

## The Factory of the Future

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### Introduction

In the early years, aircraft were relatively simple in their design and construction. Their mission was basically to fly and land safely. The simple design shapes and nonmetal composition required little in the way of heavy equipment or special tooling to form, shape and assemble the vehicle. The entire manufacturing operation was centrally located in a relatively small facility with the equipment and tools brought to the developing structure by the builders during the fabrication process. The aircraft were constructed basically one at a time, by a team of men who shared the full gamut of skills and duties required to produce the product. This integrated operation allowed the flexibility for accommodating changes in the product configuration and manufacturing processes. Each aircraft produced varied slightly as engineering improvements and field testing refined the design. Quality was built into the product by this team of skilled craftsmen who were involved in the total process from detail fabrication through final assembly.

Paperwork required for product documentation and production control was minimal. Configuration, inventory and production records were centrally located and readily available - maintained through a simple manual system by the chief engineer/builder in this integrated operating environment. Thus, manufacturing support costs were negligible.

In this "bicycle shop" manufacturing environment, a majority of the costs of the aircraft were accrued in the construction process. Direct, hands-on labor required to fabricate and assemble the product was the largest investment, comprising some 75 percent of the total cost. Material cost accounted for 10 percent with the remaining 15 percent committed to the cost of facilities, energy, support functions and the few simple tools used by the engineer/builder.

### The Maturing Years

The World Wars, World War II in particular, brought the U.S. aerospace industry into a new era of mass production and advanced manufacturing methods. The diverse, multi-mission requirements of the combat environment changed the characteristics of the product. Metallic structures, with complex shapes, were designed to meet the higher performance and durability requirements. Offensive and defensive systems were added to the aircraft along with more advanced avionics and control systems, all of which presented new manufacturing challenges to fabricate and assemble the more complex structure and to install the miles of wiring and tubing required. The aircraft became an integrated weapons system - a flying fortress of metal - strong, durable and much more difficult to configure. Field support and maintenance became critical issues necessitating tighter configuration controls. Parts had to be replaceable for quick repair, and interchangeable to assure efficient production and field support.

Product complexity coupled with high-volume, high-rate production demands and the requirements for standardized configuration ushered Henry Ford's batch-manufacturing, assembly line approach into America's aircraft factories.

With the implementation of this methodology, the "bicycle shop" environment was replaced with thousands of square feet of

factory space, dimensioned to house dozens of aerostructures in work.

The equipment and tools once brought to the single aircraft in production were now centralized at work stations. The developing aerostructures were moved to the resources, progressively located along the assemble line.

In order to facilitate batch-manufacturing, fabrication tasks were divided into numerous subtasks. This multi-level division of effort necessitated standardized fabrication and assembly methods as well as extensive production and quality control procedures, to assure proper fit and structural integrity of the subassemblies as they were joined together to produce the end item.

The number of specialized functions and the complicated logistics involved in producing an aircraft in the assembly line environment prevented the continuation of the integrated team approach, where a few skilled craftsmen performed a wide range of tasks.

The team of multi-skilled engineer/builders was replaced with scores of specialists - machinists, welders, assemblers and technicians, each performing a minute part of the now segregated task.

With the manufacturing task divided into numerous subtasks, the step-by-step precision and quality control performed by the team of engineer/builders in the early days were impossible. With the fabrication and assembly effort fragmented, even the most conscientious worker was hard pressed to verify or even envision the final result. In this atmosphere of specialization and division of labor, the functions of post-fabrication and post-assembly quality inspection became major technical and cost issues.

Segregation of the manufacturing activities established the need for more extensive planning, scheduling, material man-

agement, process control and quality assurance systems to coordinate the numerous activities and assure smooth work flow. Product complexity and logistic support needs dictated stringent configuration and data management requirements. New organizations were formed to perform the documentation and operations control functions previously handled by the team of engineer/builders.

These functions were performed by a new class of U.S. aerospace industry worker - the white collar "manufacturing support" employee. This support worker, who was not directly involved in building the product, became an "indirect" charge against the final product cost. His output, 'the paper airplane' and the mountain of paperwork required for planning, controlling and monitoring factory functions, came to be regarded as a permanent cost-of-doing-business.

The maturing years brought complication and complexity to the U.S. aerospace industry and changed the structure of product costs. Direct labor accounted for approximately 50 percent of the total cost of the aircraft.

The use of metals and the addition of complex hydraulics and electronics in aircraft designs resulted in an increase in the amount of the total product cost allotted to materials from 10 to 25 percent. The vast expanses of factory space equipped with a variety of specialized equipment, along with the new class of support workers, increased the share allotted to indirect burdens from 15 to 25 percent.

As we entered the post-world-war period, the high-rate military aircraft programs of the war years were replaced by mid- and low-rate production programs. Military philosophy shifted from an approach of assuring victory with quantities to a position of preventing conflict with sophisticated, quality weapons that posed a deterrent to the enemy. The horizon of

earth was replaced by the frontier of outer space. The unparalleled technological advances that enabled man to travel to the moon added new capabilities and dimensions to U.S. aerospace industry products. A new level of quality was needed for these products in order to assure their success in the foreign and unforgiving environment of outer space.

The growing number and complexity of government regulations and standards imposed on the industry to assure product quality and configuration, as well as production accountability, significantly contributed to the increase in resources required to manage major aerospace programs.

The flying fortresses of the World War II Era were replaced with multimission, high performance aircraft characterized by speed and agility as well as survivability.

These high-technology aircraft featured complex electronic systems, onboard computers for navigation, control of electro/mechanical systems and special mission capabilities. Structural designs and configurations became more complex as the shapes and silhouettes became more sophisticated. The requirements for lightweight, multi-contoured configurations led the industry to apply advanced materials technologies to the space age aircraft design effort.

The heavy metals that had comprised the aircraft of the maturing years were replaced wherever possible with nonmetals and hybrid materials such as composites, plastics and honeycomb structures. The manufacturing requirements for these high technology aircraft offered new and distinct challenges to the aerospace industry. Facilities were modified to provide the environmental controls necessary for storage and processing of advanced materials and components. Advanced manufacturing techniques and equipment were developed to meet shop floor requirements such as automatic tape layers for fabricating composite

skins and structures, and automatic fastening equipment to join the complex structures.

However, while automated equipment on the shop floor worked to effectively reduce the number of man-hours required to actually fabricate these advanced aerostructures, the complexity of the above-shop-floor support functions and the volume of paperwork grew unchecked, and the number of white collar manufacturing support workers continued to increase.

Space age advances in technology and its application altered the composition of product cost significantly. The addition of automated equipment on the shop floor reduced the direct labor required to produce aerostructures. As a result, the cost of direct labor fell from 50 percent of the total in the maturing years of high-rate mass production to no more than 10 percent. The inclusion of advanced computer and electronic components along with high-technology nonmetals pushed the share of total cost for materials from 25 percent to more than 55 percent. Specialized facilities, equipment and the growing ranks of manufacturing support personnel that were required to administrate the operation and manage the volumes of paperwork caused an increase in the indirect cost burdens from 25 to 35 percent.

Economic constraints, spiraling production costs, a nation-wide decline in productivity, and concerns about quality have significantly increased the costs of weapon systems over the last 15 years. This signals an end to the era in which the aerospace industry can ignore costs for the sake of performance, even when dealing with systems at the leading edge of technology.

Throughout its history, the U.S. aerospace industry has established an unsurpassed record for developing high-performance, quality aircraft that could survive in the harshest environments. The constant demands for bigger, better, faster, smarter,

more reliable aircraft have been met by the integration of advanced materials, electronics, and structures technologies into the product designs. However, while the products have progressed technologically, the manufacturing processes employed to build these complex aircraft have not developed at the same pace, resulting in higher and higher manufacturing costs.

Rising costs, coupled with growing foreign competition, have led the U.S. aerospace industry to face the fact that to compete successfully in the rapidly changing industrial environment, they must develop new manufacturing methods that are less vulnerable to shifts in the world marketplace than standardized production methods. These new methods must allow efficient, low cost operation in an environment characterized by multiple customers, proliferating product lines and low-to-mid-range production volumes. They must be responsive to variable product requirements and frequent, often unpredictable, changes in the product to meet customer needs.

Ironically, the initial efforts in modernization were, and still are, focused on the shop floor - where only 10 percent of the total cost of our aeroproducts originates. These efforts did not attack those functions that were the major contributors to cost, such as: material queues, inventory, material handling and set up, or scrap and rework. Nor did they address the integration of the above-shop-floor data management and support functions where a significant portion of indirect costs occur.

Considerable sums of money have been invested by U.S. firms on equipment and automated methods that simply served to perpetuate the old business-as-usual operation by automating the As-Is functions. This concentration on improving methods and functions that are obsolete and in some cases unnecessary for the manufacture and support of the product have not led to any significant reduction in costs. The significant capital outlays, coupled with the

maintenance of status quo staffing and re-sourcing of isolated manufacturing functions negated any real cost benefits from these "islands of automation." This status quo cost dilemma points up the need to develop a strategy for effective modernization and to establish a clearly defined road map for achieving flexible, integrated manufacturing.

Government and industry have joined forces to develop this road map through such efforts as the U.S. Air Force sponsored Integrated Computer-Aided Manufacturing (ICAM) Program which brought leading aerospace firms, industry consultants and academia together to study and assess technologies and to organize and structure plans for cost-effective and efficient implementation of technologies to meet the manufacturing requirements of current and next generation aero-structures. Studies such as the ICAM Conceptual Design for Computer Integrated Manufacturing Project, in which the Vought Aero Products Division served as prime contractor, set about establishing a framework for effective industrial modernization and a conceptual design for factory-wide, computer-integrated-manufacturing -- The Factory of The Future.

Addressing current and future aero-structures designs and corresponding manufacturing needs, the team developed a profile of the U.S. aerospace products in the mid-1990's time frame. The general characteristics included:

- o Technology-driven design features
- o High-precision hardware and software requirements
- o Complex structures and systems
- o Dynamic configurations
- o Multimission/variable mission and military/commercial roles

- o Dimensional extremes
- o High-technology/exotic materials
- o Low-rate production requirements.

Based on this analysis, it became apparent that there was a critical need for flexible manufacturing facilities that were responsive to changes in:

- o Product design and product mix;
- o Production quantities and schedules;
- o Processing sequences, equipment and technology;
- o Organizational structure and operating methods.

To provide that flexibility, the FOF objective became one of integrating computer and automation technologies to the fullest extent possible in not only shop-floor activities, but in those highly labor-intensive and historically costly areas of manufacturing support. The basic data management and decision support capabilities required for production are built into the computer systems that control the FMS providing a common information resource and improved visibility of operation allowing integration of all the organizational functions - finance, marketing, engineering, purchasing and manufacturing - to provide more effective management of the total production process. The use of advanced computer functions such as simulation and artificial intelligence in the decision making process will further reduce the labor requirements in the "above the shop floor" functions.

The Factory of the Future plan offers a hierarchical, functional structure based on the factory management, marketing, product definition and planning, information resourcing, provisioning and logistics act-

ivities that are necessary to produce current and next-generation aerostructures.

The coalescing agent in this concept is information. Information stored, controlled and disseminated from the management level to the shop floor will return the future factory environment to that state of integration and coordination found in the early days of the industry. Just as all the decision-making and tracking was maintained at a central point by the chief engineer/builder, the function and control of the factory will center in the factory control computer system - programmed with the management philosophy and goals, as determined by the firm's leaders.

This will allow implementation of a serial (one-ship-set-at-a-time) manufacturing philosophy to meet the needs of the future product line while reducing costs in inventory, work-in-process, scrap and rework, and labor. The single-aircraft focus of the early days will allow the FOF to accommodate a range of product envelopes, multi-program product mixes, variable/changing configuration and low yet "surgeable" rate production.

The information flow and decision-making process for serial production will all culminate in a modular, hierarchical factory environment comprised of integrated, flexible manufacturing systems that will provide a simple, efficient work flow from raw material to finished product. And this activity will be conducted with minimal human intervention, all under computer control.

Quality assurance will once again become an integral part of the fabrication process with the inspection function built into each flexible manufacturing cell leading eventually to in-process verification capability.

Flexible Manufacturing Systems (FMS) are regarded by many experts as the best way to meet the conflicting demands of low

volume, low cost production while improving product quality. These systems offer more than just factory automation. Flexible Manufacturing Systems provide for the physical integration of materials and equipment flowing through the factory, for shop-floor automation, wherever cost effective, and for the integration of all functions that direct, monitor and control the operation.

Flexible manufacturing systems integrate the use of hardware and software to manufacture products in the most cost-effective and efficient manner. Flexible manufacturing is the application of the "just-in-time" production philosophy to the fabrication of multiple-configuration products in mixed, small-batch (ideally one) quantities to an "only-as-needed" schedule.

The flexibility provided in the FOF environment will provide for better utilization of equipment, facilities, and labor, which are all significant contributors to the cost of the product.

We must remember in moving toward this factory of the future concept of flexible manufacturing that automation is not synonymous with flexibility in manufacturing. Conventional machines and methods, stand-alone NC machines and large transfer systems each have their place in the factory of the future depending on the volume and variety of workpieces. The key is to match operating methods and technologies to the task such that the facility most effectively satisfies its intended mission. Integration of these resources and functions in the above-shop-floor control systems will provide the management flexibility required to improve the productivity and cost effectiveness of each work cell.

Flexible, just-in-time manufacturing capabilities can reduce the cost of U.S. aerospace industry products by:

- o Reducing work-in-process, and thus reducing facility space, storage and

staging equipment, and inventory requirements

- o Reducing waste by eliminating:
  - Scrap resulting from changes to finished products that are fabricated ahead of need in batch production
  - Scrap resulting from errors made in batch manufacturing, due to the recovery capability between serially produced parts
  - Scrap resulting from human error as a result of reduced human intervention
- o Improving utilization of equipment and facilities
- o Increasing realization of labor
- o Improving productivity above as well as on the shop floor.
- o Maximizing resource utilization and distribution by automated provisioning of materials, tools, equipment, and information on an as-needed basis.

Implementing the factory of the future is a monumental task and will require careful planning. The plan must allow for incremental implementation of the flexible manufacturing cells to meet product needs. The cells must be integrated into the existing operation so as not to interrupt work flow. These criteria can be satisfied by establishing a well defined structure for the total manufacturing system and applying systems engineering methods to the total task.

#### Flexible Manufacturing Today At VAPD

We have followed this approach at VAPD in our reindustrialization efforts. Our Flexible Machining Cell (FMC), which began production operations on 2 July,

1984, is a modular component of our first flexible manufacturing system. It is the initial building block in the LTV Aerospace and Defense Company multiproduct factory of the future.

The FMC is the result of study, development, design and implementation by the VAPD Industrial Modernization (IMOD) organization, which was founded in 1982 to lead the firm's drive for reindustrialization. The flexible cell was designed using the ICAM life cycle development methodology to meet the machining needs for the current B-1B-aft and aft-intermediate fuselage subcontract effort for Rockwell International.

The VAPD Flexible Machining Cell is a computer controlled system capable of performing 4-axis machining, part cleaning, dimensional inspection and material handling functions in an unmanned environment. The cell was designed to:

- o Allow processing of similar and dissimilar parts in random order without disrupting production.
- o Allow serial (one-shipset-at-a-time) manufacturing
- o Reduce work-in-process inventory
- o Maximize machine utilization through remote set-up
- o Maximize throughput, minimize labor.

The system is comprised of the following elements:

- o Eight Cincinnati-Milacron 4-axis, single spindle, Computer Numerically Controlled (CNC) machining centers to perform profile milling, drilling, boring, reaming and tapping operations. Key features include:
  - Prismatic work area up to 32 in. x 32 in. x 36 in.

- 3-axis and 4-axis simultaneous contouring
- Automatic cutting tool storage, selection and changing
- Part surface sensing and broken tool detection
- Automatic pallet shuttle system
- o Two DEA coordinate measuring machines (CMM) with direct computer control drive system; a measuring range greater than the cutting machine envelope, and an accuracy/ repeatability tolerance closer than the cutting machine
- o System computer control network with Direct Numerical Control (DNC) capability. The total FMC computing complement includes:
  - 1 - DEC PDP 11/44, the cell host computer
  - 2 - DEC PDP 11/24 for robocarrier control
  - 2 - DEC PDP 11/23 controllers for the CMMs
  - 16 - controller/processors
  - 1 - DEC PDP 11/70 for backup, batch computing and simulation
- o Two fixture buildup stations with CRT terminals for buildup instruction
- o Automated storage and retrieval system for cutting tools; CRT terminal for tool buildup instructions, and electronic gaging
- o Two carousel storage devices. Each carousel has two load/ unload stations, with CRT terminals for operator instructions

- o Four Eaton Kenway robocarriers for transporting pallets between work stations
- o One Taylor Gaskin wash module designed for unmanned operation providing automatic part transfer, rollover, wash and discharge equipment
- o A Henry Filter, dual-flume chip removal/coolant distribution system to support all milling machines and the wash station. The system is designed to segregate and handle ferrous and nonferrous chips.

The system functions without human intervention except for the part loading/unloading operation and support areas such as fixture buildup, and cutter loading and delivery. The functions performed by the system software include:

- o Communication with the factory production data base systems to determine work order requirements and due dates based on data from the Master Schedule and Manufacturing Planning Systems, and to download the NC part programs required to control the milling and coordinate measurement machines. Upon completion of the machining and inspection functions, the system reports order status information, resource utilization and inspection results back to the appropriate management systems, closing the loop and providing the necessary integration with conventional operations
- o Management and distribution of NC part programs as well as the management of all tools within the cell
- o Managing cell functions of scheduling, traffic coordination, communication with station controllers/processors to effect the commands necessary to initiate processing or provide operator load/unload instructions.

## Operation Scenario

Part production begins when a load/unload operator loads blanks to be machined onto a pallet according to instructions displayed on a CRT. The detail instructions are supplemented by a graphic display to assure proper location and orientation on the 4-sided riser blocks. The pallet, which may contain up to 16 different parts, is then automatically shuttled onto the carousel, which has the capacity to hold up to 10 pallets. The load/unload stations are collocated in pairs adjacent to the respective carousels. The loaded pallets remain on the rotating storage carousels until all resources required to machine the particular part load included on a designated pallet are available within the cell.

When a pallet is required by the cell, a robocarrier is dispatched to retrieve the pallet from the carousel. The cart receives its commands from the PDP 11/24 controller via signals in a wire embedded in the floor. The pallet is then transported to the assigned machining center and shuttled into the input queue. Each center has a total queue capacity of five pallets, with two in the input queue, one in work and two in the output queue awaiting transport.

The machining center controller interfaces with the system computer to determine its specific task. The proper NC programs are downloaded, the proper tools are selected and changed automatically from a tool magazine containing a 90 cutter tool complement and the part is machined. The pallet is automatically rotated to machine parts on each face of the riser.

Once part machining is completed, the pallet is transported via an assigned robocarrier to a programmed wash station where chips are removed and the parts dried in preparation for inspection. After processing through the wash station, the next available robocarrier picks up the pallet and transports it to the assigned inspection station where the CMM automatically verifies part



geometry for each configuration represented on the pallet and transmits the results to the system computer. The pallet of inspected parts is then routed to the assigned carousel. Once returned to the carousel, the completed pallet load is forwarded to a load/unload station where parts are removed or remounted, as required, for additional machining. When processing is complete, the parts are logged out of the system and the work order system is updated with status information.

Further enhancements are planned for FMC, including automatic storage and retrieval systems for tools and materials, blank preparation, and robotic load and unload, to further integrate the cell with factory operations and improve productivity. Additional flexible manufacturing systems are also planned in other functional areas such as sheet metal fabrication, chemical and thermal processing, nonmetals fabrication, electrical assembly and structural assembly to complete the FOF architecture.

Advanced manufacturing technologies will be needed to bring these systems to maturity. Integration of these technologies into flexible manufacturing cells will provide the industry with a truly high technology factory of the future.

In summary, I feel the opportunity exists for the American aerospace industry to re-shape its future, to improve productivity and enhance its competitive position. The pathway to reindustrialization is clear.

The window of opportunity is relatively short lived and exists today. The expanding aerospace industries of Europe and the Far East are positioned and ready to overtake the world market in commercial as well as military aircraft. Widespread U.S. industry modernization now will assure our position in the world marketplace in the next century. Our challenge is to make this third

industrial revolution happen.

American industry, individually and collectively, can meet this challenge by committing to factories of the future featuring highly skilled labor, advanced manufacturing technologies, flexible manufacturing systems and functionally integrated organizations.