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Concurrent Engineering in the Aircraft Industry and It's Relationship to the Development Process

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ABSTRACT

The development of modern jet aircraft is a monumental undertaking which costs billions of dollars, takes several years, and usually involves thousands of people located around the globe. Aircraft companies routinely bet their future on the success of new models which underscores the importance of delivering the right product, at the right time, at a price the customer is willing to pay. Concurrent engineering techniques are being embraced by many aerospace firms to develop better customer requirements, reduce development time to market, improve manufacturability, and reduce life cycle costs. This paper investigates concurrent engineering efforts in the aerospace industry and their effect on the aircraft development process.

INTRODUCTION

The U.S. has a long history in the development and production of military and commercial aircraft [14],[15],[18],[19],[27],[33]. However, during the late 1980's and early 1990's, the commercial and military aircraft market began to change. Aircraft development costs are too high to remain competitive in the 21st century. Development cycle time to market is too long; the market changed by the time the product is developed. Increased product complexity was driving integration costs higher. Customers are demanding greater performance, more features, higher reliability, more flexibility for less money. With the end of the Cold War, shrinking defense budgets mean fewer defense contracts will be available in the foreseeable future [39]. Increased foreign and domestic competition mean smaller profit margins for aerospace companies. Survival of the fittest; who ever wins the contract must perform or will go out of business. In order to survive, U.S. aerospace companies now must focus on providing the highest value to their customers by delivering the products they want, when they want them, at a price they are willing to pay [38].

Concurrent engineering is one answer to the aerospace industry's problem. Concurrent engineering is a systematic approach that enables organizations to focus on the entire product life cycle, provide support to design teams, and emphasize that the design and manufacturing processes are as important as the product itself. Concurrent engineering also helps plan for information centered tasks, encourages multiple concept generation and evaluation cycles, designs in quality at every phase of the process, carefully prepares product requirements, and communicate the right information to the right people at the right time. These objectives equate to reducing the price, development and production cycle times, and number of defects for commercial and military aircraft [11].

Concurrent engineering techniques are being embraced by many aerospace firms to develop better customer requirements, reduce development time to market, improve manufacturability, and reduce life cycle costs. This paper investigates those concurrent engineering efforts in the aerospace industry and their effect on the aircraft development process by addressing three main issues:

1. What aspects of the aircraft development process lend themselves to concurrent engineering techniques?

2. What concurrent engineering techniques are currently being used within the aerospace industry?

3. What benefits have been documented from using concurrent engineering methods in the aircraft development process?

AIRCRAFT DEVELOPMENT PROCESS

PROGRAM MANAGEMENT & COST ESTIMATION - An airplane development project is typically managed using a program management philosophy. A program management approach is appropriate because an aircraft development program usually involves complex interdependencies of tasks, long time frame - five or six years, large investment ($5 to $6

Following the decision to proceed with a new airplane program, the process for implementing the decision follows a very orderly and disciplined procedure. Cost goals and production targets are coordinated and reviewed prior to funding the production program which is required to develop production tooling, purchase new equipment, build facilities, and acquire additional manpower. Cross functional Integrated Product Teams (IPT's) are formed to complete the configuration definition. Major suppliers are selected up front as potential program risk sharing participants. Lower tier suppliers are selected later in the process as design and configuration activities progress throughout the program. Each functional organization and major supplier assesses the work statement, evaluates cost and schedule requirements, and commits to the program objectives. The commitment process enables each organization to understand and plan their contribution to the objectives of the program. This process results in a contractual offer which is presented to a commercial or military customer.

DETAILED DESIGN, VALIDATION, AND RELEASE - The program directive, which authorizes product development, initiates the process that transforms a design concept into a real production airplane. The program directive includes the master phasing plan which defines the key events involved in the planning and scheduling for the entire program. The master phasing plan provides the framework for all subsequent scheduling, negotiating, procurement, fabrication, assembly, test, and certification. By the time the program directive is released, procurement of long-lead items such as landing gear have begun along with their associated engineering releases.

Based on the program directive and master phasing plan, an itemized engineering work statement is developed that defines the tasks required to design, plan, acquire tools, and order components and subsystems for each section of the new aircraft [8]. Design engineers and manufacturing engineers in the IPT work together to jointly develop the work statements and associated manufacturing and tooling plans. A committed event is usually scheduled for each Program Identification Number (PIN) or Work Breakdown Structure (WBS) level engineering work statement which represents a component or subsystem in the airplane. The initial buildup plan shows the number of projected deliveries during the first few years of a new program. Customer introduction plans are prepared for a customer's first delivery of a new airplane model. The material organization develops procurement plans to acquire the raw materials and initiates negotiations with suppliers regarding potential make-buy decisions. The "number one flow" schedule shows the major production events in the manufacture of the first unit of a new airplane family.

The detail design phase begins as the IPT's are formed and staffed to complete the design & development work and implement the new model into existing production facilities. The IPT is a temporary organization dedicated to the development of a new product and consists of members from many disciplines including design engineering, tooling, manufacturing engineering, manufacturing, quality assurance, customer engineering, finance, and program management. The program managers are responsible for coordinating all activities required to develop the new product within their respective functional organizations. The individual team members from each of the functions are usually collocated in a central area wherever possible to enhance communication and reduce design time. The new product development cycle time varies from approximately 24 to 36 months for a major model derivative to approximately 4 to 6 years for a complete new aircraft.

Systems engineering has been used extensively in the aerospace industry for many years to ensure that subsystem and component designs integrate within the larger airplane system [21 pg. 76-79],[26 pg. 277-315]. Cost trade studies and team decision techniques are frequently used to arrive at consensus based decisions. Usually alternatives compete in terms of customer requirements, cost, producibility, maintainability. The entire design build process functions as a systems engineering enterprise. The airplane integration group is responsible for the systems integration of various design disciplines. A product level decomposition has been provided on the following page (See Figure 1).

Computer aided design systems are used to development aircraft features and functionality [29 pg. 62]. Data from the engineering design is frequently used directly to develop tool designs, develop NC machining programs, and to create a digital mock-up. The digital mock-up [7] takes the place of a physical prototype and enables manufacturing engineers to perform producibility analysis. The digital mock-up is also used to identify conflicts between aircraft structure, systems brackets, tubing, ductwork, and electrical wiring runs. This activity is usually performed in an IPT design review meeting with the affected personnel. By the time the design is released to manufacturing, at least 80 % of the life cycle costs for the new model have been fixed [34],[36]. In other words, it is generally cost prohibitive billion), and many international business partnerships [21 pg. 34]. Since programs are composed of teams from various functional organizations and projects, a program office or program management structure is required to integrate the various elements. These would typically include coordination of project schedules, providing visibility of key program events, conducting program reviews, integrating functional organization requirements, and communicating program direction and key decisions to the whole program organization. Generally, the program management office is staffed with specialists from customer engineering, change management, program office, operations, contracts, and finance.

Estimating is one of the most complex and technically challenging areas of a new airplane program. It involves projecting the labor hours required for engineering, tooling, fabrication, assembly, certification, and facilities requirements. Cost estimates such as those from traditional project management software packages are often used. Historically, parametric cost estimates (man hours based on the size of the airplane) have been used as the basis for estimating development costs for The Boeing Company for many years [35]. These cost estimates in turn are allocated to development work on various airplane sections and systems in the form of functional department man hour budgets. These department budgets are normally transformed into head count values and are managed with respect to engineering release activity over time.

DEVELOPMENT CYCLE - Most new airplane programs proceed through similar life cycle phases; concept development, configuration refinement, detailed design validation and release, fabrication and assembly, and operations and support phases. Variations in this process depend on whether the product is a new airplane, a derivative model, or a modification maintenance airplane program. Historically, the aerospace industry has only partially integrated the design of a new product with the development of its manufacturing processes. At best, there has been a loose interface between design and manufacturing. Design groups whose primary task was to generate the design have tended to pay little attention to manufacturing issues whereas manufacturing process specialists within the planning and tooling community were often required to interpret design intent and resolve production problems. The airplane development process has generally been serial in nature across the design and manufacturing communities.

Initial designs were normally prepared and analyzed by various engineering disciplines in terms of mission attributes such as weight, mechanical integrity, strength, reliability/maintainability, and testability. Once evaluated, the designs were then returned for revisions. Usually, this process was iterated several times until an acceptable design was achieved. This updated design was then forwarded to manufacturing and tooling engineers/planners who established fabrication and assembly sequences, job instructions, processing requirements, tool designs and fabrication plans, and quality assurance measurement and inspection requirements. The development process has been lengthy and unwieldy with product and process changes originating at many points during the evolution of the manufacturing plan. These problems have been compounded by a failure to integrate both customers and suppliers into the design and development process.

However, in an effort to become more competitive, this process is evolving with many aerospace companies [13]. Product development can be segmented into several distinct phases that must be thoroughly planned and carefully managed. Concurrent engineering techniques are being embraced by many aerospace firms to develop better customer requirements, reduce development time to market, improve manufacturability, and reduce life cycle costs. These techniques can now be found in all phases of the airplane development life cycle and are described in the following sections.

CONCEPT DEVELOPMENT - The concept development phase includes market requirements, initial customer contact, and product configuration selection. During this phase program leaders work with customers and product development engineers to define the proper configuration of a new airplane. Configuration requirements are developed through market studies, focus groups with key airline/military customers, discussions with maintenance mechanics, competitive analysis, and bench marking other aircraft manufacturers. Key product characteristics are refined through trade studies using high level cost, manufacturing, and supportability models to refine requirements and identify key product characteristics. Cooperation between designers and manufacturing engineers is important to ensure that designs for producible. Typical requirements include speed, range, payload, furnishings, reliability, cost, maintainability, and commonality with other type designs.

CONFIGURATION REFINEMENT - The configuration refinement phase begins with the preliminary design concept and proceeds through a review of the technology, cost, and schedule factors. During this phase, research data from the sales & marketing department is analyzed with respect to a customer demand for a new aircraft or major model derivative for a particular market segment. Product development engineers conduct technical feasibility studies to refine the design configuration, performance, range, payload, new materials, propulsion systems, flight controls, and offerable options for the proposed new product. Generally, sufficient launch orders, a strong market forecast, approval of the product configuration, and an acceptable program plan [37] are required to obtain a go-ahead decision from the board of directors. Following the sales review, the final authorization is given to offer the product and the airplane configuration is "frozen" which signals the beginning of the engineering design and development work.

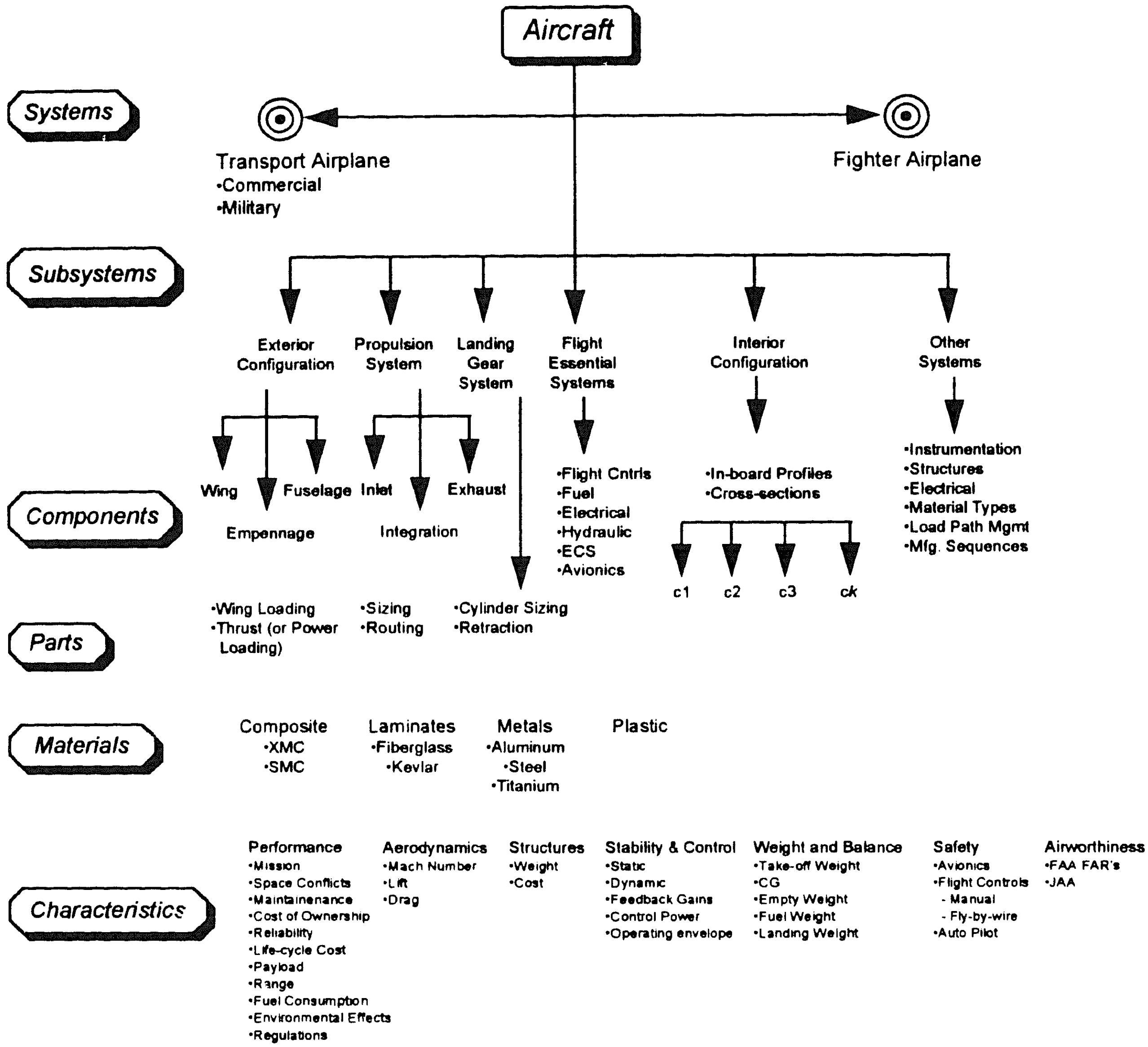

Figure 1 - Product Level Decomposition [26 pg. 295]

(See Figure 2) to make further changes other than correcting a major design error or significant tooling deficiency.

Design validation includes the validation of both the product design and its manufacturing processes. In addition to computer based verification, initial samples of the product (prototype, development, or preproduction units) are fabricated, assembled, and tested to prove that customer requirements are met. The capability of the manufacturing processes are verified and Statistical Process Control (SPC) is applied at critical points in the manufacturing flow to control key product characteristics.

FABRICATION AND ASSEMBLY - The 90% engineering drawing release point is a key event in the development of an new airplane and normally signals the beginning of the fabrication, assembly, test and delivery phase. By this time most components have been designed, tools have been designed and are in fabrication, manufacturing plans are completed, and parts have been ordered. Work in the production area is normally scheduled by the I.E. organization based on the master production schedule or "number one flow" for the airplane. The "number one flow" controls the phasing of major aircraft sections and subsystems throughout the assembly process. During initial production and subsequent full rate production, the use of SPC is refined and expanded, defects are tracked, root cause analyses are performed, and corrective actions are put in place. Activity to reduce and control variability in key product characteristics is essential.

TESTING & CERTIFICATION -_A new aircraft is tested in many ways. Most start early with wind tunnel tests to determine the exact configuration of the airframe. Next, structural tests are performed on new materials. A systems integration lab or "iron bird" is often developed to integrate all the airplane systems together [29 pg. 154]. Functional tests are usually performed on various airplane systems and avionics while in final assembly. The flight test program usually consists of several aircraft each of which is fitted with special instruments to measure various operating parameters of the aircraft while in flight. A rigorous testing process is required by the FAA and JAA or military to certify or accept a new aircraft. Other tests include the structural fatigue tests which culminates in the destruction of the wings and other components. Engine manufactures must also go through extensive testing to certify new aircraft propulsion systems. Cold weather, hot weather, and altitude airport testing are also performed in an effort to certify a new aircraft.

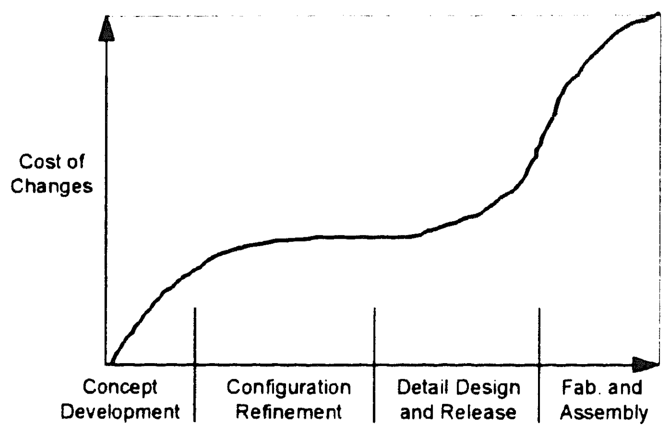

Figure 2 - Cost of Changes Over Time [41 pg. 3]

OPERATION & SUPPORT - Before a new airplane type is delivered to an airline or military customer, pilots, maintenance, and operations crew receive special training to ensure that they are ready and able to bring the new airplane into their fleet with no problems. Pilots receive training in the flight deck operations and flying properties of the new aircraft using computer based training and full motion flight simulators. Maintenance personnel also receive a variety of computer based training along with a "hands on" maintenance simulator covering most of the line maintenance tasks expected for the new airplane. Cabin personnel also receive general operations, safety, and evacuation training to help prepare them for the new arrival into their fleet.

CONCURRENT ENGINEERING IN THE LITERATURE

Concurrent engineering is an umbrella of techniques which help organizations develop better customer requirements, reduce development time to market, improve manufacturability, and reduce life cycle costs. Although concurrent engineering often appears under different names such as simultaneous engineering, a number of trade publications, business journals, books, and company documents were reviewed for evidence of concurrent engineering techniques in use at aerospace companies. A review of the literature showed that several aerospace companies world wide are using a variety of concurrent engineering techniques. Table 1, which consolidates the literature findings, is organized by manufacturer with respect to various airplane programs.

Both commercial and military aircraft manufacturers were found to be using these techniques at some level. Six different companies were identified in the literature as "active" users of concurrent engineering including The Boeing Company, McDonnell Douglas, Dassault Aviation, British Aerospace, Aerospatiale, and Raytheon Beech Aircraft. The concurrent engineering techniques found in the literature have been listed in Figure 3. It is interesting to note the differences in scale and techniques used across various aerospace companies.

DPD	Digital Product Definition
DPA	Digital Preassembly/Mock-up
CIM	Computer Integrated Mfg
LM	Lean Manufacturing
DFX	Design For X-ability
TQM	Total Quality Mgmt
QFD	Quality Function Deployment

Figure 3 - Common Concurrent Engineering Techniques

The benefits from using concurrent engineering techniques were also quantified where possible. In some cases, however, they were not stated in a quantifiable manner. It should be noted that these findings should be considered incomplete and suspect at best. There are probably many cases where concurrent engineering techniques are used in the aerospace industry but are not publicized or documented in the literature. Another limitation lies in the belief that without first hand knowledge of the airplane programs listed, one cannot be sure that the benefits cited were not the results of other factors working behind the scenes. However, if taken at face value, we can accept that several companies are using concurrent engineering techniques and seeing benefits.

Concurrent Engineering Techniques & Benefits In the Aerospace Industry

Aerospace Company	Airplane Program	Benefits Attributed to CE	CE Techniques	Source
The Boeing Company	777	50% Reduction In Engr. Changes Due To Design Errors. Significant Reduction In Defects That Reached The Factory.	IPT, CI, SI, DPD, DPA, DFX, CIM	[7],[20]
	737-X	Currently In Product Development Using IPT's And Concurrent Product And Process Definition.	IPT, CI, SI, DPD, DPA, DFX, CIM	[41]
	F-22	Currently In Product Development Using IPT's And Concurrent Product And Process Definition.	IPT, CI, SI, DPD, DPA, DFX, CIM	[40]
McDonnell Douglas	C-17	Saved $68M Due To Common Automatic Test Equipment. Reduced Number Of Parts And Fasteners On Cargo Door Assy.	IPT,SI,CI,DFX, TQM,LM, QFD	[12],[23],
	F-15	Fuselage Formers, 38% Fewer Parts, 49% Fewer Fasteners, 45% Fewer Fastener Types, 55% Fewer Fab & Assy Tools, 75% Less Assy Time, 29% Reduction In Defects.	IPT,SI,CI,CIM, DPD,DFX,TQM, QFD	[13],[12]
	F/A-18E/F	33% Fewer Parts (4,400 Parts, Fewer Fasteners) 1500 Pounds Under Weight First Major Airplane Join Significantly Below Cost Estimate	IPT,SI,CI,CIM, DPD,DFX,TQM, QFD	[13],[28],[12]
	MD-11	Reduced Number Of Parts By 3800, Weight By 240 Lbs, And Cost Per Airplane By $127,000. Reduced Assembly Flow From 200 Down To 109 Days.	IPT,SI,TQM, DFX, QFD, LM	[12]
Dassault Aviation	Military Fighters	Use CE Techniques, But Did Cite Benefits.	IPT,DPD,DPA CIM	[24]
British Aerospace	BAE146 Airbus Wings	Development Time Reduced From 36 To 18 Months.	IPT,SI, QFD, TQM LM	[26 pg. 210], [30]
Aerospatiale	A300,A320, A330,A340	Use CE Techniques, But Did Cite Benefits.	IPT,SI,CIM, DPD, TQM	[5],[25]
Raytheon Beech Aircraft	Not Specified	80% Reduction In Flowtime, 94% Reduction In WIP, 80% Reduction in Facility Space, 600% Increase In Inventory Turns	IPT,SI, LM,	[20]

IPT = Integrated Product Teams
DPD = Digital Product Definition
LM = Lean Manufacturing
QFD = Quality Function Deployment

SI = Supplier Involvement on Product Team
DPA = Digital Preassembly/Mock-up
DFX = Design For X-ability

CI = Customer Involvement on Product Team
CIM = Computer Integrated Mfg.
TQM = Total Quality Mgmt

Table 1 Concurrent Engineering Benefits Cited In The Literature

ANALYSIS OF CONCURRENT ENGINEERING FINDINGS

Several companies were using digital product definition and digital pre-assembly to detect problems early in the design process. The Boeing 777 was the industry's first 100% digitally designed airplanc. CATIA 3D models were used for interference checking with the digital mockup, and manufacturing plan graphics, tooling definition, and NC programming for this program [7]. Dassault Aviation was also involved with digital product definition in the area of feature based modeling [24]. Aerospaciale [25] and McDonnell Douglas [28] discussed Computer Integrated Manufacturing (CIM) techniques for improved data communications, re-usability of data, concurrent product and process definition, and product data management.

Design For Manufacturability (DFM) techniques were evident at McDonnell Douglas on both commercial and military airplane programs [12],[13],[28]. DFM was cited as an enabling technology to help reduce the number of parts, reduce number of fastener types, reduce component weights, and improve re-usability of test equipment [23]. Customer and supplier involvement early in the process were also a key factors. The use of Quality Function Deployment (QFD) was also noted. McDonnell Douglas embraces lean manufacturing as a key vehicle to integrate various concurrent engineering techniques [12],[20].

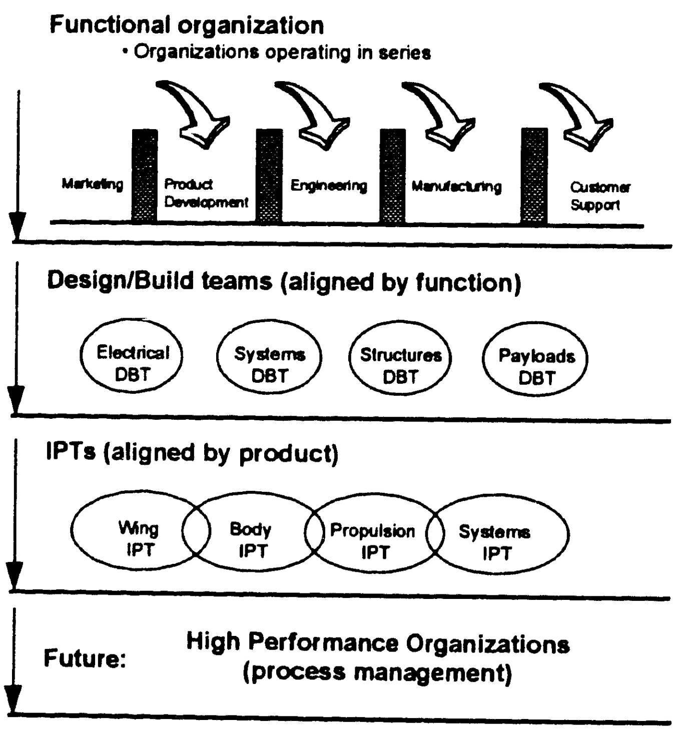

Figure 4 - Evolution of Product Development Teams at The Boeing Company [41]

Although many concurrent engineering techniques are in use across the industry, the most significant technique referenced in the literature appears to be the integrated product team or IPT. This technique was very popular in both the U.S. and Europe [9]. This is not surprising given the level of attention teams have received in the business community over the last several years. Many aerospace companies are making the transition from serial processes run by functional organizations to cross-functional teams [1].

At the Boeing Company (See Figure 4), teams have evolved from functional organizations into design/build teams. These were cross-functional teams that worked functionally to develop airplane structural sections or systems. Next, the design/build teams evolved into IPT's which were cross functional teams that had the responsibility to integrate all airplane structures and systems within a product such as a wing or fuselage section. The IPT's also have the responsibility for integration between products such as the wing to body join. Future teams may take on the characteristics of high performance teams that achieve unprecedented levels of success in bringing products to market in record cycle times at significantly reduced costs [16].

During the mid 1980's, The Boeing Company set the stage for teaming by introducing thousands of employees to team concepts and behaviors as a part of its continuous quality improvement plan. Specialized training classes in quality improvement, team building, and communication skills were conducted to give employees basic group problem solving skills. During the early 1990's, Boeing emphasized world class competitiveness training, people skills training, team based quality improvement techniques [31], and the seven planning tools [4]. The key message here was to get people used to working and learning together [32]. Most Boeing training courses included cross-functional teaming exercises regardless of the subject matter. This was a deliberate strategy to help employees get used to working in teams and accepting other points of view.

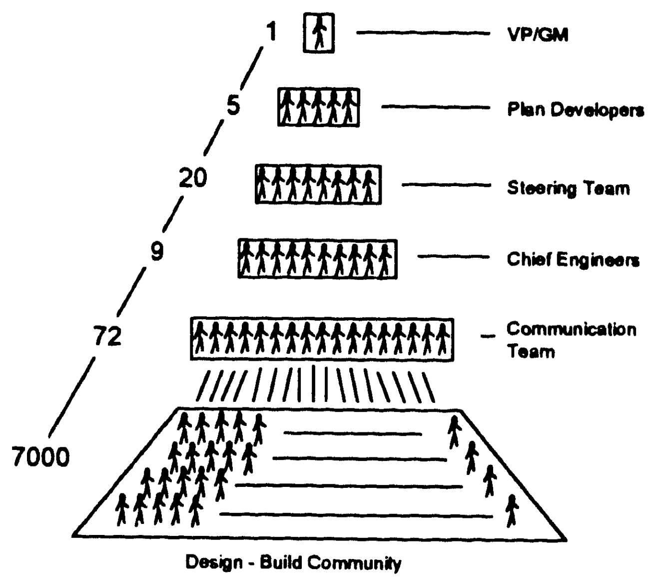

Figure 5 - The 777 Communications Chain [40]

Communications and teamwork in large scale development projects can have a significant effect on the success of an airplane development program. Communications and teamwork was one of the most important aspects of the Boeing 777 development program. The challenge here was to communicate the right message in a timely manner to over 7,000 team members (See Figure 5). Information such as program direction, goals [3], status, and key initiatives, must be effectively delivered to the lowest level in order for the working level IPT's to be successful.

CONCURRENT ENGINEERING AND IT'S EFFECTS ON AIRCRAFT DEVELOPMENT

Prasad [26 pg. 169-170] described the basic components of concurrent engineering as early problem discovery, early decision making, work structuring, teamwork affinity, knowledge leveraging, common understanding, ownership, and constancy of purpose. Together, these principles can have a significant effect on the development of a new airplane program. However, concurrent engineering is not the solution to all product development problems. Handfield [10] has conducted research regarding the effects of concurrent engineering on breakthrough and incremental improvement make-to-order products. Specifically, he focused on three main performance measures; development time, quality, and delivery time. Handfield's research consisted of in-depth surveys of 31 product lines from firms producing computers, electronics, transportation equipment, fiber optic cable, industrial pumps, telecommunications products, office systems, and aeronautical equipment. He used an analysis of variance model to quantify and describe the effects of concurrent engineering and its relation to key performance measures.

Although the aircraft development process may not be an exact match with the make-to-order products in his study, there may be parallels to those described in his paper. Handfield's key findings show that it is more beneficial to use concurrent engineering on incremental improvement and breakthrough development projects when there is not a requirement for significant learning and experimentation during the development process. Where there is significant learning required during the development process, Hanfield's data suggests that it may be more cost efficient to use a serial product development process for both incremental and breakthrough products. This provides some interesting issues when looking at the aircraft development process.

CRITIQUE OF THE BOEING 777 PROGRAM

The Boeing 777 commercial transport represents an attempt to produce an evolutionary aircraft. Market demand has sized, shaped, and launched the newest member of the Boeing family [6] which was designed to be the most preferred wide-body twin engine airliner in the world. In creating the 777, Boeing used fundamentally new approaches to designing and building an airplane [22]. The 777 program established design/build teams (DBT's) to develop each element of the airplane's airframe and systems. Under this approach, all of the different specialties involved in airplane development - designers, manufacturing representatives, tooling, engineers, finance specialists, suppliers, and customers worked jointly to create the airplane's parts and systems. Collocated team members (See Figure 6) worked concurrently, sharing their knowledge rather than just applying their skills sequentially[2][17].

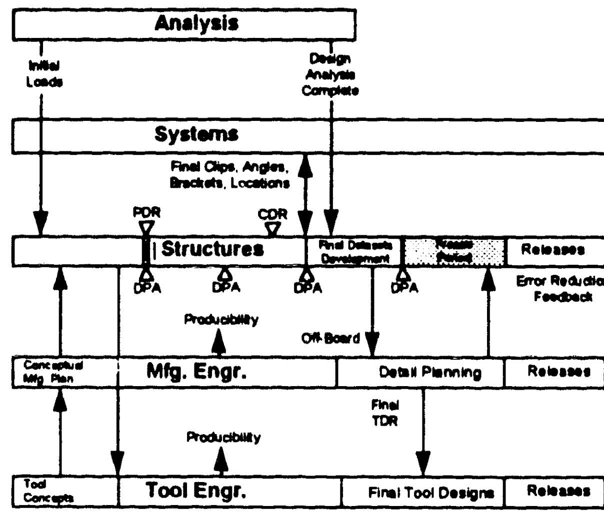

Figure 6 - Concurrent Product & Process Development

Since all affected disciplines were involved, problems were resolved early in the process, long before they reached the production phase. Digital mock-ups and digital pre-assembly helped design build teams integrate all systems and components and check for interferences. Designing in parallel reduced design cycle time and improved design quality because more design alternatives could be evaluated. Figure 7 shows that the design drawing and release time was shortened for the 777. Integrated product teams also helped reduce organizational barriers and improve communication.

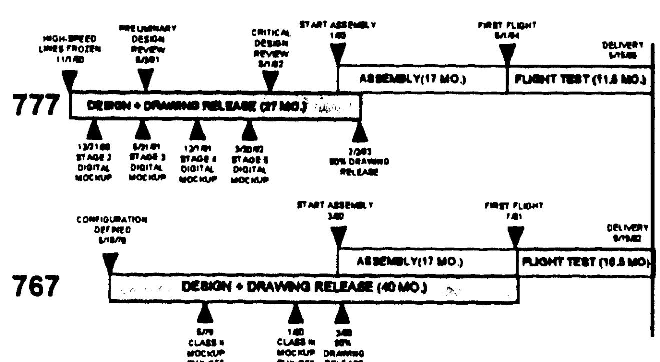

Figure 7 - Comparison of the Boeing 767 and 777 Airplane Development Schedules [22]

CONCURRENT ENGINEERING BENEFITS IN THE AEROSPACE INDUSTRY

The literature cited several benefits from using concurrent engineering which have been summarized in Table 1 of Appendix I. Taken at face value, the benefits cited are consistent with those reported in other industries [26 pg. 210]. Technology also plays an important role in reducing product life cycle costs in the aircraft industry. Recent advances in solids modeling, digital preassembly, rapid prototyping, etc. have also contributed to improving the bottom line. Although the benefits from technology in concurrent engineering are very important, they may well be overshadowed by the efforts of integrated development teams which are well documented in the literature. Figure 8 below depicts the recurring and non-recurring cost picture for a typical aircraft development and production program. The benefits highlighted from concurrent engineering and integrated product development work together to shrink the total cost circle.

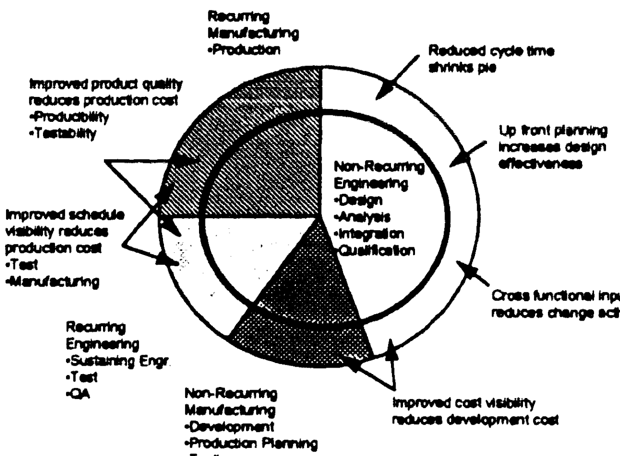

Figure 8 - Benefits From Integrated Product Team's [40]

CRITICAL SUCCESS FACTORS

There are several critical success factors that determine the difference between successful and unsuccessful implementations of concurrent engineering. The lessons learned from the Boeing F-22 program [40] highlight the critical elements that contributed to the success of their integrated product development effort. These include:

- Organizational Structure - Inter-team integration must be built into the organization. A top level integration team is necessary. Video teleconferencing was used to facilitate communication across geographic locations.
- Culture - Continuous upper management support is required. Training is required to make cultural adjustments. However, reluctance to embrace change will keep it from working.
- Empowerment - Management must not overturn product team decisions.
- Functional Diversity - Engineering must appreciate functional diversity. Early vendor and operations inputs are invaluable to the program effort.
- Rewards - Compensation must recognize evolution in employee development changes (greater breadth & team contributions).
- Programmatics - Teams should have budget authority.
- Costs - Costs should be collected by product and by function. It is also important to have cost and schedule visibility at the working level to let IPT members know whether or not they are on track.
- Leadership - Best qualified personnel should lead teams. Selecting the right team leader is critical (team and technical skills, significant administrative time). Team leaders must provide leadership as well as technical knowledge.
- Work Teams - Teams should be product oriented. Membership should be cross-functional. The right team members are critical and key members should be on board from beginning. Customers, subcontractors, suppliers, and teammates should be represented. Team size should be less than 20. Team membership must also be stable over time. Teams must also be collocated.
- Team Processes - Document the team charter. Allocate work tasks from WBS or integrated master plan. Status team effectiveness periodically.
- Information - Teams must have access to information (cost, status, issues, geometry, product, etc.).

CONCLUSION

This paper addressed three main issues; aspects of the aircraft development process that lend themselves to concurrent engineering techniques, concurrent engineering techniques that are currently being used within the aerospace industry, and thet benefits that have been documented from using concurrent engineering methods in the aircraft development process. Several examples of concurrent engineering were found in the aerospace industry. Several aspects of the aircraft development process were identified that lend themselves to concurrent engineering methods. Based on a review of the literature, a number of benefits were cited by companies who use concurrent engineering techniques during the aircraft development process. Several factors critical to the success of integrated product development teams were also discussed.

Based on these findings, it is clear that concurrent engineering can and should be a part of the aircraft develoment process. Many success stories have resulted from the application of various concurrent engineering techniques on new and existing airplane programs. Although computer technology is a vital link to improving the design process, the most powerful leverage lies in the power of integrated product teams. This organization structure is the "key enabler" which will allow ordinary people to come together to achieve significant reduction in development costs and cycle time. It is recommended that aerospace companies who wish to make breakthrough advances in reduced cycle time, improved design quality, and increased customer satisfaction first start with integrated product teams. Without this teaming structure in place, it is unlikely that most companies will achieve the benefits outlined in this paper.

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