful new plane could lock up its chosen market segment for as long as 20 years, producing sales of $25-45 billion and huge profits. It was also likely to bring great prestige, power, and influence to the company and managers that created it.

Success required a long-term view. Competitive pricing was essential. Pricing practices, however, contributed risks of their own. New plane prices were based not on the cost of producing the first airplane, but on the average cost of 300 to 400 planes, when required labor hours had declined because of learning. This effect, the so-called learning curve, was hardly unique to airframe manufacturing. But small annual volumes and long manufacturing cycles—even during peak periods Boeing planned to build only eight 767s per month—meant that break-even points stretched further into the future in airframe manufacturing than was typical of most other industries, where mass production was the norm.

Manufacturers were therefore anxious to build orders for new planes as quickly as possible. Buyers—primarily the 50 leading airlines around the world—used that knowledge to enhance their bargaining positions, often delaying orders until the last possible moment. Negotiations on price, design modifications, and after-sales parts and service became especially aggressive in the 1970s, when airlines that had been making steady profits began losing large sums of money. Cost savings became a dominant concern. As Richard Ferris, the CEO of United Airlines, remarked: "Don't bug me about interior design or customer preference, just guarantee the seat-mile performance."[3]

The Boeing Company

Boeing was the sales leader of the airframe industry, as well as one of America's leading exporters. It had built more commercial airplanes than any other company in the world. Sales in 1981 were $9.2 billion; of the total, $5.1 billion were ascribed to the Boeing Commercial Airplane Company, the firm's aircraft manufacturing division. Other divisions produced missiles, rockets, helicopters, space equipment, computers and electronics.

History The Boeing Company was founded in 1916 by William E. Boeing, the son of a wealthy timber man who had studied engineering at Yale. In its earliest days, the company built military aircraft for use in World War I. It began to prosper in the 1920s and 1930s, when the civil aviation market expanded, primarily because of the demand for mail carrying. At about that time, William Boeing issued a challenge that has remained the company's credo:

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[2]John Newhouse, *The Sporty Game* (New York: Alfred A. Knopf, 1982), p. 4.

> Our job is to keep everlastingly at research and experimentation, to adapt our laboratories to production as soon as possible, and to let no new improvement in flying and flying equipment pass us by.

To meet this challenge, Boeing originally relied on extensive vertical integration. It not only manufactured entire planes itself, but also provided engines through its Pratt & Whitney subsidiary, and bought and flew planes through its United Air Lines subsidiary. A government mandate separated the three entities in 1934. As the costs of developing and producing new aircraft grew ever larger, the company became even more focused. By the late 1970s and early 1980s, Boeing no longer assumed all development costs itself, nor did it fabricate entire airplanes. Instead, it carefully selected partners, some of whom participated on a risk-sharing basis, who were then subcontracted portions of each plane and developed and built parts and subassemblies that Boeing later assembled. The primary exceptions were the nose section and wings, which Boeing continued to build in-house. One manager summarized the situation in the 1970s by saying: "Today Boeing is an assembler who makes wings."

In part, such efforts to limit up-front investment and reduce risks were prompted by Boeing's near disastrous experiences with its first wide-bodied jet, the 747. In 1969, when the company was introducing the 737 as well as the 747, management problems, declining productivity, steep development costs and unanticipated problems with the engine, plus cutbacks in commercial and government orders, produced a severe cash crunch. Boeing was close to bankruptcy. In the next three years, the company's work force fell from 150,000 to 50,000; unemployment in Seattle, Boeing's home base, rose to 14%. Eventually, such belt tightening, plus efforts to resolve problems with the 737 and 747 programs, carried the day, and Boeing emerged from the crisis leaner and stronger, but with a renewed sense of the inherent risks of major development programs.

Strategy Ever since the 707 was introduced in 1955, Boeing had competed by selling families of planes. Each new generation of aircraft was created with several variations in mind, drawing on the same base airframe concept. By 1987 the 747, for example, was being offered in eleven varieties, including the 747-100B (standard), 747-200B (long range), 747F (freighter), and 747C (convertible to either passenger or cargo configurations). Flexible designs with inherent growth potential were essential to this approach. Modifications such as a stretched fuselage to increase capacity had to be accommodated without wholesale revisions in design or the need to start up entirely separate development programs.

A more efficient design and development process was only one benefit of the family of planes concept. There were manufacturing benefits as well. A common family of planes, produced on a common assembly line, ensured that learning was not lost as new models were added. Experience accumulated rapidly, as Thornton observed:

> We're good partly because we build lots of airplanes. And each new plane absorbs everything we have learned from earlier models.

One result of this approach was break-even points that were reached far earlier than they would have been without shared designs.

Other cornerstones of Boeing's strategy were expertise in global marketing, technological leadership, customer support, and production skills. Large centralized facilities were coupled with sophisticated manufacturing systems and tools for project management. The result, according to informed observers, was the industry's low-cost producer. Or as one aerospace analyst summarized

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[3]Ibid., p. 84. Seat-mile performance is the cost of operating a plane divided by the product of miles flown and the number of seats available.

the company's reputation: "If someone hired me to rebuild the Great Pyramid, I'd ask . . . Boeing to assemble it."[4]

Culture Boeing managers believed that the company had a distinct corporate identity. Teamwork was especially valued, as was interfunctional cooperation. According to Dexter Haas, a manager in corporate planning:

> At Boeing, employees are expected to be both competent and capable of working as members of a team. We feel that technically brilliant but uncooperative individuals can do as much harm to a program as cooperative but mediocre team members.

Such concerns were especially acute on new plane programs, which were a prime vehicle for management development. Programs required close cooperation among managers for five to ten years, often under intense time pressures and 60-70 hour work weeks. To make these programs work, Thornton commented, "You don't necessarily select the best people; you select the best team."

Once selected, teams were granted considerable autonomy. But a disciplined decision-making process was expected, as was detailed planning. Both were viewed by managers as characteristic Boeing traits. According to Fred Cerf, director of systems and equipment:

> A part of Boeing's culture is absolute dedication to commitments—from individuals within the company and from suppliers. We expect people to honor their commitments and adhere to plans. We don't regard plans as exercises, but as forecasted events.

Meeting schedules was an especially high priority for managers. A variety of tools, several of them unique to Boeing, were used to develop realistic schedules and monitor them over time. Among them were a Master Phasing Plan, which mapped out the entire development cycle, including critical milestones, for each new plane program; parametric estimating techniques, which estimated costs and established relationships between critical sections of a schedule, such as the time at which engineering drawings were released and the start up of production, by using historical data drawn from earlier plane programs; and a management visibility system, which was designed to surface problems before they became serious enough to cause delays. Regular communication was encouraged, even if it meant bringing bad news. According to John Schmick, director of planning:

> Early exposure of problems is not a sin at Boeing. We tend not to kill our managers for taking that approach. Here, it's much worse if you bury the problem.

The 767 Program

In 1969, Boeing assembled a New Airplane Program (NAP) study group. Its goal was not to develop a new plane, but to review the company's past experiences with each of its major programs—the 707, 727, 737, and 747—so that problems, such as those incurred by the 737 and 747 programs, would not be repeated. As Neil Standal, a member of the NAP group who later became the 767 program manager, observed:

> We knew that we were going to have another commercial airplane. But we didn't know what, or when, it was going to be. Our objective was to provide lessons

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[4]Ibid., p. 139.

> for the future, to look at our history and decide what we had done right and what we had done wrong.

This process, called Project Homework, took three years and produced a long list of "lessons learned," as well as a reasonable idea of the costs of developing the next generation airplane.

Meanwhile, pressures were beginning to mount within Boeing to launch a new airplane program. Salespeople were especially insistent, as T.A. ("T") Wilson, Boeing's chairman, recalled:

> Our salespeople kept saying, "We need a new product." They didn't really care what it was, as long as it was new.

Because the company's last new plane, the 747, had been launched in 1966, there was also concern among the board of directors that Boeing's next generation of leaders was not being trained in the best way possible: by developing a new plane of their own.

In 1973, at Wilson's behest, Boeing initiated a new airplane study, naming it the 7X7 (X stood for development model). Key team members, including J.F. Sutter, the program's first leader, and Dean Thornton, who replaced Sutter after he was promoted to vice president of operations and development, were handpicked by Wilson. The team was given a broad charter: to define and, if approved, to develop, Boeing's next generation airplane.

Program Definition

The first stage of the process, called program definition, extended from May 1973 to December 1977 (see **Exhibit 1**). During this period, Boeing worked the puzzle of market, technology, and cost. Team members projected airline needs into the future to see if there were holes in the market not met by existing planes; considered alternative plane configurations; examined new technologies to see what might be available within the next few years; and estimated, in a preliminary fashion, likely development and production costs.

Market assessment Forecasting the airframe market for the 1980s and 1990s was a complex and challenging task. Market analysts began by talking directly with the major airlines to get their estimates of future needs. That information was then combined with econometric models to generate three forecasts—optimistic, conservative, and expected—for each market segment. Segments were defined by range of travel—short (less than 1,500 nautical miles), medium (1,500—3,000 nautical miles), and long (greater than 3,000 nautical miles)–and all forecasts were based on the following assumptions: continued regulation of the airline industry; continued airline preferences for routes that directly linked pairs of major cities; steadily rising fuel prices; and no new competition from other airframe manufacturers in the medium range market. Complete forecasts were run annually and readjusted quarterly.

Boeing's expected forecast for 1990 was a total market of $100 billion. The critical medium range segment—the expected target of the new airplane—was estimated at $19 billion. In that segment, Boeing expected to capture 100% of domestic sales. Continued production of the 727 would meet most replacement needs, and the 7X7 would be positioned for market growth.

Configuration While these forecasts were being developed, another group was working on design specifications. After a year or two of study, the basics were decided. Market research indicated that the new plane should carry approximately 200 passengers; have a one-stop, U.S. transcontinental range; and offer minimal fuel burn. The last requirement was regarded as especially important. With the rise in oil prices that followed the 1973 Arab oil embargo, fuel costs had become an ever larger portion of airlines' operating expenses. Moreover, airline preferences were changing, as Frank Shrontz, president and CEO, observed:

> In the old days, airlines were infatuated with technology for its own sake. Today the rationale for purchasing a new plane is cost savings and profitability.

Market needs were thus reasonably clear, at least within broad outlines. Designers, however, still faced a number of critical choices. All involved some aspect of the plane's basic shape.

The most vexing question was whether to design the 7X7 with two or three engines. A two-engine version would be lighter and more fuel efficient; a three-engine version would offer greater range. But exactly what were the tradeoffs? And how far was engine technology likely to advance in the next few years? Boeing, after all, did not build its own engines, but bought them from one of three manufacturers: General Electric, Pratt & Whitney, and Rolls Royce. Airlines paid separately for airframes and engines; however, they could only choose engines that were offered for the airplane. (This was necessary because Boeing guaranteed the performance of every plane it sold.) Early in the 7X7 program, managers chose to offer engines from both General Electric and Pratt & Whitney, despite the additional time and expense that Boeing would incur. This decision was a direct outgrowth of the company's experiences with the 747. Managers felt that continued competition among engine manufacturers was essential to moderate costs. Equally important, competition was expected to provide a steady stream of improvements in engine technology.

The certification decision proved to be far easier than the choice between a two- and three-engine plane. In fact, for most of the program definition phase, the 7X7 team worked simultaneously on two- and three-engine models. Eventually, fuel efficiency won out—as one manager put it, "in those days, an engineer would shoot his mother-in-law for a tenth of a percent improvement in fuel savings"—and the two-engine version was selected.

Other key configuration decisions involved the wings and tail. Both decisions showed the family of planes concept in action, and the need for designs that were adaptable to future needs. The 7X7 was conceived originally as a medium-range aircraft; however, later additions to the 7X7 family were expected to target longer-range flights. Engineers therefore selected a wing size—3,000 square feet—that was larger than necessary for short- and medium-range flights. It added weight to the basic design, with some loss of fuel efficiency. But the design was highly adaptable: it could be used, without modification, on longer-range versions and stretched models with greater carrying capacity.

Because they were so complex, configuration decisions required the close coordination of marketing, engineering, and production personnel. The airlines were also intimately involved. After a new configuration was developed, Boeing's marketing managers brought it to the airlines, who reviewed, among other things, its flight characteristics, range, cruising speed, interior, cockpit, systems, and operating costs. Their reactions were then fed back to designers, and the process was repeated. Haas observed:

> Designing airplanes to best meet the unique requirements of customers is a difficult process. Each airline would prefer that it was designed a bit differently—a little longer, a little shorter, a few more people, a few less. Therefore, the configuration changes constantly.

Technology Configuration decisions could not be made without assessing the technology that was then available. What was desired by the market might not be possible or economical given the current state of knowledge.

Technology development was an ongoing process at Boeing, and included such areas as structures, flight systems, aircraft systems (hydraulic and electrical), and aerodynamics. Each area had its own chief engineer, who was responsible for overseeing research, development, and application of the technology. The last requirement was regarded as especially critical, as David Norton, chief of technology, pointed out:

> There is nothing that brings me up quicker than thinking of how long we have to live with our decisions. At Boeing, applying a new technology is as important as developing it. We had better be right.

When a new plane was proposed, engineers first reviewed all existing technology projects to see if any were appropriate. They asked three questions of every project: (1) What is its ultimate value to the customer? (2) Is it an acceptable technological risk? and (3) Can it be incorporated within schedule and cost? Responsibility for answering these questions was divided among the chief engineers of each technology and a chief engineer in charge of the plane program. Line engineers therefore reported through a matrix, and were accountable to two bosses: the chief engineer of their technology and the chief engineer of the program. The former was more concerned with technical questions (e.g., What is the most efficient approach? Will we have a technologically superior product?), while the latter had more practical concerns (e.g., What will the airlines think of the new technology? How will its initial costs compare with the reduced maintenance costs expected over the plane's lifetime? What will be the program's cost and schedule?).

A number of the "new" technologies considered for the 7X7 had, in fact, already been employed elsewhere, primarily on space vehicles. They were therefore regarded as proven, with few technological risks. For example, digital avionics prototype systems in the cockpit, which replaced the traditional analog systems, had originally been developed for the SST program in 1969. Because it offered improved reliability, more accurate flight paths, lower maintenance costs, and the potential for a two-person cockpit, it was incorporated into the 7X7 with little debate.

Decisions involving unproven technologies were considerably more difficult. As Everette Webb, the 7X7's chief engineer, pointed out: "In such cases, deciding what is an acceptable risk is largely a judgment call." Composites provide an example of Boeing's approach.

Composites are complex materials, formed by combining two or more complementary substances. They appeal to airframe manufacturers because they combine great strength with light weight. In the 1960s and 1970s, Boeing engineers conducted a number of laboratory tests on large, composite panels; eventually, they found a promising material, a mixture of graphite and kevlar. Laboratory tests, however, were not regarded as representative of the "real world airline environment." To gather such data, Boeing worked with a small number of airlines and conducted limited, in-service tests. Boeing fabricated structural parts, such as wing control surfaces or spoiler panels, using composites; had them installed on a plane then in production; and monitored the material's performance as the plane underwent normal airline use. These tests soon indicated a problem with water absorption in environments of high heat and humidity, such as Brazil. A layer of fiberglass was added to the composite panels to solve the problem, and tests continued through the early 1970s. Yet, despite the tests, engineers decided against using composites for the 7X7's primary structure, and recommended instead that they be used only for secondary parts, where the safety risks were lower. Norton explained: "We push technology very hard, but we're conservative about implementation."

Audit teams Audit teams were also active during the program definition phase, starting in September 1976. Teams were staffed by experienced Boeing managers, and were assigned to review every significant element of the 7X7 program, including technology, finance, manufacturing, and management. Teams acted as "devil's advocates," and a typical audit took three months. According to Standal:

> In the past, we occasionally used outside consultants as auditors. But we found that, for the most part, we do a better job with our own people. We isolate them organizationally and give them a separate reporting line straight to T. Wilson.

Cost Definition

In September 1977, the 7X7 program was renamed the 767, and in January 1978, the cost definition phase began (see **Exhibit 1**). This shift was a major step: it indicated escalating program commitment and required the authorization of the president of the Boeing Commercial Airplane Company. Approximately $100 million had already been spent on the 7X7; most of it, however, was regarded as part of ongoing research and development. Now the critical decision was at hand: Would Boeing commit to building a new plane and, in the process, incur up-front costs of several billion dollars?

Only the board of directors could make such a decision. First, however, detailed cost estimates were necessary; they, in turn, had to be based on a single configuration. Cost definition forced engineers and marketing managers to stand up and say, "We want to offer *this* airplane." The 767's basic design, including the long-delayed choice between two and three engines, was finally frozen in place in May 1978 (see **Exhibit 2**).

Parametric estimates Once the basic design was established, costs could be estimated using a parametric estimating technique. This method, adapted by Boeing, had been developed by the New Airplane Program study group from comparisons of the 707, 727, 737, and 747. It predicted the costs of a new plane from design characteristics, such as weight, speed, and length, and historical relationships, such as the number of parts per airplane, that were known well in advance of production.

The critical calculation involved assembly labor hours. Managers began with data from a benchmark (and profitable) program, the 727, and noted, for every major section of the plane, the number of labor hours per pound required to build the first unit. That number was then multiplied by the expected weight of the same section of the 767; this result, in turn, was multiplied by a factor that reflected Boeing's historical experience in improving the relationship between labor hours and weight as it moved to the next generation airplane. Totaling the results for all plane sections provided an estimate of the labor hours required to build the first 767. A learning curve was then applied to estimate the number of labor hours required to build subsequent planes.

Engineers believed that the historical relationships underlying these calculations remained valid for long periods. According to Dennis Wilson, manager of scheduling for the 767:

> Unless we drastically change the way we do business, we will be able to use the same parametrics to compare programs. After all, an airplane is an airplane.

Parametric estimates were, however, carefully fine-tuned to account for differences in plane programs. Adjustments could go in either direction. Improved equipment and management control systems, an enforced reduction in engineering change orders, and heavy use of Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) suggested that the 767 would require fewer hours than predicted by parametrics derived from the 727; increased product complexity and a larger variety of customers suggested that more hours would be required. These factors were combined to form a final, adjusted estimate of total assembly hours.

A similar process was used to develop the Master Phasing Plan, which established the program schedule and identified major milestones (see **Exhibit 3**). The critical task was linking the schedules of interdependent groups, such as engineering and production, to avoid schedule compression or delays. Parametrics were used for that purpose. For example, comparisons of the 727 and 747 programs suggested that, if problems were to be avoided, fabrication should not begin until 25% of structural engineering drawings were complete, and that major assembly should not begin until 90% of engineering drawings were complete. Such values became the baseline for the 767's Master Phasing Plan. The initial plan was completed in October 1977, and was revised repeatedly as more up-to-date information became available.

The Go/No-Go decision In February 1978, Boeing's board of directors was asked to commit to the 767. Prior to that time, Wilson and the 767 team had briefed them, reviewing all aspects of the program. The board agreed to authorize the new plane, but only if two conditions were met: commitments to purchase were received from one foreign and two domestic airlines, and pre-production orders totaled at least 100 planes.

On July 14, 1978, United Airlines placed a $1 billion order for 30 767s, making it Boeing's first customer. Being the first customer had certain risks—the offer to sell was conditional, and could be canceled at a later date—but offered advantages as well. Prices were lower, and the first buyer had an opportunity to help shape the plane's final configuration. By November 1978, American and Delta Airlines had also placed orders, bringing the total to 80 planes, with an additional 79 on option. The board then committed Boeing to full production of the 767. The cost definition phase had ended in July 1978; meanwhile, teams began to flesh out the details of supplier and production management.

Supplier Management

A complete 767 consisted of 3.1 million parts, which were supplied by 1,300 vendors. Of these, the most important were the two program participants and four major subcontractors, who built such critical parts as body structures, tail sections, and landing gear. Program participants were, in effect, risk-sharing partners who bore a portion of the costs of design, development, and tooling; major subcontractors were similar, but took on a smaller share of the work. Both were necessary because new airplane programs had become too big for Boeing, or any other single company, to handle alone. On the 767, Aeritalia, the Italian aircraft manufacturer, and the Japan Aircraft Development Company (JADC), a consortium made up of Mitsubishi, Kawasaki, and Fuji Industries, were the two program participants. Both were contracted with in September 1978.

In the late 1960s and 1970s, Aeritalia had worked with Boeing on several proposed airplane designs, including one plane with short-field takeoff and landing capacity. Based on that experience, Aeritalia asked to participate in future work with Boeing. Cerf recalled:

> Boeing honored Aeritalia's request. We decided that they would produce the 767's wing control surfaces and tail, parts which were considered to be significant but which were less critical than body panels to the final assembly line. As it turned out, materials technology advanced in the meantime, and most of the control surface parts were changed from aluminum structure to graphite composites. That helped to make them one of the more complex jobs on the airplane.

JADC, on the other hand, was responsible for the several large body sections. The Japanese participants had been interested in working with Boeing for years and had done progressively more important work on other aircraft. Now, their workmanship was considered exacting enough to meet Boeing standards for the production of major sections of structure.

Technology transfer Boeing worked closely with all of its subcontractors, from initial planning to final delivery. Cerf observed:

> Generally, at Boeing we do not contract with suppliers and then walk away. We feel responsible for them and *have* to make it work. This was especially true of the 767 program participants. Because the content of their work was so significant, a failure would have precluded our ability to salvage an industrial operation of this size.

To begin, the Italian and Japanese participants were asked to work together with Boeing engineers. Engineering management helped to select the Italian and Japanese engineers who would participate in the 767 program, and rated them according to their skill levels. The Italian and

Japanese engineers then worked alongside Boeing engineers in Seattle. At the 25% structures release point (a critical milestone, at which point stress analyses had been completed), they returned to their home companies, accompanied by their Boeing engineering counterparts, who were then integrated into the Italian and Japanese engineering organizations. At the same time, in mid-1978, Boeing established residence teams in Italy and Japan, consisting of some of Boeing's best operations people. The operations teams evaluated and helped to establish participants' facilities, training, and manufacturing processes, and also certified their quality assurance processes. If problems arose, rapid communication with Seattle was often necessary; this was assured by a private telephone network connecting Boeing to each participant.

An example of supplier management: The Japanese Transportation Plan Initially, JADC had argued that transporting body sections from its factories in Japan to Boeing's assembly plant near Seattle would present few problems. Boeing, to be absolutely certain, had insisted that scale models of all sections be built and carried along the proposed route. The parts proved to be too large for Japan's narrow, rural roads; as a result, an old steel factory, located closer to shipping facilities, was converted by one Japanese company to assemble major sections. Another company constructed a final assembly plant located directly on the water. As insurance, Boeing also requested that the body sections be air transportable, and their designs were sized accordingly.

Boeing then put one of its transportation specialists to work with his Japanese counterparts to develop a transportation plan. This effort took several months, as Cerf recalled:

> We went through a major exercise to prove that all of the Japanese companies could support our assembly schedule in Seattle. We brought their representatives to see the complete plan, which covered the walls of a huge meeting room, and worked with them carefully to plan what would be on their shipping docks, what would be on the high seas, and what would be in our plants at any one time.
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> The level of detail was quite astounding. We kept asking them representative questions, such as "Do you have the right permits and who will get them? What does the transportation container look like and has it been stressed properly for transport by sea?" Surprisingly, the Japanese didn't object to this process at all. They weren't just cooperative; they were used to working at this level of detail and wanted to learn all we knew.
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> All of this was a good thing because there was no backup once the decision was made to build the major body sections in Japan. We were committed because our plants at Boeing were working at capacity.

Production Management

Part fabrication began in July 1979, minor (subsection) assembly in April 1980, and major assembly in July 1980. Such long lead times were necessary to meet the planned rollout of the first 767 in August 1981. Flight tests began immediately after rollout, and FAA certification was expected in July 1982.

All 767s were assembled in Everett, Washington, in the same facility used for 747s. Half of the building was devoted to assembly of major subsections; the other half to final assembly. In the final stages of assembly, a line flow process was used, with seven major work stations (see **Exhibit 4** for a rough sequence of manufacturing operations). Every four days, partially completed planes were moved, using large overhead cranes, from one work station to the next. At each work station, teams of skilled employees positioned a single plane in massive tools and fixtures, and then riveted, wired, and connected parts and pieces.

During the assembly stage, managers faced two critical tasks: maintaining schedule, and ensuring that learning curve goals were met. Both were complicated by a key difference between airframe manufacturing and other industries: the difficulty of managing a large number of engineering change orders. Haas observed:

> An airplane is not something you design, turn over to manufacturing, and then forget. The configuration is constantly changing. So you commit to a schedule, and then incorporate changes and improvements as they come.

This task was especially critical because cost estimates assumed that assembly labor hours would decline predictably over time, following a preset learning curve. Managers therefore had to ensure that learning goals were met at the same time that they were accommodating unanticipated changes.

Scheduling and change control Requests for changes came from internal and external sources. Some, such as the color of carpeting or seating arrangements, were negotiated by airline customers; others, such as parts or wiring changes, were proposed by engineers. In total, the two sources generated 12,000 changes on the first 767.

Managers tracked these changes carefully. Even before the plane's basic design was frozen, all major changes had to be filed using the same formal procedure. This was done to ensure that specifications remained accurate. Once assembly began, a Production Change Board, chaired by the operations department, reviewed all engineering change requests and assessed their likely impact on schedule and cost. If the changes were approved, an implementation plan was then developed. Three general approaches were used: incorporating changes into the normal flow of production; installing old parts as originally planned and then retrofitting new parts off-line, outside the normal flow of production; and expediting changes by assigning additional workers, a process known as "blue streak."

In all cases, a primary concern was maintaining schedule. Boeing faced substantial penalties if a plane was delivered even one day late, because airlines planned their schedules around promised delivery dates and expected a new plane to be flying immediately. According to Haas:

> For a long time, we have stressed the importance of schedule performance. The airplane *will* move [from one work station to the next] on the day that it is supposed to move. Management will get in a lot more trouble for not moving an airplane, assembly, or part on schedule than for a budget overrun. Over the years, budgets have gained significantly in importance, but not at the expense of schedules.

To ensure that schedules were maintained, Boeing employed a management visibility system. Schedules were prominently posted, and marathon status meetings, which were attended by representatives of all affected departments, were held weekly to review slippages and highlight potential problems. Every manager discussed what he or she was doing and what he or she was owed by others. The emphasis was on early notification, as Dennis Wilson observed:

> If I'm at a status meeting and I find that someone has missed a critical milestone, the first question I ask is, "Why didn't you tell me about the problem last week?," not, "Why did you miss the milestone?"

In June 1981, as assembly of the first 767 moved into its final stages, a First Flight Committee was established. The committee reported directly to Dean Thornton and met daily during the six weeks before the plane's first test flight. At that point, the test pilot had final say in setting priorities and selecting the tasks to be completed.

Learning curves Learning curves were also used to manage the assembly process. Based on historical experience, Boeing had developed learning curves for every major work center. Machining, assembly, and sheet metal fabrication had curves of their own, each with a different slope. However, curves were used in the same way at all centers.

To begin, an optimum crew size was defined for the operation, based on available work space, engineering guidelines, and tooling to be employed. For example, the optimal size for forward body section assembly was eight people. A parametric estimate was then made of the number of labor hours needed to assemble that section of the very first 767. The total (in this case, 6,000 hours) was then divided by the number of labor hours available each day (in this case, 128 hours, equal to eight people working eight hours per shift, two shifts per day) to give the number of days to complete the very first assembly (47 days).

At this point, a learning curve was invoked. The next assembly would be scheduled not for 47 days but for a lesser number, to reflect the historical rate of learning on that operation. The same number of people would be employed, but they would work faster and more efficiently. (When precise calculations were impossible, Boeing varied staffing levels within minimum and maximum values, rather than sticking to a single, optimal crew size.)

Learning curves were also applied to change management. Work centers were initially staffed to reflect a large number of changes. For example, of the eight people assigned to forward body section assembly, three might initially be responsible for incorporating changes. But because the number of changes fell sharply as more planes were produced—the first 767 had 12,000 changes, while the seventieth 767 had only 500—fewer people would be needed for the activity as time passed, and staffing would be reduced over time.

Such improvements did not come automatically. Three tools were used to ensure that targets were met: specific work station goals; stand-up meetings with first-line supervisors; and the management visibility system discussed earlier. Hourly goals were set for every employee and displayed prominently on bar charts by their work stations. The game, as one manager put it, then became "worker versus bar chart." Stand-up meetings were held only if targets were not met. First-line supervisors had to stand up at these meetings and identify what was impeding their ability to meet learning curve goals. Managers were then responsible for solving the problems.

Three-Crew to Two-Crew Conversion

In the late 1970s, airframe manufacturers, led by Boeing, proposed a switch from three- to two-person cockpits. Advanced technology, they argued, had made a three-person crew unnecessary. The Air Line Pilots Association (ALPA) objected strongly to these arguments, claiming that safety levels were certain to fall if the number of crew members was reduced. To resolve the debate, a presidential task force was convened; both parties agreed to accept its findings. In July 1981, the task force concluded that two-person cockpits presented no unusual safety problems, and that manufacturers could offer them on all planes.

Airlines, including those that had already ordered 767s, soon expressed an interest in having their planes delivered with two-person cockpits. Boeing had anticipated such a response and, years earlier, had conducted preliminary studies to determine how best to convert the 767 from its original, three-person cockpit design to a two-person model (see **Exhibit 5** for a comparison of the two cockpits). Further studies were immediately begun; their goal was to identify the number of planes then in process that would require rework or modification to become two-crew models, and the likely impact of these changes on cost and schedule. Engineers concluded that the thirty-first 767 was still far enough from completion that it, and all subsequent planes, could be built with two-person cockpits without modification. Thirty planes, however, were in relatively advanced stages of production. Some were nearly ready to be rolled out and flown; others had complete cockpits but were not yet tested; others had bare cockpits without any electronics installed. But since all thirty were being built according to the plane's original, three-person cockpit design, all would require some modification.

Customers were notified of the additional cost and delivery delay they could expect on these thirty planes. The impact was not large: a small percentage increase in costs and an average delay of one month from promised delivery dates. All but one airline chose to have their planes built with two-person cockpits.

In August 1981 a special task force, reporting directly to Thornton, was formed to determine the best way of modifying these planes. It soon narrowed the choice to two alternatives: (1) building the thirty airplanes as they had originally been designed, with three-person cockpits, and then converting them to two-person cockpits after they had left the production floor (but before delivery to customers), and (2) modifying the production plans for the thirty airplanes so that conversion would take place during production and no parts would be installed only to be removed later (which meant leaving some cockpits temporarily unfinished while drawings and parts for two-person cockpits were being developed).

Completion of production and subsequent modification In this approach, production would continue as planned, without delay. Neither learning curves nor schedules would be disrupted by attempts to modify airplanes during the assembly process. The modification program would be managed as a separate, tightly-controlled activity, apart from the normal flow of production, and special teams of "modification experts," skilled at parts removal, modification, and repair, would be assigned to it. Approximately one million additional labor hours were thought to be required if this method were used.

The primary advantage of this approach was that flaps, ailerons, landing gear, hydraulics, and other airplane systems would be functionally tested during the final assembly process, as originally planned. Problems would be identified and corrected on the spot, rather than hidden or disguised by subsequent assembly activities. And because the airplane that rolled out of production would be fully tested and functional, any problems identified after installation of the two-person cockpit could be isolated, with some assurance, to the cockpit area.

The risk of this approach was the potential "loss of configuration" (i.e., when the plane was actually built, the integrity of the overall design might be compromised). Parts required for three-person cockpits would be installed firmly in place, only to be removed and replaced later by modification experts. (Because these parts had been ordered months before and were already on hand and paid for, this option did not impose greater scrap costs than the other option.) If the modification was not done carefully, many of the plane's operating systems might be disrupted. Boeing experts, however, believed that the management controls used for modification would prevent this from occurring. To minimize the risk, additional functional testing would be required after modification.

Space was also a problem. There was not enough room within the factory to modify all thirty planes. Work would therefore have to be done outside, but even then space was limited. A special parking plan would have to be developed, and the planes being modified would have to be parked extremely close together. The required arrangement would violate fire regulations, so special fire control plans and waivers would be necessary.

Several managers had reservations about this approach, for they objected to its underlying philosophy. The end result would be an airplane that had been modified, after the fact, to accommodate a two-person cockpit. As Standal put it: "It goes against our grain and better judgment to roll out an aircraft and then tear the guts out."

Modification during production In this approach, all modification of the thirty planes would be done during production, rather than after the fact. No parts would be installed only to be removed later. Instead, all panels, instruments, and switches that were associated with three-person cockpits would be identified and their installation halted. Meanwhile, production would continue on other sections of the plane. Once plans and parts were available for two-person cockpits, they would be incorporated within the flow of production.

This was the traditional method of making engineering and design changes. It was used routinely for the thousands of configuration changes on every new airplane. The primary advantage of this approach was that all parts were installed only once. Because there would be no installation and subsequent removal, the configuration was more likely to remain secure. Moreover, because modification would occur during production, all activities would be controlled by normal management procedures, rather than by a separate program.

The primary disadvantage of this approach was that the original production plan would be disrupted. Separate plans would have to be developed for the first thirty airplanes, which required modification, and all subsequent planes. Learning curves would be disrupted as well, because a large number of additional workers would have to be added temporarily, at selected work stations, to complete the modification of the first thirty planes. If this method were used, modification was expected to require approximately two million additional labor hours.

Because all cockpit work would be deferred until engineering drawings and parts were available for two-crew models, test procedures would also have to change. Traditionally, functional testing was done sequentially, with each system (flaps, ailerons, etc.) tested as it became operational. That approach would be impossible here because all cockpit work would be deferred until complete plans and drawings were available. Functional testing would therefore have to be done after the two-person cockpit was fully installed. Problems might not be detected and corrected immediately and might well be hidden by systems that were installed later, making problem diagnosis much more difficult.

* * * *

Thornton knew that it was time to make a choice between the two approaches so that production could continue. The risks, however, were great; as his staff kept telling him, the decision was a potential "show-stopper." He wondered: "Should I authorize after-the-fact conversion of planes or modification during production? And for what reasons?"

Exhibit 1 Critical Program Decisions and Reviews

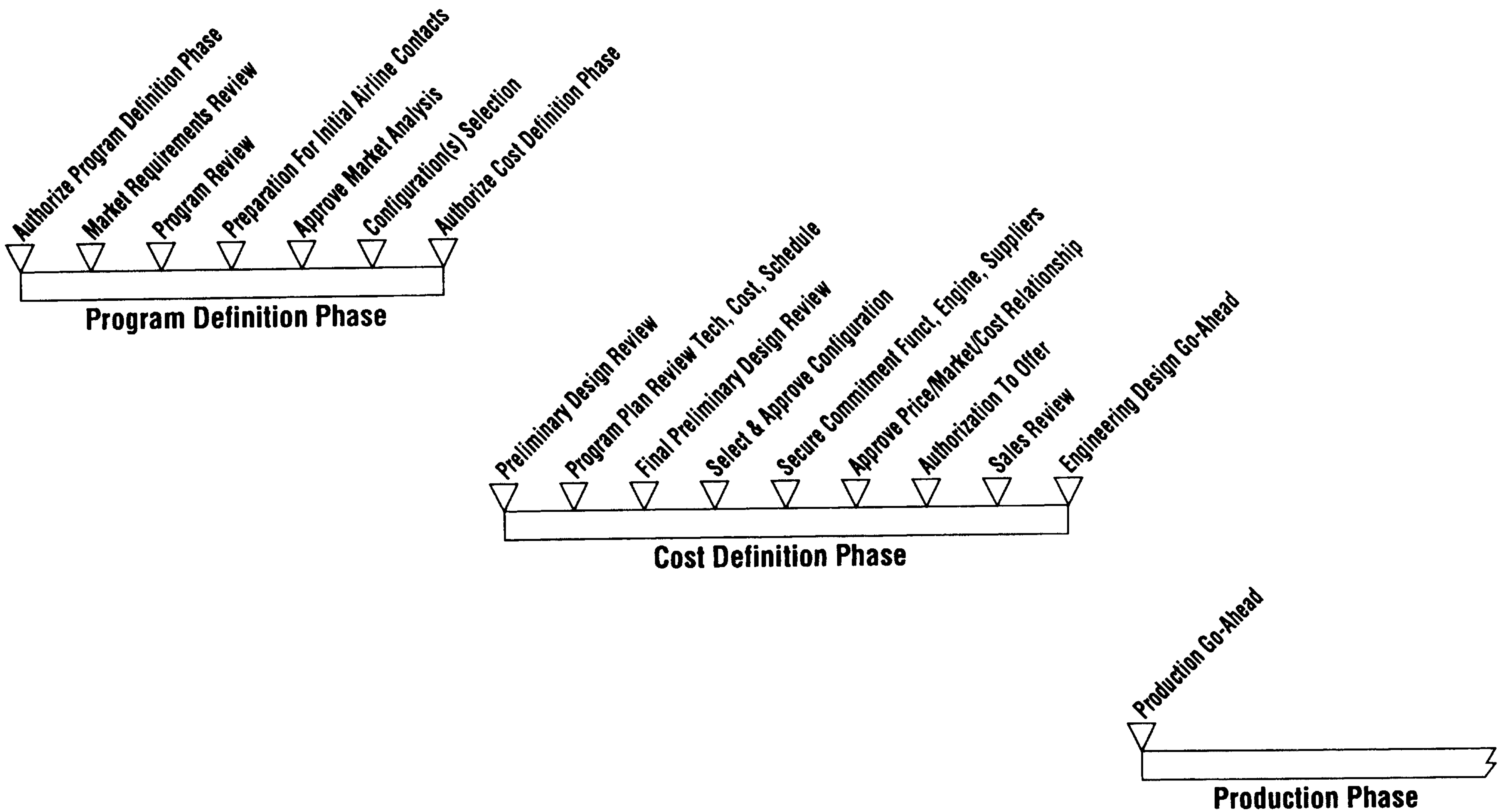
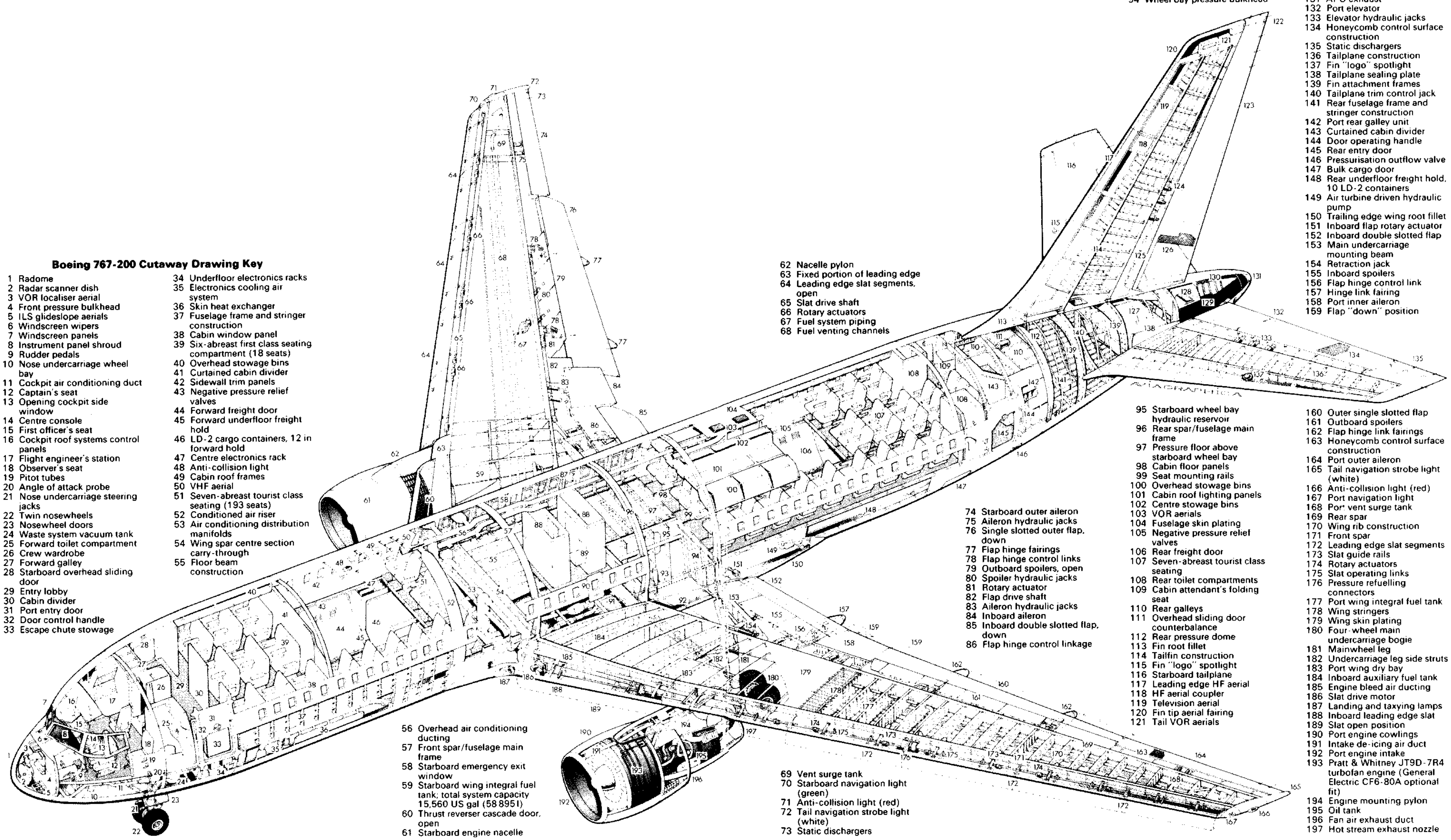


Exhibit 2 Airplane Configuration



Boeing 767-200 Cutaway Drawing Key

1 Radome
2 Radar scanner dish
3 VOR localiser aerial
4 Front pressure bulkhead
5 ILS glideslope aerials
6 Windscreen wipers
7 Windscreen panels
8 Instrument panel shroud
9 Rudder pedals
10 Nose undercarriage wheel bay
11 Cockpit air conditioning duct
12 Captain's seat
13 Opening cockpit side window
14 Centre console
15 First officer's seat
16 Cockpit roof systems control panels
17 Flight engineer's station
18 Observer's seat
19 Pitot tubes
20 Angle of attack probe
21 Nose undercarriage steering jacks
22 Twin nosewheels
23 Nosewheel doors
24 Waste system vacuum tank
25 Forward toilet compartment
26 Crew wardrobe
27 Forward galley
28 Starboard overhead sliding door
29 Entry lobby
30 Cabin divider
31 Port entry door
32 Door control handle
33 Escape chute stowage
34 Underfloor electronics racks
35 Electronics cooling air system
36 Skin heat exchanger
37 Fuselage frame and stringer construction
38 Cabin window panel
39 Six-abreast first class seating compartment (18 seats)
40 Overhead stowage bins
41 Curtained cabin divider
42 Sidewall trim panels
43 Negative pressure relief valves
44 Forward freight door
45 Forward underfloor freight hold
46 LD-2 cargo containers, 12 in forward hold
47 Centre electronics rack
48 Anti-collision light
49 Cabin roof frames
50 VHF aerial
51 Seven-abreast tourist class seating (193 seats)
52 Conditioned air riser
53 Air conditioning distribution manifolds
54 Wing spar centre section carry-through
55 Floor beam construction
56 Overhead air conditioning ducting
57 Front spar/fuselage main frame
58 Starboard emergency exit window
59 Starboard wing integral fuel tank; total system capacity 15,560 US gal (58 895 l)
60 Thrust reverser cascade door, open
61 Starboard engine nacelle
62 Nacelle pylon
63 Fixed portion of leading edge
64 Leading edge slat segments, open
65 Slat drive shaft
66 Rotary actuators
67 Fuel system piping
68 Fuel venting channels
69 Vent surge tank
70 Starboard navigation light (green)
71 Anti-collision light (red)
72 Tail navigation strobe light (white)
73 Static dischargers
74 Starboard outer aileron
75 Aileron hydraulic jacks
76 Single slotted outer flap, down
77 Flap hinge fairings
78 Flap hinge control links
79 Outboard spoilers, open
80 Spoiler hydraulic jacks
81 Rotary actuator
82 Flap drive shaft
83 Aileron hydraulic jacks
84 Inboard aileron
85 Inboard double slotted flap, down
86 Flap hinge control linkage
construction
88 Mid-cabin toilet compartments
89 Cabin attendant's folding seat
90 Port emergency exit window
91 Ventral air conditioning plant, port and starboard
92 Mainwheel doors
93 Door jack
94 Wheel bay pressure bulkhead
95 Starboard wheel bay hydraulic reservoir
96 Rear spar/fuselage main frame
97 Pressure floor above starboard wheel bay
98 Cabin floor panels
99 Seat mounting rails
100 Overhead stowage bins
101 Cabin roof lighting panels
102 Centre stowage bins
103 VOR aerials
104 Fuselage skin plating
105 Negative pressure relief valves
106 Rear freight door
107 Seven-abreast tourist class seating
108 Rear toilet compartments
109 Cabin attendant's folding seat
110 Rear galleys
111 Overhead sliding door counterbalance
112 Rear pressure dome
113 Fin root fillet
114 Tailfin construction
115 Fin "logo" spotlight
116 Starboard tailplane
117 Leading edge HF aerial
118 HF aerial coupler
119 Television aerial
120 Fin tip aerial fairing
121 Tail VOR aerials
122
123 Rudder
124 Rudder hydraulic jacks
125 Balance weights
126 Rudder honeycomb construction
127 Tailplane centre section
128 APU intake plenum
129 Gas turbine auxiliary power unit (APU)
130 Tailcone
131 APU exhaust
132 Port elevator
133 Elevator hydraulic jacks
134 Honeycomb control surface construction
135 Static dischargers
136 Tailplane construction
137 Fin "logo" spotlight
138 Tailplane sealing plate
139 Fin attachment frames
140 Tailplane trim control jack
141 Rear fuselage frame and stringer construction
142 Port rear galley unit
143 Curtained cabin divider
144 Door operating handle
145 Rear entry door
146 Pressurisation outflow valve
147 Bulk cargo door
148 Rear underfloor freight hold, 10 LD-2 containers
149 Air turbine driven hydraulic pump
150 Trailing edge wing root fillet
151 Inboard flap rotary actuator
152 Inboard double slotted flap
153 Main undercarriage mounting beam
154 Retraction jack
155 Inboard spoilers
156 Flap hinge control link
157 Hinge link fairing
158 Port inner aileron
159 Flap "down" position
160 Outer single slotted flap
161 Outboard spoilers
162 Flap hinge link fairings
163 Honeycomb control surface construction
164 Port outer aileron
165 Tail navigation strobe light (white)
166 Anti-collision light (red)
167 Port navigation light
168 Port vent surge tank
169 Rear spar
170 Wing rib construction
171 Front spar
172 Leading edge slat segments
173 Slat guide rails
174 Rotary actuators
175 Slat operating links
176 Pressure refuelling connectors
177 Port wing integral fuel tank
178 Wing stringers
179 Wing skin plating
180 Four-wheel main undercarriage bogie
181 Mainwheel leg
182 Undercarriage leg side struts
183 Port wing dry bay
184 Inboard auxiliary fuel tank
185 Engine bleed air ducting
186 Slat drive motor
187 Landing and taxying lamps
188 Inboard leading edge slat
189 Slat open position
190 Port engine cowlings
191 Intake de-icing air duct
192 Port engine intake
193 Pratt & Whitney JT9D-7R4 turbofan engine (General Electric CF6-80A optional fit)
194 Engine mounting pylon
195 Oil tank
196 Fan air exhaust duct
197 Hot stream exhaust nozzle

Exhibit 3 Program Master Phasing Plan—December 2, 1977 Initial Model

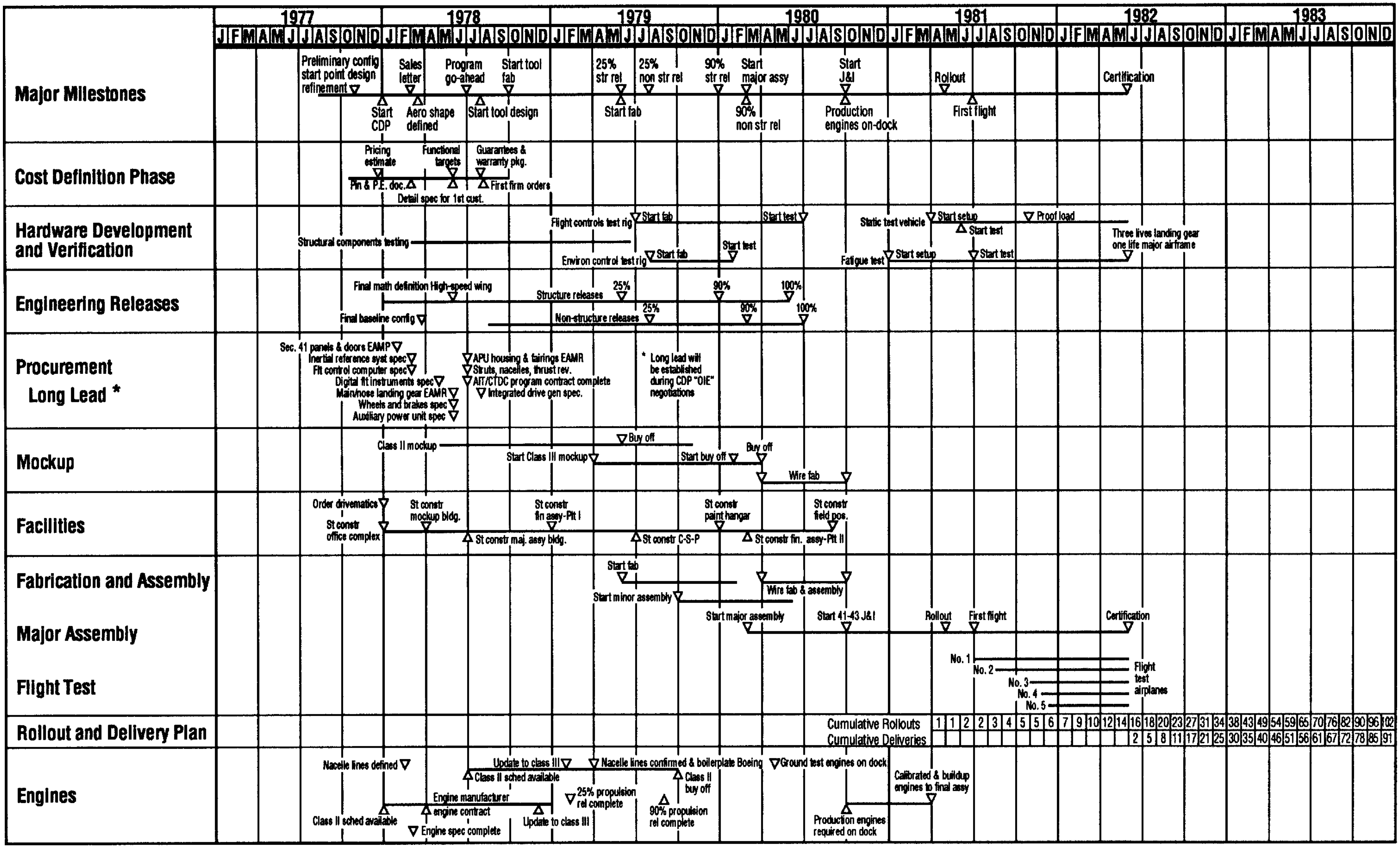


Exhibit 4 767-200 Manufacturing Sequence

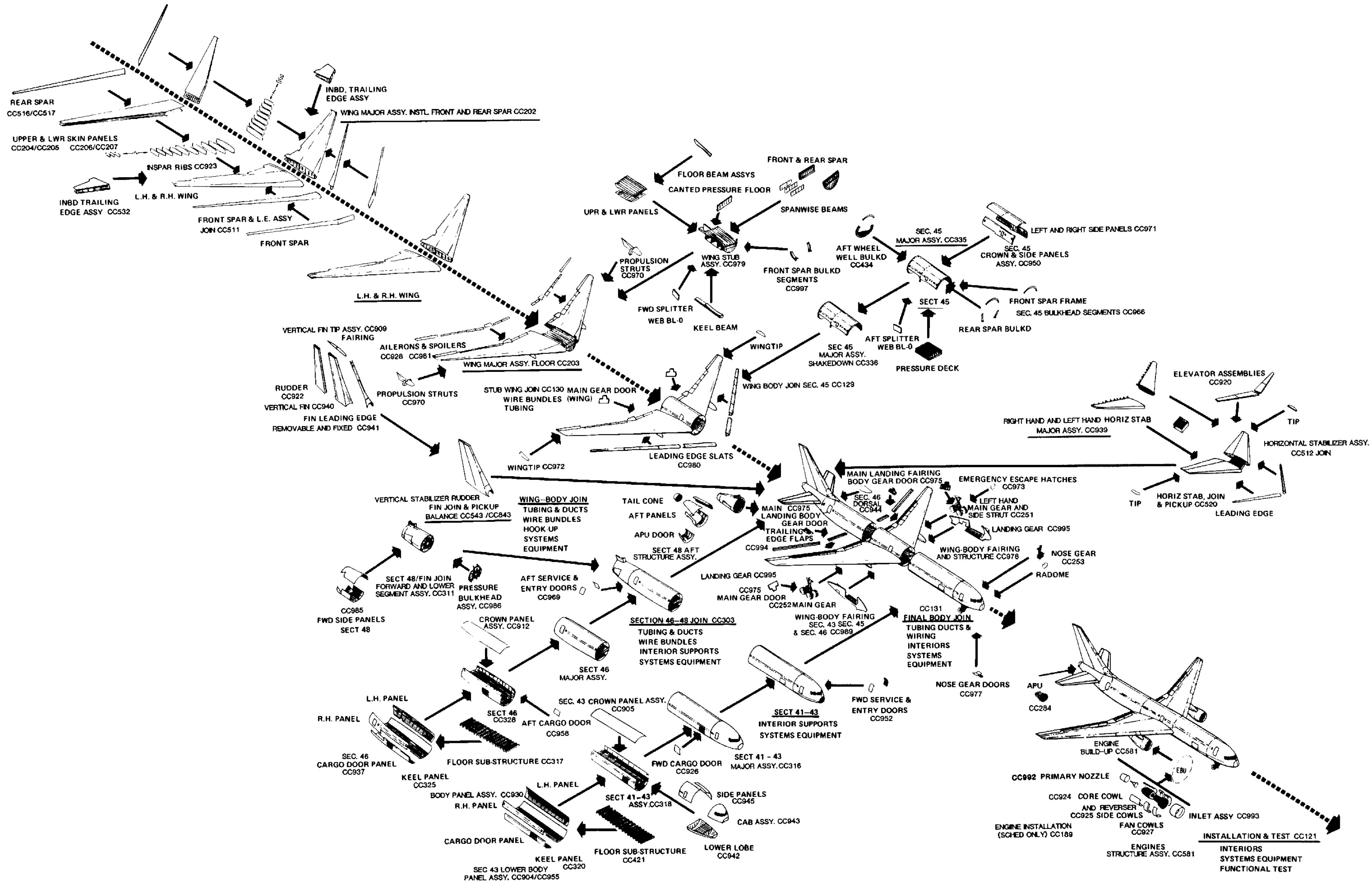


Exhibit 5 Three-Crew and Two-Crew Cockpit Designs