Innovation and Transfer of U.S. Air Force Manufacturing Technology: Three Case Studies (1981)

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Abstract: Air Force sponsorship of manufacturing technology projects is often based on the hope that the results will not only benefit the original contractors but will also be transferred to other Air Force contractors. This report describes research on attempts to transfer three Air Force-sponsored innovations--projects on hot isostatic pressing, automatic assembly drilling, and composite tape-laying. The hot isostatic pressing project was successfully transferred, while attempts to transfer the other two were judged failures by the Air Force. The study found that concepts might transfer at times when particular embodiments (physical configurations) of a concept do not. To judge whether an attempted transfer of technology is successful, one should determine whether the concept or the embodiment is the more valuable part.

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Innovation and Transfer of U.S. Air Force Manufacturing Technology

Three Case Studies

a report to the
U.S. Air Force Systems Command

by the
Committee on Computer-Aided Manufacturing
Manufacturing Studies Board
Assembly of Engineering
National Research Council

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INTRODUCTION

Air Force sponsorship of manufacturing technology projects is often based on the hope that the results will not only benefit the original contractors but also will be transferred to other Air Force contractors. Some innovations seem to be readily adopted by other contractors, but others, though considered likely candidates for diffusion among contractors, are rejected for a variety of reasons. An understanding of those reasons and the process by which investment decisions are made will enable the Air Force to establish policies and procedures to enhance the likelihood of successful technology transfer to its contractors.

At the request of the Air Force Systems Command (AFSC), the Committee on Computer-Aided Manufacturing studied three instances involving manufacturing research and development (R&D) projects completed under contract to the Air Force. The AFSC supported the projects with the understanding that detailed information about them would be made available without charge to other Air Force contractors. Each technology was considered by at least two firms other than the developer. In one case the technology was transferred; in the other two cases the technology has not been adopted by firms other than the developer, at least until this report was prepared in the summer of 1981.

The committee has examined all three instances as case studies. From the evidence provided, the committee developed a model to describe the decision-making process used by potential adopters of innovations. Its objectives were to explain why attempted transfers of military-sponsored manufacturing technology succeed or fail and to propose changes in contracting procedures to increase the diffusion of such technology.

In the following sections we describe the research procedures used, the framework for analysis, case study findings, and recommendations. Detailed case study reports form the three appendices.

RESEARCH PROCEDURES

A list of projects and the outcomes of attempted transfers was provided by the AFSC through the Air Force Materials Laboratory (AFML). Three cases were selected:

1. Hot isostatic pressing,
2. Automatic assembly drilling, and
3. Advanced composite tape-laying head.

1. General Electric investigated hot isostatic pressing (HIP) as a method to repair castings made of nickel, titanium, aluminum, and steel. Several vendors adopted the process. The committee research team contacted Howmet and TRW, who are adopters, and also studied intra-organizational transfer within General Electric.

2. Grumman had a contract to locate, precision drill, and countersink fastener holes by means of an automated drill-head mounted on a computer-controlled gantry. Grumman is currently using its automatic assembly drilling machine at a low rate of production. Though offered the machine, Fairchild and General Dynamics rejected it. Northrop discussed buying one but so far has not. The AFML considers the outcome of this case to be a failure. This judgment is based on a limited interpretation of transfer. It does not take into account instances where firms used knowledge of the Grumman work as a foundation for advancing the technology.

3. General Dynamics was one of several firms under contract to develop manufacturing methods for composite production integration equipment. The only advanced tape-laying head model currently in steady production at General Dynamics is a prototype machine. Ingersoll-Rand built a more advanced version for General Dynamics, but General Dynamics claims it has not worked reliably. Grumman rejected the General Dynamics approach in favor of one designed by LTV. McDonnell-Douglas might supplement its current broadgoods approach with a tape layer in the future, but at present no other company has adopted the General Dynamics concepts. The AFML considers the transfer of the tape laying head to be a failure.

Each case includes an originating organization and at least two potential adopters. All told, eight firms have had an active part in the three cases. Consultants to the committee, Margaret Graham of the Harvard Business School and Clint Stanovsky of the Massachusetts Institute of Technology, interviewed key individuals--developers, evaluators, and decision makers--at each firm. The parties interviewed are shown in the table on the following page.

FRAMEWORK AND ITS THEORETICAL UNDERPINNINGS

Figure 1 is the decision-making framework developed for analyzing the empirical information. It shows decisions to be made before adopting an innovation, considerations that enter into each decision, and the research questions raised at each decision point. In general the committee conceives of the process as one or more decision-makers weighing the perceived risk and perceived leverage of an innovation and comparing the outcome to other alternatives.

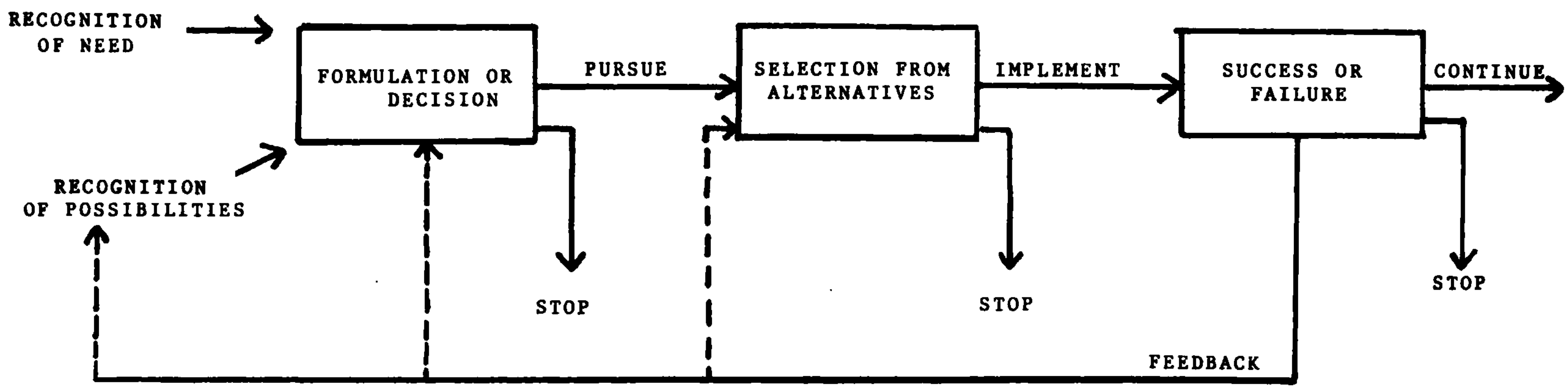
Case Study Interviews

Firm	Interviewees	Status*
General Electric Evendale, Ohio	Peter Bailey Ernest Kerczinick Ken Stalker	Originator of 1
Howmet Whitehall, Michigan	Bill Freeman Don Preston	Adopter of 1
General Electric Lynn, Massachusetts	Steel Irons	Adopter of 1
TRW	Jack Alexander (now at Precision Castparts Corp.)	Potential adopter of 1
Grumman Bethpage, Long Island	John Hubner Carl Micillo	Originator of 2 Potential adopter of 3
General Dynamics Forth Worth, Texas	James Ashton Grant Davis Wendall Eliot	Potential adopter of 2 Originator of 3
McDonnell-Douglas St. Louis, Missouri	Terry Howick Paul Meyer	Potential adopter of 2 Potential adopter of 3
Northrop Los Angeles, California	Don Stansbarger	Potential adopter of 2 Potential adopter of 3

*1. Hot isostatic pressing
2. Automatic assembly drilling
3. Advanced composite tape-laying head

FIGURE 1

A STRUCTURE TO EXAMINE MANUFACTURING INNOVATION: WHY ARE INNOVATIONS ADOPTED OR IGNORED?



PERCEIVED

Complexity — Applicability

Leverage: Pay-off ÷ cost — Probability of success (risk)

EVALUATED

Applicability
Risk
Leverage

ACTUAL

Applicability
Leverage

1. Was awareness of technical possibilities a significant help in the decision to pursue an innovation? A significant hindrance?
2. Was need a major determinant?
3. Were alternatives considered? Was the specific innovation rejected in favor of an alternative?
4. To what extent did the decision-makers proceed because of low risk? Because of high leverage? To what extent did the decision-makers proceed despite high risk? Despite low leverage?
5. Was the decision making explicit?
6. Were leverage and risk re-evaluated prior to selecting an alternative? Did these become more or less important as implementation became imminent?
7. Did the attempted innovation succeed or fail because of accurate or inaccurate assessments? because of determined or half-hearted pursuit?
8. In general, what is the relative importance of each of the following: awareness of technical possibilities, risk reduction, perceived need, and leverage (payoff in proportion to cost)?

The initial decision to consider adopting an innovation arises from recognition of a need, combined with recognition that a solution might be technically feasible. The decision to pursue the possibility or not will be based on perceptions of leverage (payoff relative to cost) and risk, tempered by perceptions of complexity and applicability of possible solutions. Research questions for this portion of the decision-making process are:

- Was awareness of technical possibilities a significant help in the decision to pursue an innovation? A significant hindrance?
- Was need a major determinant?
- Were alternatives considered? Was the specific innovation rejected in favor of an alternative?
- To what extent did the decision-makers proceed because of low risk? Because of high leverage? To what extent did the decision-makers proceed despite high risk? Despite low leverage?
- Was the decision making explicit?

As the decision-maker approaches the selection of a particular option:

- Were leverage and risk re-evaluated? Did these become more or less important as implementation became imminent?

The final portion of the framework shows the decision to implement an innovation or not. The success or failure of an implemented innovation will provide feedback to future decisions about investments in new technology. Questions to ask at that time are:

- Did the attempted innovation succeed or fail. . .
  - because of (despite) accurate or inaccurate assessments?
  - because of (despite) determined or half-hearted pursuit?

The committee does not address the last set of questions; its analysis ends with the decision to implement or not. In general this report seeks to determine the relative importance of each of the following:

- Awareness of technical possibilities,
- Risk reduction,
- Perceived need, and
- Leverage (payoff in proportion to cost).

A range of interdisciplinary innovation literature has bearing on the characterization of the parties and the techniques in question. The industrial buyer behavior studies, for instance, apply diffusion research to marketing. Webster and Wind[1] identify five organizational roles (deciders, influencers, buyers, users, and gatekeepers) and four key determinants (individual factors, interpersonal factors, organizational factors, and environmental factors). With these, they correlate several decision stages in the buying process.

Baker[2] offers a less complicated model that weighs the importance of different factors in the buying decision. His approach has the virtue of ranking the importance of many of the factors identified by Webster and Wind. While his attempt to weight these factors with precision is somewhat suspect, the notion of crude ranking makes sense.

A major factor that distinguishes the Air Force from other users of industrial innovation is its non-profit status. Transfer of medical technology, then, may be analogous. Gordon and Fisher, in The Diffusion of Medical Technology,[3] sketch an excellent methodology that is similar to those cited earlier but emphasize the primacy of performance (or efficacy in the case of drugs) for non-profit enterprises.

This study differs from most previous research on diffusion in that it seeks to explain not only the adoption of technology but also failure to adopt. This approach requires careful definition of the potential set of adopters. Another unusual aspect of this study is the attempt to characterize each innovation according to its chief technical attributes, as well as by the customary set of characteristics common to all industrial products.[4] White and Graham[5] characterize a technology according to the core concept, the embodiment, the operating characteristics, and the market characteristics. The concept of a new technology may be distinguished from its embodiment as a candidate for transfer. Not all successful transfers require that the embodiment be adopted; in some cases transfer of the concept is all that is intended or desired.

ANALYSIS OF CASE STUDY FINDINGS

Case studies are presented below in terms of the decision-making process at the originating firms and at the potential adopters. The cases are described in greater detail in the appendices.

HIP Casting Consolidation Technology

Originators

Both General Electric Evendale, which was the AFML contractor, and Howmet Turbine Components Corporation were originators of the hot isostatic pressing (HIP) casting process. Their decisions to pursue the technology were based on different planned applications. General

Electric, as an engine builder for military aircraft, specified in its designs castings that used HIP and also used the process to salvage unacceptable castings that had been received from vendors. Howmet and other parts suppliers used the HIP casting technique to produce products and to cut down on the number of castings rejected because of unacceptable porosity.

The HIP casting concept involves the application of high temperature and pressure to metal parts that have already been cast. The embodiment involves use of an autoclave to accomplish this application. The contract that General Electric performed for the AFML provided for the use of HIP casting on metals used in airplane engine construction. The basic concept had already been demonstrated for aluminum castings by Alcoa when General Electric first experimented with HIP for casting other metals. Battelle's publicity for the technique prompted both General Electric and Howmet to consider further development programs. For both companies the original benefit of HIP appeared to be casting repair (scrap reduction for Howmet and salvage reduction for General Electric) rather than product enhancement.

Decision to Pursue

General Electric's Evendale operation was responsible for investigating all relevant forms of manufacturing technology, and it was Evendale that decided to pursue HIP casting. For General Electric, low risk appears to have been the important motivating factor in the decision in two respects. First, General Electric was able to do its first experiments using an autoclave that was already available for its nuclear work. Second, and critically important, the AFML was willing to fund the project as soon as General Electric had brought the potential benefits and generic appeal of HIP casting to the attention of Air Force officials.

For Howmet low risk also played some part in the decision to pursue the technology, because Howmet was able to send early castings to Battelle to be processed in its autoclave. But perceived payoff seemed to be a stronger motivator for Howmet from the outset. The payoff was anticipated not only in terms of the tangible benefits that Howmet could realize if HIP casting reduced the scrap rate, but also in terms of the enhancement of Howmet's image as an innovator in its industry. Accordingly, Howmet investigated the HIP casting process at its own expense, avoiding the requirements that accompany government support for development.

The first stage of investigation quickly revealed to both companies that HIP casting offered larger benefits than they had perceived at first. The process not only repaired bad castings but improved good ones as well. For Howmet this meant a potential competitive advantage in its market; for General Electric it meant the possibility of improved performance in its engines. The new information made the adoption decision less complicated for Howmet and more so for General Electric. While the findings increased the leverage of HIP casting for Howmet, it meant that General Electric Evendale had to convince the engine designers and General Electric Lynn, which produced its engines, to specify HIP-cast components in new engine designs.

Decision to Adopt

The decision to adopt HIP casting was a gradual one for both companies. With old equipment that could be modified, Howmet was able to test its commitment to the process before investing heavily in new autoclaves specifically adapted for the new purpose. General Electric could also adopt gradually, by testing HIP-cast parts as replacements and in prototypes before actually using them in new development engines.

As of 1980, Howmet can be said to have adopted HIP casting fully, General Electric provisionally. In view of the enhanced leverage revealed in the early stages of investigation, Howmet committed substantial sums to purchase an autoclave for HIP in 1975. By investing at this time, Howmet anticipated demand and planned to develop a market. General Electric Lynn is still evaluating the test data relating to the use of HIP castings as replacements, but there are strong indications that it may soon specify HIP castings for the next major group of development engines.

Other Adopters

Other parts suppliers have adopted HIP castings without committing themselves to major investment. The existence of companies that will use the HIP technique for them has made this possible. TRW, for example, will continue to send out its HIP casting work until the volume of demand seems to warrant buying autoclaves for internal use. Here, leverage clearly outweighs risk as a motivating factor.

Findings from the HIP Casting Case

1. The AFML has termed the hot isostatic pressing contract with General Electric a case of successful transfer. Clearly AFML announcements and conferences, as well as conferences and reports generated by private research, have been important in diffusing the concept. General Electric's contract seems to have had little to do with diffusing the embodiment of the technique. If General Electric does decide to specify HIP castings in its next major engine design, it will be instrumental in transferring the embodied technique as well.

2. In the case of HIP casting, the form of the technological embodiment was a factor that promoted diffusion. Although autoclaves require significant capital investment, they are separable, stand-alone pieces of equipment that can be used with minor modifications for a variety of tasks. The existence of autoclaves made it possible for HIP casting users to try different applications without investing heavily ahead of time; and once a commitment to adopt was made it was possible to invest gradually.

3. An important aspect of the HIP casting process, which may account for its successful diffusion, is its benefits when included in designs. This aspect of HIP casting secured the support of influential design engineers and increased the size of the potential market, while allowing a premium to be charged for the product fabricated as a result of the technique.

4. Because of the design implications, the relationship of the AFML contractor, General Electric, to the potential adopters is important in the diffusion process. All suppliers can be expected to adopt the process in some way if General Electric specifies the use of HIP for cast components for its new engine designs. The timing of this diffusion will be closely linked with major new engine contracts. For all but conscious pioneers like Howmet, major new contracts are likely to trigger the adoption of the new technique.

Automated Assembly Fixture Drilling

The motivation for automated assembly fixture drilling was a desire to automate labor-intensive and monotonous tasks in airframe assembly. This need had been defined and promoted in several Air Force conferences in the early 1970s. Automation in assembly would not only reduce cost and improve consistency, but it would reduce dependence on trained manual personnel. With the recent appearance of minicomputers capable of being operated on the shop floor, the enabling technology was at hand. Both Grumman and General Dynamics chose to pursue concepts related to automated drilling.

The Air Force Materials Laboratory chose Grumman as its contractor to develop and demonstrate automated drilling in preference to General Dynamics, which was also competing for the contract. The Grumman approach was preferred because it added a scanning mechanism as a locating device in addition to the computer control of the drillhead.

Originator

The factor that first motivated Grumman to pursue the automated drilling technology was its perceived leverage. While Grumman lacked a high volume airframe contract to which the technique could be applied in the near term, Grumman's Advanced Materials and Development

Group had a standing mandate to explore all potential manufacturing cost-reduction opportunities. Grumman saw in the technique a variety of potential short-term payoffs such as chances for quid-pro-quo subcontracting, royalties, and demonstration funding from the Air Force for technology that had generic appeal to the industry at large.

Demonstration of the automated drilling technique entailed relatively little risk for Grumman. It was able to show feasibility for the equipment by drilling production panels in Plant Twelve where the equipment had originally been developed. Later it was able to move the same prototype equipment to the A-6 assembly line. Volumes on the A-6 program were low enough that the prototype automated assembly fixture was adequate for the task without modification. The same piece of equipment could be used to perform the Air Force contracts, enabling Grumman to evaluate the economics for both the A-6 and the A-10 parts.

Adopters

Since all airframe manufacture requires drilling numerous holes, the Grumman device was viewed by Grumman and the AFML as highly generic and potentially transferable to all airframe manufacturers. Immediate potential adopters were those companies tooling up for new contracts in 1974, Fairchild and General Dynamics. The AFML suggested that Grumman demonstrate the technique on an F-16 part produced by General Dynamics. In the view of the AFML, then, General Dynamics was the designated adopter. Other airframe manufacturers monitored the development of new techniques but were unlikely to adopt new tooling in the middle of a program. Despite the assessment of its general quality, the Grumman device has not transferred to any other company as of 1980, though several companies have given it favorable evaluations that may result in transfer in the future.

General Dynamics was one of the first companies to be given a demonstration of the automated assembly fixture drilling, even before Grumman received AFML funding to demonstrate it. General Dynamics had also been pursuing automated drilling, using its own research money. Its loss of the development contract to Grumman naturally affected its evaluation of Grumman's approach, but the ultimate decision not to adopt the Grumman device was motivated first by high perceived risk and secondarily by questionable leverage. The perceived risk in the Grumman device derived from two sources--doubtful applicability and poor relations between the two companies. Leverage appeared low, not only because Grumman proposed to charge substantial royalties, but also because the equipment would be costly to replicate at General Dynamics in view of the poor communications between the two companies. Grumman had tried unsuccessfully to interest Cincinnati Milacron in building the machine, and General Dynamics was unwilling to rely on Grumman drawings as the basis for the transfer. In the end General Dynamics chose to reject both the Grumman device and its own earlier approach to automated drilling in favor of a robotic wing driller. This device reflected General Dynamics's preference for lower cost, less dedicated equipment.

McDonnell was not tooling up when Grumman first demonstrated its automated assembly fixture drilling system, though its engineers thought the concept had high potential leverage. After watching Grumman's demonstration, McDonnell seriously considered investing in the technology. Evaluation of the Grumman approach ultimately revealed poor applicability without extensive modification. There was high perceived risk in replicating equipment that was not built by a machine tool maker. In the end McDonnell also chose to develop its own equipment, but, unlike General Dynamics, it chose to adopt certain Grumman concepts--in particular, scanning for accuracy of hole location.

Fairchild came closest to actual adoption of the Grumman equipment, signing a lease agreement in 1976. In the end insufficient leverage prevented the transfer there too, but in Fairchild's case the problem was one of timing. Had the Grumman demonstration occurred when Fairchild was tooling up for the A-10 instead of a year later, Fairchild would probably have adopted the technology.

In 1977-78 Northrop considered buying a wing drilling system, with the understanding that it would cost $250,000. Northrop's manufacturing processes group conducted a feasibility study that showed a marginally acceptable payback. But when Grumman raised the price to $1.2 million, Northrop could no longer anticipate sufficient leverage in adopting the system and rejected it on economic grounds.

Findings from the Automated Fixture Drilling Case

1. The AFML has labeled the Grumman device a case of failed transfer, yet it may still attract adopters. The Grumman concepts for automating drilling, especially the use of a scanning device for hole location, have already been transferred, even though the complete embodiment has not. The demonstration of the Grumman device clearly stimulated at least one company, McDonnell, to look at automated drilling in assembly for the first time.

2. Transferring technology into an interrelated system such as an assembly operation is bound to require some adaptation. The amount of adaptation depends on two factors: the similarity of the products being assembled and the similarity of organizational design and manufacturing philosophies. Both McDonnell and General Dynamics found that the Grumman device needed significant adaptation for their needs, in part because of their higher volumes of production and in part because of the different types of drilling required. Fairchild and Northrop have production volumes more comparable to Grumman's, and their manufacturing philosophies are similar.

3. Relations between the companies involved in a transfer have a profound influence on the success or failure of adoption. If past dealings have been good or if the companies are currently involved in joint work, such as a subcontracting arrangement, then the process of transfer is aided. By contrast, if there is a history of previous conflict among the parties to a potential transfer, the perceived risk of transferring and adapting a technology becomes high. Even very thorough reports and demonstrations contain only a fraction of the information and know-how required to transfer a complex embodiment.

4. The Grumman device would have been much more likely to spread in its embodied form if a machine tool builder had replicated the device. In cases such as General Dynamics and McDonnell, where adoption involves significant adaptation of the original embodiment, the costs of transfer may well exceed the cost of building equipment from scratch. If a machine tool company, with its know-how and warranties, were to produce the equipment, adopters might be willing to forgo some adaptations.

The Advanced Composite Tape-Laying Head

The advanced composite tape-laying head is designed to automate the process of fabricating laminated parts from advanced fiber composite tape. Composite materials (boron or graphite fibers in a resin base) are available in either tape or broadgoods form. Uncertainty concerning the format and cost of the materials has kept production technology fluid over the past 20 years. There are numerous materials suppliers, and although there has been some standardization of widths, there are still many different combinations of material and adhesive systems, each with slightly different handling properties. With the additional problems of storage and poor shelf-life, the difficulties of settling on a stable production system become enormous. Whether in tape form or in broadgoods the material has to be dispensed, laid up carefully ply on ply, and cut accurately in any of several ways, not necessarily in that order. The concept of the tape-laying head is the automation of this process for the tape format, heretofore an intensely manual process. The tape is dispensed, its deposition controlled so there are no gaps or overlaps, and then it is sheared evenly and accurately.

Originator

When General Dynamics chose to pursue the automation of tape laying in the mid-1960s it seemed to all that the price of composite materials would decrease and more composites would be used as a consequence. The company's first prototype machine gained support from the AFML to develop an improved version built by Conrac. The series of AFML contracts that followed reduced the risk for General Dynamics to invest in tape-laying automation but the real motivation was perceived leverage. In the late 1960s General Dynamics planned to design a high-volume, low-cost fighter aircraft, using some composite parts, and manual production costs were considered to be prohibitive. The firm projected a need for 15 tape-laying machines in the mid-1970s. Since all military aircraft were expected to incorporate composite materials in a few years, the AFML saw the automated tape-layer as highly generic.

General Dynamics experimented further with the Conrac and other improved prototype heads. It adopted and modified its concept in a machine built by Ingersoll-Rand for production of the F-16 in 1976. In 1977 it began a further AFML contract to improve the tracking capability of the head, as well as to introduce flexibility as to length of strips laid down and versatility in cutting. Its latest AFML contract was designed to perfect the concepts for use in an integrated, fully automated composite production system.

General Dynamics chose to stay with the tape approach, even after broadgoods became available, not only because it had already invested extensively in tape technology but because it saw tape as the lower cost approach (less waste, more versatility, fewer materials control problems). The company placed such importance on low-cost manufacturing that it was willing to limit the freedom of its designers if that were necessary.

Since the time material suppliers made broadgoods available, a number of equipment makers that had previously focused on the garment industry have entered the aerospace market. Because of the large number of competitors in the field, the equipment builders have tended to custom design equipment--and charge custom prices. General Dynamics has not yet found an equipment maker to produce its most recent version of the tape-laying head at an acceptable price.

Adopters

The tape concepts that had seemed generic in the late 1960s when the AFML funded the early General Dynamics contracts were called into question when broadgoods became available. The broadgoods philosophy won enough converts to narrow the field of potential adopters considerably. Three different groups emerged: companies such as General Dynamics that stayed with tape, companies such as Grumman that adopted a hybrid philosophy, and companies such as Northrop that moved entirely into broadgoods.

Grumman closely followed General Dynamics into the area of composites automation. It began investigating the automated tape-laying concept when General Dynamics demonstrated the Conrac. In 1969 Grumman projected a need for perhaps one-third of the volume projected by General Dynamics. Grumman evaluated the Conrac for its own use but rejected the General Dynamics embodiment in favor of its own mechanized tape dispensor. The objections to the General Dynamics approach might be regarded as technicalities, but they reflected enduring differences in priorities. General Dynamics emphasized cost and volume; its primary concern was economic. Grumman insisted on various performance characteristics such as individual ply inspection and accurate cutting before it turned to cost considerations. As a result, Grumman chose to pursue other available options, including its own. It learned from General Dynamics's concepts but did not adopt them.

Grumman moved closer to adopting a particular tape layer in 1974-75 when it foresaw a need to automate its composite production in order to manage the huge B-1 bomber stabilizer. Its need was again defined not so much in terms of cost as in terms of performance. Having evaluated the three leading tape layers, it chose LTV's because it would lay up smaller individual pieces of tape than the one for General Dynamics. Grumman then pushed for defining an entire integrated composite production system and reducing cost on a system-wide basis. In 1975-76 the AFML funded Grumman's integrated laminating center, thus leading the firm permanently away from the advanced tape head concepts.

When broadgoods appeared in the early 1970s, other companies reassessed their entire composite production systems. McDonnell had been tracking and evaluating the automated tape-laying concepts at each stage and had built its own more rudimentary equipment. McDonnell's leadership in composites was based on sophisticated design, not manufacturing technology. Broadgoods seemed to offer more flexibility to designers. McDonnell opted for laser cutting as its major production investment. In the end, therefore, compatibility with manufacturing philosophy became the key factor in McDonnell's non-adoption of the tape-laying device, and awareness was the trigger for adoption of the alternative system. This decision may be changed eventually. McDonnell could still adopt tape-laying equipment when it does such a high volume of composite parts and structures that a subsidiary tape capability becomes desirable to enhance flexibility.

Northrop waited to pursue automation in composites until broadgoods were available. Its volume of composites was so low that risk reduction and awareness of technologies consistent with its philosophy were the decisive factors. Manufacturing flexibility is the main consideration for Northrop. Since broadgoods satisfy that requirement more than tape, the company does not consider itself a member of the class of potential adopters for a tape-laying head in the foreseeable future.

Findings from the Advanced Composite Tape-Laying Case

1. The AFML has judged the advanced composite tape layer to be a failure not only because no other company has adopted the concepts but because General Dynamics has yet to put its most recent improved

version of the head into production. The problem is the difficulty of getting an equipment builder to produce the head at an acceptable price.

2. In a technology as fluid as composites technology, embodiments are extremely unlikely to transfer. Each attempt to embody concepts raises new problems and the whole system is so unstable that embodiment in other than prototype form is prohibitively risky. Even concepts in this environment are more likely to stimulate further development than to transfer intact.

3. An added barrier to transfer is the reluctance of machine tool builders to become involved in an unstable technology without charging custom prices.

4. Individual manufacturing philosophies, consistent over time, play an important role in aiding or obstructing transfer. Even though General Dynamics and Grumman have very similar composite concepts, the differences in their manufacturing philosophies inhibit transfer.

OBSERVATIONS AND RECOMMENDATIONS

Aspects of Technology

Whenever technology transfer is discussed, too little attention is generally directed towards the characteristics of the technologies. A few distinctions need to be borne in mind.

First, it is important to distinguish between concepts and their embodiments. It is possible for concepts to transfer while particular embodiments--physical configurations of those concepts--do not. The reverse is also true. For each individual technology, therefore, it is important to decide whether the real value is in the technology concept or in its embodiment. A transfer should be judged successful if the valuable part has transferred.

Another aspect of the concept versus embodiment question is related to the category labeled generic. A striking feature of the cases treated here is that although the concepts judged to be generic frequently proved to be so, the particular embodiments often impeded their transfer. Some embodiments, such as that of hot isostatic pressing, are more permissive in this sense than others. While there has been concern about the amount of capital investment involved, perceived risk is related as much to flexibility, reusability, and adaptability as it is to actual risk.

Yet a third aspect of a technology that must be noted is the uncertainty associated with a high rate of change. If a whole process area is changing as rapidly as composite production is changing, for instance, then to look for transfer of whole concepts, let alone of whole embodiments, is to look for premature standardization. In a rapidly changing field, stimulation of new concepts may be the greatest contribution that an Air Force-sponsored project can make.

Aspects of Transferring Organizations

The Committee on Computer-Aided Manufacturing, in its 1979 annual report, addressed technology transfer and the characteristics of participating organizations. That report distinguished between transfer to large sophisticated firms and to smaller and less sophisticated organizations, between transfer within the aerospace enterprise and to or from non-aerospace firms. The committee recommended in 1979 that the ICAM program take advantage of the potential role of hardware and software vendors and machine tool builders, that it stress communication between transferring and adopting organizations, and recognize that standards for systems design will be adopted more readily than computer code.[6] The case studies just completed tend to confirm those observations.

Compatibility between the existing systems and philosophies of the parties to a potential transfer are a necessary but insufficient condition for adoption. Minor differences can be modified, but the costs of modification and communication soon exceed the cost of in-house development for most system embodiments. This factor is one of the main reasons that machine tool builders often play an important role; the value they add as a neutral party reduces the urge to redo the embodiment.

Rapport between originators and adopters significantly reduces the perceived risk in adoption as well as the costs associated with transfer.

Companies such as Grumman, Northrop, and General Dynamics, which possess R&D-dedicated groups that routinely track process technologies are likely to pursue concepts as opportunities, without a high perceived leverage. However, clearly defined need and high leverage are critical to outright adoption by all companies.

For Air Force contractors, outright adoption hinges almost always on a major new program, because that is when capital investments are made. Awareness of demonstrated capability in a particular new setting may help to reduce the perceived risk, but it is not enough alone to stimulate any activity other than consideration. Availability on the open market, however, may well lead to adoption because the machine tool builder offers ways of reducing the risk and buffering the uncertainty. The phrase "we are not machine tool builders," heard so frequently among contractors, indicates what an important, if indirect, role machine tool suppliers have played in initiating or inhibiting the transfers that the Air Force has wished to encourage in the past.

Recommendations for Air Force Action

The observations stated above have implications for Air Force practices that can or do influence technology transfer. Recommendations to enhance technology transfer among Air Force contractors follow.

First, it would be useful for the Air Force, when considering awarding contracts designed to encourage transfer, to address the distinction between concept and embodiment in light of objectives. In many instances the real objectives, carefully defined, can best be met by proof and demonstration of a concept. The Air Force should broaden its interpretation of successful transfer to recognize the benefits of transferring the concept. If a generic embodiment transfer is really required, the embodiment might be developed cooperatively or in cooperation with a machine tool builder at the start. If a technology has significant and apparent benefits when included in designs, there may be no need to fund development or demonstration as it is likely to be adopted rapidly in the natural course of events.

Second, the Air Force should take into account the often decisive role of machine tool builders in transferring technologies. To gain their cooperation the Air Force might offer incentives that are not administered through the contractor.

Third, guidelines for dealing with potential users ought to take into account their problems in adaptation. Better contracting procedures might help to establish the responsibilities of originators and adopters as a formal condition for funding. Efforts should be made to identify receptive users and to consider their needs early in a development program. Gaining adopters at an early stage, particularly receptive adopters with a stake in the technology to be transferred, could greatly increase the acceptance and use of the new technology.

Recommendations for Additional Study

The three cases are examples of hardware manufacturing technology. However, the framework for this study also applies when the embodiment of computer-aided manufacturing technology is software.

As suggested from the case studies, it is important to distinguish between concept and embodiment; in the case of software the embodiment would be represented by the code--either source code or machine code. The case studies suggest that computer-aided manufacturing technologies may transfer easily in concept, whereas the embodiment (code) may prove not to be generic or transferable at all.

In these three cases it appears that a machine tool builder's active involvement will usually improve transferability. Analogously, a software house or even a computer hardware house might be important to the transferability of computer-aided manufacturing technologies.

This discussion suggests significant applicability of the present studies to issues concerning the transfer of computer-aided manufacturing technology. To test these inferences we recommend the study of one or more additional cases involving the transfer or potential transfer of a computer-aided manufacturing technology where embodiment is a computer code.

As manufacturing systems become more complex and more integrated, transfers of hardware/software combinations will be increasingly common. We further recommend one or more case studies of the transfer of systems that, of necessity, involve such combinations.

NOTES

[1]Frederick E. Webster and Yoram Wind, Organizational Buying Behavior (Englewood Cliffs, N.J.: Prentice-Hall, 1972).

[2]Michael J. Baker, "Industrial Buying Behavior and Adoption," in Michael J. Baker, ed., Industrial Innovation: Technology, Policy, Diffusion (McMillan: London, 1979).

[3]Gerald Gordon and Lawrence Fisher, eds. The Diffusion of Medical Technology (Cambridge, Mass.: Ballinger Publishing Co., 1975).

[4]George Hayward, in Baker 1979, compares the attributes of a technology as perceived by different parties to a transfer transaction.

[5]George R. White and Margaret B.W. Graham, "How to Spot a Technological Winner," Harvard Business Review, v. 56, no. 2, Mar-Apr, 1978.

[6]Committee on Computer-Aided Manufacturing, The Committee on Computer-Aided Manufacturing in 1979, Annual Report (National Academy of Sciences: Washington, D.C., 1980) pp. 20-21.

Appendix A

HIP Casting Consolidation Technology

Hot isostatic pressing (HIP) is a generic name for materials processing at high temperature and pressure. The earliest applications of HIP include powder metallurgy and consolidation of carbides. This study examines the development and diffusion of the concept of HIP casting: hot isostatic pressing for the purpose of closing porosity in castings.

The following technical and market structure conditions underlie the technology transfer process.

Technical Conditions

1. Alcoa holds the earliest patents for HIP casting, with applications to aluminum castings. (See the chronology at the end of the appendix.) This work preceded the efforts of Air Force contractors and subcontractors and established the concept of HIP casting explored by Battelle, General Electric, and Howmet.

2. The concept of HIP casting is the dominant attribute of the technology to be transferred. Conferences and technical reports resulting from private research and the AFML have been important contributions to the diffusion of the concept.

3. Current HIP casting equipment (which embodies the concept) is similar to the autoclave technology used for powder metallurgy and carbide production at the time of early HIP casting development. Modifications of such equipment are necessary for HIP casting. Powder metallurgy uses lower temperatures and protects the materials in an envelope; the proximity of HIP casting temperatures to melting and the exposure of parts require closer temperature and environmental controls. Necessary operating changes are minor.

4. HIP casting research was first undertaken to lower rework and scrap rates for cast parts. In many cases HIP casting has also improved material properties and increased the uniformity of batches of cast parts. These added benefits have been an incentive to specify HIP-cast components during the design of new products.

5. In some cases, improved investment casting techniques, directional solidification, single crystal castings, or use of forgings are technical alternatives to HIP casting. In other cases, however, practical technical alternatives do not exist.

6. Technical questions about the design and process control for large pressure vessels have so far limited the size of HIP autoclaves and so limit the size of HIP-cast parts. One of the largest HIP facilities, installed by Pratt and Whitney in 1975, is an 80-inch high cylindrical chamber with an inside diameter of 46 inches. These size restrictions tend to make HIP casting of large components financially--if not technically--infeasible at the present state of the art.

Market Structure Conditions

1. In the aircraft engine supply market (where the HIP casting applications under study have been developed), the important participants are engine buyers, their contractors, and the contractors' parts suppliers. Primary engine buyers include defense and commercial users of jet and gas turbine engines. General Electric and Pratt and Whitney have been the important engine suppliers for this study. Parts suppliers are foundries, notably Howmet Turbine Components Corporation, Precision Castparts Corporation (PCC), and TRW.

2. Adoption of HIP casting technology has a double meaning. A parts supplier becomes an adopter by purchasing HIP casting equipment. A contractor adopts the technology by specifying HIP-cast components in its designs. When a contractor becomes an adopter, the parts supplier may invest in HIP casting facilities, find an outside HIP casting service (see conditions #3 and #4 below), or forgo bidding on the specified part.

3. Development of other HIP technologies created sources of HIP casting capacity for contractors and parts suppliers. Because of their earlier research in powder metallurgy and cemented carbide, Battelle and Industrial Materials Technology (IMT) were the major sources of HIP capacity during the development of HIP casting. More recently Battelle has avoided that role, but IMT and other firms provide HIP casting job shop services to parts suppliers. When Howmet acquired production facilities, it began to provide job shop service to other parts suppliers; TRW, for example, sends part of its HIP casting business to Howmet. Thus, parts suppliers can choose between in-house and outside HIP casting operations.

4. The availability of outside HIP casting services enables parts suppliers and contractors to experiment with the technology and adopt it gradually. As their technical experience and customer demand increase, firms may then choose to invest in their own HIP casting capacity.

5. Much of the present demand for HIP-cast aircraft engine parts is for after-market components. Lead times for introducing new processes to aircraft engine production can be quite long. Adoption of new technology for full-scale production awaits a new generation of

engines because of testing requirements and because of the structure of contracts between engine builders and engine users. Pratt and Whitney has specified titanium castings using HIP for both original equipment and after-market components in the F-110 program.

The Air Force Materials Laboratory (AFML) became involved in HIP casting when General Electric Evendale offered the AFML laboratory evidence of feasibility in 1971. The AFML saw HIP casting as a generic manufacturing technology, beneficial to all users of castings but not likely to be developed quickly by industry. Proponents of HIP casting in the AFML, convinced that the potential benefits were great, advocated and won funding for General Electric's work in 1972 through the Manufacturing Technology program. The AFML hoped to demonstrate the efficacy of HIP casting and to provide sufficient process specifications to allow adoption by parts suppliers.

While General Electric pursued its research in Evendale, Howmet began to develop its own HIP casting process without AFML funding. Both companies can be considered originators of the technology.

General Electric

The Technical Systems and Materials Division of General Electric (GE) produces jet engines for aircraft, industrial, and marine applications as well as electronics and materials for space, defense, medical, communications, and computing applications. General Electric has a matrix organization, with Engineering, Manufacturing, Project Management, and Quality Control divisions in each of its plants. Two of the aircraft engine plants were included in this case study: a facility in Evendale, Ohio, primarily producing large commercial engines, and a facility in Lynn, Massachusetts, producing small military engines as well as combustors, nozzles, and frames for use in other plants. Researchers at GE Schenectady Materials and Processes Laboratory in the Gas Turbine Products Division carried out early HIP casting research and presented a paper to the Seven Springs Conference of the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) in 1972. HIP casting development under the AFML contract was the responsibility of a group working in the Engineering Division of GE's Evendale Plant.

General Electric does much of its Technical Systems and Materials business as a direct government contractor. The firm has years of experience in R&D and production projects for the government and continues to seek government contracts. Evendale, located close to the AFML in Dayton, Ohio, follows a policy of using Air Force funds for risky R&D that it might not otherwise undertake. Within GE, design and manufacturing considerations are tightly coupled, but managers in the Manufacturing Technology Operation believe that product design considerations ultimately drive decisions related to production processes.

Changes from wrought to cast turbine blades and the increasing blade tip speeds of the supersonic transport program fostered General Electric's initial interest in HIP casting. During 1969 and 1970 General Electric obtained laboratory confirmation of the technical feasibility of such techniques. In 1972 they acquired Air Force funds for development of a prototype. Evendale hoped to use HIP-cast parts by persuading the foundries that supply cast engine components to adopt HIP casting techniques.

In 1974 General Electric completed its first AFML contract in HIP casting, an investigation of its application to aluminum and superalloys. That year the firm received another AFML contract, to obtain data for titanium and three other superalloys.

Howmet Turbine Components Corporation

Howmet believes itself to be the largest supplier of turbine blades to the U.S. aircraft industry. A wholly owned subsidiary of Pechiney Ugine Kuhlmann of France, Howmet specializes in the production of investment castings used in the hot section of gas turbine engines. In addition, Howmet produces its own air and vacuum melted alloys, manufactures ceramic products for its casting operations, precision machines and coats its finished castings, and produces titanium ingot for the aerospace industry. Howmet facilities in Whitehall, Michigan, include a research center and HIP casting facilities. A materials research and development (R&D) group at the Technical Center was responsible for preproduction HIP casting research.

Howmet is well established as a supplier to government contractors but prefers not to involve itself extensively in government R&D projects. Managers at Howmet believe that requirements to justify and generalize federally funded research force contractors to undertake additional work that does not benefit them. They prefer to retain maximum control over the nature and duration of R&D projects. Howmet has an aggressive R&D program for its own purposes and considers itself to be the leading supplier of high-technology cast high-temperature engine components.

In 1965 Howmet researchers began to investigate applications of HIP for closure of porosity in titanium- and cobalt-based alloy castings. The research was completed in 1967, with positive results for titanium. A Howmet team investigating techniques for elimination of microshrinkage attended a conference of the AIME in 1972. There they heard a presentation on HIP casting given by workers from GE Schenectady. After the conference Howmet researchers recovered the results of earlier Howmet research and initiated development using powder metallurgy facilities at Industrial Materials Technology (IMT) and, later, at Battelle.

By 1974, with about $750,000 invested in R&D, Howment was HIP casting several of its customers' parts and considering purchase of its own HIP casting facilities. Howmet oontinued to monitor General Electric's work while developing HIP casting technology to production readiness. Howmet developed casting preparation procedures, post-HIP heat treating routines for restoration of material properties, and established process tolerance for a wide variety of its customers' alloys.

Adoption of HIP casting in the aircraft engine industry occurs in two ways. First, oontractors attracted by the potential cost savings and materials properties resulting from the technique may place orders for HIP cast parts with their subcontractors. These orders may be for experimental work, development, after-market components, repairs, or production. Second, parts suppliers may decide that demand justifies the purchase of HIP casting equipment. Parts suppliers that have not adopted the technology may employ the services of outside HIP casting facilities such as those of IMT and Battelle. The decision to adopt frequently follows a period of using outside HIP casting services.

Parts Suppliers

1. Howmet Turbine Components Corporation

Howmet, at the completion of its HIP casting development project, had to decide whether to continue to subcontract for HIP casting or to acquire its own equipment. Investment costs were first estimated in 1974 as $1 million. In 1975 Howmet tried to organize a joint venture with two of its major customers to share the risks and profits of HIP casting equipment. Howmet presented evidence on the improved and more uniform properties of HIP-cast components. The firm's customers, whose analyses focused on projected rework and scrap cost savings, declined to join Howmet in investing in HIP casting.

After hesitation, Howmet decided to assume the risks of investment alone. Approval was given for purchase of a pressure vessel from Automation, Inc., and a furnace designed and produced by Battelle. In making this decision, Howmet let commitment to technological leadership be the deciding factor. Full production began in 1977, with the largest order placed by GE Evendale. In 1978 Howmet built another furnace under license from Battelle at a cost of $80,000.

At present Howmet's titanium casting division augments demand for HIP casting of engine components. Howmet also offers HIP casting services to other parts suppliers.

2. TRW

TRW is a major competitor to Howmet in the turbine blade market but not in titanium. Researchers at TRW first considered purchasing HIP casting facilities in 1972, when General Electric's work in the area became widely available. Like other parts suppliers, TRW's options included improvements in casting processes and contracts for outside HIP services.

Volume was the primary consideration for TRW. They found that requests for airfoil HIP castings were too limited to support the expense of in-house equipment. TRW lacks the titanium work available to the Howmet HIP casting operation and was not interested in providing a HIP casting service to other parts suppliers. On this basis, TRW has elected not to purchase HIP casting equipment. Howmet and IMT do much of the HIP casting work for TRW.

Recently, TRW has approved the purchase of a small HIP casting unit for research and development. The company reviews annually its decision not to purchase HIP casting equipment for production.

3. Precision Castparts Corporation

Precision Castparts Corporation (PCC) is a supplier of large aluminum and superalloy investment castings (e.g. structural components for large gas turbine engines) and engine airfoils. It began supplying HIP-cast components before 1976 but does not have its own HIP casting capacity. PCC sends its large components from its Portland, Oregon, location to Crucible, a Pittsburgh-based foundry. Industrial Materials Technology HIP casts PCC's small components in a Portland facility that depends on PCC's business.

Precision Castparts Corporation's decision not to adopt HIP casting by purchasing equipment is based on its customers' demand. GE Evendale is at present PCC's largest user of HIP-cast parts. Pratt and Whitney is in the process of evaluating several substantial commitments to HIP castings from PCC. Fiat, MTU (Germany), and a mix of smaller customers provide the balance of the demand. PCC and IMT are both prepared for the eventual acquisition by PCC of IMT's Portland facility. PCC is also considering the purchase of equipment suitable for large structural HIP castings if sufficient demand develops.

Engine Builders: GE Lynn

Engine builders provide the demand for HIP castings which drives the investment decision of the part suppliers. Within GE, the demand entails technology transfer from engineering materials research to engineers responsible for the design and production of specific engine programs.

Material processing innovations at GE are often developed during an ongoing engine production program but not fully adopted until a later engine goes into development. The transfer of HIP casting to GE's Lynn

Aircraft Engine operations, still in process, seems to fit this pattern. At present, GE Lynn is in the early stages of adopting the techniques first developed by the Engineering Division materials R&D group in Evendale in 1972-74.

Three obstacles have slowed adoption of HIP casting at Lynn.

1. Equipment Availability -- until recently HIP casting was available only from Battelle (which wished to avoid production commitments) and IMT. Growth of IMT's capacity and Howmet's new operations suggest that when GE Lynn is ready to adopt fully HIP castings, production capacity will be available.

2. Engineering Confidence -- Materials engineers require full documentation of materials properties at the operating conditions of the engine in question. Though Evendale has supplied verification of materials properties at some temperatures, these temperatures are not necessarily the same as those for which current engine components are designed. Development of materials data, especially low and high cycle fatigue and stress rupture properties, will be carried out in Lynn. Adoption requires operating experience with HIP-cast parts. At present, HIP casting is becoming an "approved repair procedure." Once this is accomplished, HIP-cast parts will be verified with at least 150 hours of factory engine use.

3. Contract Cost Controls -- HIP casting can add $200-$300 per engine in foundry costs that are subject to the scrutiny of project cost accountants. Offsetting savings in rework and ship time are included in overhead and are not as readily visible to oost controllers. Further, GE's customers already have a workable contract and are only gradually being educated to the benefits that justify what appears to be an expensive change in production techniques.

Introduction of HIP casting through the design and development of new engines avoids these obstacles. During development designers can take full advantage of improvements in materials properties afforded by HIP casting and gain engine use verification of materials properties during engine testing. GE is very likely to specify HIP-cast components for future engines, though GE engineers expect to continue their efforts to improve conventional casting techniques as well.

HIP Casting Chronology

1967	:	Alcoa, working with Battelle, patents the concept of HIP casting for aluminum.
1965-67	:	Howmet performs research on HIP castings of titanium- and cobalt-based alloys.
1971-72	:	GE offers evidence of feasibility to the AFML. Howmet, after hearing a report from GE, recovers past research and begins R&D.
1974	:	GE completes its first AFML contract, reporting success in densification of Rene'80 and Ti-6 Al -4V castings.
1975	:	Howmet commits to capital investment in HIP casting facilities.
1976	:	Testing, development, experimental, and after-market use of HIP-cast components.
1977	:	Howmet begins full production.
1978	:	Howmet invests in additional production capacity.
1980	:	GE completes its second AFML study, "Manufacturing Methods for Low Cost Turbine Engine Components of Cast Superalloys."

Appendix B

Automated Assembly Fixture Drilling

The Automated Assembly Fixture Drilling System was conceived as a way to automate drilling of such large contoured structures as wings that would otherwise have to be drilled manually. Like other types of automated assembly tasks it became feasible only when mini-computers became available that could operate in a shop floor environment. The system's task is to scan the piece to be drilled, storing the information in its computer memory, locate and check the hole coordinates, and then drill and countersink holes in a wing skin and understructure, or other large component, mounted in a fixture. The system consists of a CNC drill unit mounted on a vertical gantry capable of five-axis movement, a scanning camera to guide and check the work, and a modified fixture to accommodate the automated drilling.

Certain conditions related to the technical and market environment for this system need to be understood as background to the case of technology transfer. A discussion of these conditions follows.

Technical Conditions

1. Grumman holds a basic patent in Automated Assembly Fixture Drilling because the only developmental work on the device was funded by internal R&D money.

2. Much of the drilling in aircraft manufacture (250,000-400,000 holes per average fighter, three times as many per average bomber) could be automated by other means, but existing methods were not adequate for drilling large contoured places that had to be mounted in fixtures.

3. The distinctive concept of the Grumman system was its use of a scanning technique to locate and correct the holes prior to drilling. The embodiment introduced other equipment features as issues--for example, the ruggedness and cost of the system as it was configured by Grumman.

4. The drilling task varies along several dimensions. The needed accuracy and measurement capability of the equipment depends on such factors as wing configuration, structure, and whether holes are through skin only or into substructure. The ruggedness of the equipment needed in terms of force delivered, durability, and reliability depends on the volume of shipsets assembled and the type of material (e.g., aluminum or titanium versus composites) to be drilled.

5. The main drivers for automating the drilling task have been increasingly tighter tolerances, the expense of templates, and the time and cost involved in manual work when pilot drilling and back drilling are required. Another driver is the need for consistency to reduce the danger of major scrappage. A human driller becomes progressively less accurate during an eight-hour shift.

6. Other automated alternatives to Grumman's device have been explored in the industry. One has been the location of holes using a laser beam, locater, or some other form of sensor that can look through the wing skin at its substructure. Another alternative is a robotic driller (see below in General Dynamics).

Market Conditions

1. Aircraft manufacturers have a variety of cooperative manufacturing arrangements. Contractors act as prime contractors for some programs and subcontractors for others. Major structural parts are often subcontracted to other firms. In this case, Grumman was to have the subcontract, under Rockwell's prime contract, for the B-1 Bomber horizontal stabilizer.

2. A number of traditional divisions have existed in the industry that tend to affect relationships among contractors. One is the traditional identification with a particular branch of military service. General Dynamics has historically worked primarily for the Air Force whereas Grumman has historically worked more for the Navy. These historical relationships do not prevent companies from designing planes for either service, but the differences in the ways the two services have dealt with their contractors and the somewhat different design traditions have some effect on company development and manufacturing philosophies.

3. Shortages of skilled labor and large fluctuations in company workforces between major programs have been driving factors towards automation of airframe assembly, particularly during the 1970s. General Dynamics' Fort Worth division, for instance, has fluctuated between 35,000 workers at the height of the F-111 program and 6,000 workers before the F-16 program began to build up production.

4. Because of the nature of Air Force contracting procedures, major new capital equipment is rarely purchased by an airframe manufacturer outside the time when the company is tooling up for a major new program. Most companies monitor developments in tooling routinely, but the cost of shifting equipment in the middle of a program is generally prohibitive.

In 1969 and 1970, the Air Force Materials Laboratory began to call for proposals for new ways to automate assembly. The Sagamore and French Lick Conferences both emphasized the Air Force's interest in acquisition cost reduction, a shift from its traditional emphasis on manufacturing for "state of the art" performance. Programs that were seen as appropriate for Air Force funding would, according to regulations, have to be technically feasible as demonstrated in the company laboratory, generic (applicable to other Air Force programs with a clear indication of payback), and beyond the normal risk of industry. Programs should promise cost reduction, materials conservation, or shorter lead times.

An assumption behind the funding that was not necessarily reflected in specific contracts was that a technology would be reported in such a way that it could transfer readily. Anyone skilled in the art should be able to practice. Theoretically, only lead-time and experience would separate the originator from the adopters. Transfer was desirable to provide a second source for all forms of manufacture. Although spreading the new cost reduction concepts was recognized as valuable, the one sure evidence of successful payback for Air Force funding would be the physical replication of a system in another company's manufacturing facility. In most cases, then, the AFML considers a transfer successful if the embodiment as well as the concept is transferred.

Both Grumman and General Dynamics took up the AFML challenge to apply automation to drilling in the early 1970s. General Dynamics began to pursue the concept in conjunction with its F-16 program, for which the first prototype was produced in 1974. Grumman was not in the early stages of a major new program; its F-14 was already too advanced in 1974. Nevertheless it pursued the concept in anticipation of later programs. Both companies submitted contract proposals for their systems as part of the Air Force Manufacturing Methods Program in 1975.

The AFML Manufacturing Technology Group selected Grumman's approach to fund because it was judged technically superior. Assessors at the AFML did not believe that General Dynamics' tripod locating approach was technically feasible. Further, Grumman's proposal to include a scanning device as part of the system was attractive. Since Grumman did not itself have a major airplane program coming up to which the new system could be applied, the AFML suggested that Grumman should cooperate with General Dynamics and demonstrate its system on an F-16 part. Grumman thus became the originator of this automated wing drilling system and General Dynamics became, in the AFML's view, the designated adopter.

Grumman

Grumman Aerospace had roughly $1.2 billion in sales in the mid-1970s, of which all but $100 million was aerospace business. The company was attempting to diversify to lessen its dependence on the volatile defense industries by producing mass transit vehicles and by subcontracting for commercial aviation houses. Nevertheless it still relied on military business, mostly from the Navy. Because it had no prime contracts for major new weapons systems, Grumman was seeking major subcontracting business.

Grumman was non-unionized, and it tried to stabilize its work levels as much as possible to avoid laying off skilled workers and engineers. Any new process technologies that it might develop were regarded as potential sources of income and possible opportunities to gain significant subcontracts on a quid pro quo basis. Upper management made known its expectation that any other company that adopted Grumman's technology should be prepared to provide Grumman with a reasonable return on its investment in one form or another. Such a return should not only cover Grumman's development cost but also offset the potential cost and risk to Grumman in transferring its development. The additional costs of transfer included extraordinary amounts of documentation and potential legal liability.

Grumman's Advanced Development Group was located in a separate facility, Plant Twelve on Bethpage, Long Island. Its staff consisted of a core of 35 permanent employees and a number of others borrowed from the different divisions that the group served. Advanced Development had a standing mandate to find opportunities in high cost areas of production, to anticipate production processes needed for major new programs, and to formulate responses to critical material shortages if they arise. The automated wing drilling device was pursued not only because it was expected to offer savings in direct labor cost, throughput time, and fixture fabrication, but also because it would enable Grumman to drill wings with improved consistency. Grumman takes pride in its reputation for quality and consistency in its production processes. As a result the firm sought equipment designed for a high degree of accuracy. Grumman's stated objectives for the automated assembly wing drilling system were first to reduce production labor with a minimum of capital investment and, second, to improve hole quality.

Grumman demonstrated an early prototype version of its device to representatives from General Dynamics and Fairchild in 1975 before its contract with the AFML began in May 1975. The Grumman representatives indicated their intention to hold the capital equipment cost to $100,000. They also said that the company planned to charge a royalty as a licensing fee. A figure of five cents per hole was suggested.

Shortly after the demonstration, Grumman requested drawings of the F-16 wing from General Dynamics. It received a few documents in response, but the flow of information soon ceased. When it was clear to Grumman that General Dynamics did not intend to cooperate further, the Advanced Development Group shifted to demonstrating the wing drilling system on Grumman's own A-6 program. The results of their evaluation on the A-6 part (rated at about one shipset per month) showed savings of 40 percent with potential further improvement through the learning curve effect if a larger volume of components were drilled.

General Dynamics

General Dynamics was one of the largest defense contractors in the country in the mid-1970s. Its Fort Worth Division had produced bombers for the Air Force for a long time. The F-111 had been its first fighter program. The F-111 program had encountered such serious cost overruns that the Fort Worth division had mounted a thorough cost reduction effort in order to sell its F-16 program. The F-16 was designed to be smaller, lighter, and simpler than earlier fighter designs. Its low cost was partly responsible for its successful sales, said to be the largest single buy in history. At peak rate, production would reach 20 shipsets per month, an unusually high volume that required General Dynamics to rethink its approach to manufacturing in many areas.

One of the main ways General Dynamics chose to reduce cost was by reducing direct labor, which had the added advantage of moderating the workforce fluctuation that the Fort Worth Division had typically experienced from one airframe program to the next. As a result the General Dynamics Manufacturing Technology group was seeking to automate such labor-intensive operations as wing drilling.

General Dynamics had strained relations with Grumman in the early 1970s because of a bad experience with the F-111 program. In the early stages of the F-111 the two companies had been partners, with General Dynamics taking the design lead for the Air Force version, and Grumman the design lead for the Navy version. Then the Navy had pulled out of the F-111 program in favor of Grumman's F-14 which began in 1968-69, and relations between the two companies were damaged. When Grumman showed interest in subcontracting in the composite production area for the F-16, General Dynamics refused to do business.

General Dynamics' loss of the automated wing drilling contract to Grumman did nothing to improve its predisposition to cooperate on its further development, especially when Grumman indicated its intent to charge a royalty for use of its system in what General Dynamics interpreted as a violation of the spirit of Air Force sponsorship. Nevertheless, when Grumman demonstrated its system for the industry in 1976, General Dynamics evaluated the system for use on the F-16. General Dynamics had already abandoned its own former approach to automated wing drilling. Grumman continued to request a royalty for its proprietary interest in the system. The Air Force contract had funded the fixture and the software development, but it had not compensated the company for its prior investment. The AFML left negotiation of licensing arrangements strictly up to the parties involved unless and until an impasse was reached.

General Dynamics manufacturing technology personnel who went to investigate the Grumman system reported that the equipment had now been designed for the A-6 and would consequently require considerable adaptation for use on the F-16. The following problems were cited:

1) General Dynamics questioned the ruggedness (structural rigidity) of the Grumman prototype for use on the much higher volume F-16. The 60 pounds of force that the Grumman drill delivered was also lower than General Dynamics needed for its wing application.

2) Grumman had tried unsuccessfully to interest Cincinnati Milacron in building the machine, and General Dynamics was uncomfortable purchasing for use in production what amounted to nothing more than a set of drawings, because the system would still be only a prototype when they had replicated it in Fort Worth. Poor communications with Grumman only increased the anticipated difficulty of getting all the necessary information.

3) Because the F-16 had been designed to be easily manufactured, the Grumman system was designed to be more accurate than was necessary for the General Dynamics application. Taking into consideration the original cost of the equipment and the royalty Grumman was asking, the General Dynamics evaluation showed that the cost of adopting the Grumman system would be roughly comparable to the cost of designing and developing a wing drilling system using a robot. The General Dynamics organization had been looking for suitable robotics applications in which to gain experience, and the wing was such an application. A robot would be less accurate than the Grumman system but would have the advantages of lower capital cost and flexibility for use on other tasks.

Taking all these factors into account, General Dynamics rejected the Grumman system in favor of developing its own robot driller. Because the economic evaluation was indecisive, the risk caused by the poor relations between the two companies, as well as the existence of attractive alternatives, added up to non-adoption of the Grumman automated assembly fixture drilling system.

Fairchild (not interviewed)

When General Dynamics rejected the Grumman system in 1976, Fairchild, which was also in the early production stages of a new program, the A-10, agreed to cooperate in evaluating the Grumman system. Fairchild signed an agreement to lease the system and indicated its intention to adopt if the economics proved attractive. The AFML supported this further demonstration of the system with a new contract. Tooling had already been completed for the A-10 program, but it seemed possible that the savings from the Grumman system would be sufficient to justify the unusual step of changing in mid-program. Grumman was no longer demanding a royalty for use of its concepts; the AFML had involved itself in the discussions at the beginning of the cooperative demonstration program, and licensing terms agreeable to both parties had been stipulated in the demonstration contract. In early 1979 Fairchild rejected the Grumman system, saying that the savings that could be expected two years into the program were not sufficient to warrant changeover. Timing was clearly the decisive factor in the non-adoption since the AFML had funded the reduction of uncertainty.

McDonnell

McDonnell was approaching the $2 billion mark in revenues from military aircraft, mostly for Navy use, in the mid-1970s. It was known as a design house, dominated by engineering and highly conservative in manufacturing matters. No separate manufacturing technology group existed at McDonnell to anticipate future production processes. New equipment was adopted when it constituted a low-risk investment that promised to pay off in the short term. McDonnell paid attention to the reports issued by the AFML concerning new processes. It rarely competed for development contracts, however, in part because it lacked a separate manufacturing technology organization to focus on such matters.

The 1976 Grumman demonstration spurred McDonnell's manufacturing process engineers to pursue the automated wing drilling concept. Until the F-18 program, manual drilling had seemed the most economical approach for wings. But the F-18, McDonnell's first significant composite airplane, required more tooling than previous planes. Ordinary numerically controlled equipment would not be adequate for F-18 wings because the presence of seal grooves on their edges made the holes harder to locate through simple edge distance measurement. Grumman's scanning approach seemed to provide the solution to this unusual measurement problem.

After careful evaluation of the Grumman system for their F-18 application, the McDonnell process engineers chose to develop their own system. The Grumman equipment fell short of their needs in several ways. The F-18 wing was a heavier machining task than the A-10, requiring 80-250 pounds of force delivered instead of Grumman's 60. Moreover the complexity of the drilling task on the F-18's graphite and titanium skin was much greater than the aluminum drilling task on the A-6, requiring many more tool changes. Changing the Grumman tool took 10 to 15 minutes, which posed a serious obstacle to adoption.

McDonnell's device was to be heavier duty, rated for 12 shipsets per month. As of 1980, the McDonnell device has yet to be adopted in production, in part because McDonnell has yet to find a machine tool builder to build it. This is unusual because McDonnell, operator of the largest numerically controlled machine shop in the Free World, rarely has trouble gaining the attention of machine tool companies when it wants something.

Northrop

Northrop Aviation was one of the smaller military aircraft producers in the late 1970s. It was traditionally a Navy contractor, and in the late 1970s it was planning for its F-18 subcontract under McDonnell's prime contract. Northrop had a longstanding reputation as a low-cost producer characterized by innovative manufacturing. Lacking the organizational resources to do much research, it followed a policy of seeking innovative process equipment from a variety of sources and adapting it for use in airframe production. Upper management encouraged this receptivity by not insisting on strictly short-term paybacks.

Engineers in the manufacturing process organization at Northrop became aware of the Grumman device by reading the interim reports of the A-10 contract. The Grumman scanning approach was attractive to them for use on the vertical stabilizer. In 1978 they began a feasibility study on the Grumman system applied to the F-18 component, assuming a capital cost of $250,000 for the automated fixture drilling system. Since they were proposing to do 10 shipsets per month there were some doubts about the system's structural rigidity, but they estimated that it would not be too complicated to adapt to their purposes. They calculated expected savings of about 28 percent, yielding a modest but acceptable payback period of nearly four years. Towards the end of the feasibility study, however, Grumman raised the capital figure to $1.2 million. At that point Northrop rejected the Grumman system on financial grounds and turned to less expensive alternatives, such as a laser locater device with a calculated cost of $15,000. No alternative has yet been adopted because the F-18 stabilizer has undergone some design changes.

Automated Fixture Drilling Chronology

1969-73	Series of Air Force-sponsored acquisition cost reduction conferences.
1974	Automated fixture developed at Grumman and first production panels drilled a year later.
1975	Grumman demonstrates Automated Assembly Fixture Drilling to General Dynamics and Fairchild.
1976	Grumman performs the Air Force contract evaluating 5-axis operation on A-6 parts, using the fixture on the A-6 assembly line.
1976	Fairchild signs a lease agreement for the Grumman system; General Dynamics rejects the system and opts for its own robotics approach.
1977	AFML contract supports application of the Automated Fixture Drilling System to Fairchild's A-10 stabilizer.
1978-79	Discussions between Northrop and Grumman result in rejection by Northrop because of increased capital cost.
1979	Fairchild rejects the system and cites timing as sole reason for rejection.

Appendix C

Advanced Composite Tape-Laying Head

The Advanced Composite Tape Laying Head automates the highly labor-intensive job of laying up laminated composite parts. The tasks the tape-laying machine is designed to accomplish are part of the overall composites production process, which consists of tcol set-up, material orientation, material cutting, lay-up, cure, post-cure, and machining. The advanced tape-laying machine represents one set of concepts developed to achieve an automated approach to the process. The machine--of which the head is the most critical component--comprises a bed on which the part is laid up, a gantry to carry the head, and computer control mechanisms for the drive and the head. The head and its control determine the orientation of the fiber, the location of the ply and its termination, and the compaction of the entire laminate structure. The head consists of a tape roll supply system, a tape cutting system, a tape transport, tape laydown rollers, and compactors. All are controlled by a mini-computer.

The following conditions, technical and market, underlie this case of technology transfer.

Technical Conditions

1. General Dynamics holds several of the key patents for advanced composite tape laying.

2. Advanced composite materials are composed of either graphite or boron fibers in a resin base. They are unidirectional and must be laminated or woven to achieve the tremendous structural properties needed for airplane construction. When laid up and cured they have a strength-to-weight advantage of roughly 30 percent over aluminum. The unidirectional characteristic and the state before curing pose difficult handling problems in manufacture. For instance, the material comes on backing paper which protects its adhesive surface and allows it to be rolled, but the backing paper frequently gets out of alignment with the material itself. Furthermore, its perishability means it has to be dated and used in order of purchase.

3. Advanced composite materials have been changing rapidly since the early 1960s in format, cost, and composition. Accordingly, the processes to manufacture composite components have been highly unstable. Nevertheless there has been a great deal of pressure to stabilize production processes because composite materials offer immediate performance benefits in aircraft. The two driving forces

behind automation of composite manufacturing are labor cost and ease of handling, as larger and larger components are laid up. It is estimated that on the average lay-up costs account for 17 percent, and handling costs 47 percent, of total composite manufacturing cost.

4. Many types of composite material formats are available. The two principal categories are tape and broadgoods. Broadgoods can be unidirectional or woven. Tape comes in one-inch, three-inch, and six-inch widths, broadgoods in multiples of one inch. Adhesive systems differ from supplier to supplier and even from lot to lot. McDonnell's composite area, for example, deals with five different suppliers selling four different materials in 5-10 different formats with 8-10 different adhesive systems.

5. The cost of composite materials has decreased significantly since they were first introduced, but not as rapidly as was first predicted. In 1968 boron composites were $500/pound. In 1972 graphite had supplemented boron at $100/pound, and now graphite is $40/pound and boron is $200/pound. Broadgoods are sold at premium prices, currently about $70/pound.

6. Originally composites could be purchased only in the form of tape. Broadgoods became available in the early 1970s, which gave rise to competing design and manufacturing philosophies. Some organizations maintained their preferences for tape, and other chose broadgoods instead. Today there are three schools of composite manufacture--tape, represented by General Dynamics; broadgoods, represented by Northrop; and hybrid, represented by Grumman. The tape school claims it is the low-cost approach, emphasizing the low scrap and easy handling properties of its format. The broadgoods school maintains that its format is more flexible to design requirements, and the hybrid school sees its approach as the most versatile.

7. The chief concepts of the advanced composite tape laying technology are the computer-controlled handling, laying up, cutting, and compaction of composite tapes. The embodiment of these concepts can be performed with equal effectiveness using a variety of different combined techniques. Thus the real value lies in the concept of automating these steps.

Market Conditions

1. Until very recently advanced composites accounted for only a negligible part of every military airplane. The evolution of composites in McDonnell fighters illustrates the rate of growth in composite use. The McDonnell F-15 Eagle has a boron and graphite empennage accounting for two percent of the materials in the plane. The F-18A Hornet now in prototype contains 10 percent graphite composites of which 800 pounds are produced by McDonnell and 400 by Northrop. The VTOL Harrier, still in early preproduction phase,

contains 25 percent composite materials. Composites experts foresee that by 1990 there will be military planes they call "blackbirds," constructed of 55 to 60 percent composite materials. At the same time the size of components is increasing rapidly. The new Harrier design, for example, calls for 28-foot wing skins.

2. The first use of composites has been for airplane skins, but some companies are beginning to experiment with composite structural parts, as in the McDonnell Harrier. Designers disagree as to whether airplanes will incorporate significant structural use of composites in this century. The cost sensitivity in recent military acquisitions has led to a countervailing trend in which weight has been sacrificed for cost.

3. Three firms have staked out leadership positions in various aspects of the composites area. Two of these, General Dynamics and Grumman, have been leaders in composites manufacturing--General Dynamics for the fuselage and Grumman for the wing. McDonnell also claims leadership, but its leadership has to do with the intricacies of composite design and with the types of advanced composite structures its designers are incorporating into aircraft.

4. Adoption of composite equipment for limited production use is not quite as dependent on major program commitments as the adoption of other forms of automation has been in conventional assembly areas. Most airframe companies recognize a need to gain experience in automating this new technical area in advance of volume production. Visions of future composites factories differ according to the production philosophies of different companies. The chief philosophical split seems to center on the balance between design and manufacturing. McDonnell and Grumman, for instance, hold the philosophy that the highest priorities should be design enabling and airplane performance, while General Dynamics tends to emphasize manufacturing considerations.

5. The machine tool companies play a pivotal role in composite automation. They have been responsible for producing some of the key parts of equipment, in some cases transferring the technology from other industries such as adhesive tape producers and the garment industry. Since the materials suppliers made broadgoods available, a whole new set of equipment makers, previously focused on the garment industry, have entered the market. The result has been that the previous suppliers perceived smaller markets and became less willing to commit themselves to equipment design without charging custom prices.

The Air Force Materials Laboratory began to sponsor development of composite production technology in the mid-1960s when it funded General Dynamics to develop and improve its first composite tape-laying machine. In the late 1960s the Air Force Scottsdale Conference devoted a good deal of attention to composite automation. Both General Dynamics and Grumman announced that they expected high volume use of automated composite production in the next decade. General Dynamics projected a need for 15 tape laying machines for its F-16 program, and Grumman anticipated that 5 would be needed for its F-14 program.

After funding a second General Dynamics contract in the early 1970s, the AFML acknowledged the proliferation of composite manufacturing technologies by funding a group of four different integrated composite production system programs in 1976-79. These projects had two objectives: to find out where the costs were in composite manufacturing and to encourage complete automation of the entire labor-intensive process. The case described here is a program to improve still further the General Dynamics advanced composite tape laying head, one of the first projects funded under the AFML manufacturing technology group's composites production integration program.

General Dynamics

General Dynamics (see description in Appendix B) was a pioneer in automating composites production. It developed its first mechanized device for lay-up of advanced fiber composite tape in 1965, using corporate funding, and took out basic patents covering the technique. At that time composite materials were available only in tape form. General Dynamics was the first user of three-inch tape instead of the one-inch format previously available.

Having proved the feasibility of its tape-laying concepts, General Dynamics requested support from the AFML for a development program to build and demonstrate a full-scale tape-laying machine. The machine was designed and built by Conrac Corporation, a subcontractor to General Dynamics. The Conrac machine contained computer control, a head that moved along three axes, a six-inch guillotine shear, and a sprocketed tape guide system that used the tape backing paper to orient the tapes. The machine would lay a strip of tape no less than 9.75 inches long. It was a prototype, but one that proved sturdy enough for production use.

In 1972 General Dynamics, by this time well into the prototype phase of the F-16, secured another Air Force contract to develop a new tape laying head capable of positioning the tape without a sprocketed guidance system. The improved head went into production on F-16 prototypes in May 1974.

In the early 1970s materials suppliers began making broadgoods available. Many companies saw in broadgoods the possibility for greater design flexibility--albeit at greater cost--but General Dynamics maintained a steadfast commitment to tape on several grounds.

- Broadgoods cost more per pound.

- Tape was, by General Dynamics's estimate, the lowest cost approach by 10 percent. Since tape was laid up and cut to near final shape there was less scrap than with broadgoods.

- The extra handling problems caused by the material's limited shelf life and the varied mix of materials required a sophisticated storage, inventory control, and retrieval system.

- The tape could be inspected as it was laid down; broadgoods required more sophisticated inspection ahead of time or higher scrap parts later.

- Flexibility and intelligence could be incorporated in the machine, not in skilled workers.

- Still another important consideration was General Dynamics's organizational investment and proprietary position in tape equipment.

The composite production philosophy that emerged as General Dynamics defined its choices relative to those of other composite users emphasized three factors. First, it was of highest importance that each composite part be fabricated in the most cost-effective manner. Second, the investment should be made in sophisticated equipment rather than in materials handling and control systems. Third, General Dynamics would instruct its designers to design composite components that were manufactured using the tape-based process, even if that required them to limit their designs as to weight or performance to some degree. The embodiment of this philosophy was a system using ply-on-ply, near net shape laminates with automatic process control.

As the F-16 production program began in 1976, the Air Force funded General Dynamics to develop new manufacturing concepts for tape laying to overcome the drawbacks of its previous tape layers and provide for a fully automated composite production system. The chief objectives of the contract were to eliminate hand laying, cut any form or angle (which the guillotine shear would not do), and lay pieces shorter than the 9.75 inch minimum. While the program was underway the Conrac improved head was used in production for lay up of vertical stabilizers.

This program continued under changing leadership from 1976 until after the final report in March 1980. The head remains in the laboratory. Through it is said to work, General Dynamics has so far had difficulty getting a machine tool builder to build it at an acceptable price. Ingersoll-Rand has meanwhile built a non-prototype version of the Conrac which is being debugged for production. A new version of this equipment, capable of laying one-inch and six-inch tapes, is out for bid, but bids so far are more than twice the previous machine cost. To adopt the latest improved head supported by the AFML into production would require debugging it on the Conrac which, through nominally a prototype, has been the most reliable production equipment

General Dynamics has had. Even provisional adoption of the new head, therefore, will probably await the successful and reliable operation of the Ingersoll-Rand.

Grumman

Grumman (see description in Appendix B), like General Dynamics, had pursued mechanization followed by automation of composite production since the early days of composite materals availability. In the late 1960s it borrowed the Conrac machine for evaluation. It rejected the Conrac as too inaccurate in lay-up and cutting and purchased instead a Metro tape head. The Grumman lay-up approach differed from that of General Dynamics. While General Dynamics laid up its plies one over the other on a large template, Grumman inspected each ply separately and then fit each ply into a stepped frame. Grumman's plies had to have precision edges in order to fit whereas General Dynamics' could be near final shape and then trimmed after curing.

The Metro machine had been developed by the Metro Company for use at 3M. Grumman's Advanced Development Group modified the Metro machine for centerline tracking to eliminate the sprocket holes and four-inch paper. In 1969 it built its own mechanical Flintstone machine for the F-14 program. In anticipation of work on the unwieldy B-1 bomber structure, the horizontal stabilizer, it modified the Flintstone to handle larger F-14 mylars. From the beginning, then, two factors drove Grumman to pursue composite production technology. One was accurate lay-up leading to consistent, high quality production; the other was handling of large parts.

In the early 1970s Grumman saw broadgoods as an opportunity for increased design flexibility. Beginning to analyze the entire composite production process as a system, the Advanced Production Process Group began on its own to develop concepts for an integrated laminating center (ILC) in 1974-76. The reports of GD's improved tape head were available in 1974. Grumman compared the General Dynamics head with two other "class" machines designed to do similar tasks, the LTV head and the Boeing Vertol head. This time versatility was the decisive criterion because the LTV head could deal with shorter minimum lengths of tape. Grumman once again rejected the General Dynamics alternative in favor of the LTV head to incorporate into its planned laminating center. In 1977 Grumman received AFML funding for evaluation of and demonstration of ILC concepts as applied to the B-1 stabilizer. The ILC combined tape laying capability with broadgoods production capability in the same facility. It eventually installed a laser cutter to cut the broadgoods. It was rated to produce eight stabilizers per month.

While the previous case (Appendix B) shows that there were poor communications between Grumman and General Dynamics during the period in question, the decisive factor in Grumman's non-adoption of the

General Dynamics tape laying machine seems to have been the existence of alternatives that more closely matched Grumman's preferred manufacturing philosophy, which emphasized consistency, accuracy, and versatility for design performance over manufacturing cost effectiveness and volume production.

McDonnell

McDonnell Douglas (see description in Appendix B) pursued a leadership position of a different kind from Grumman and General Dynamics in the area of composite materials. Known as an engineering-dominated design house, McDonnell favored the production technology that was the most flexible from the design point of view. By the late 1960s it was clear that McDonnell designers would find many uses for composites in numerous configurations.

McDonnell began tracking tape-laying machines in 1969 when Boeing Vertol demonstrated its version of a tape layer using 2 1/2 inch fiberglass tape. After the Scottsdale Conference, where General Dynamics and Grumman projected big needs for tape-laying equipment on their next programs, McDonnell monitored the Air Force's sponsored developments of the Conrac used by General Dynamics. Its composite engineers made trips to Vertol and to LTV to see their versions. But all had unacceptable gaps and overlaps by McDonnell's standards.

In May 1972 the McDonnell manufacturing process engineers became aware of a new approach to composite production using broadgoods cut by a laser cutter. After evaluating this approach in comparison with the General Dynamics and LTV tape layers, McDonnell ordered a laser cutter in 1974. McDonnell's chief reasons for opting for the laser were its need for accuracy in cutting, laydown accuracy, and the ability to cut irregular shapes. The firm also wanted a throughput rate that none of the tape layers available offered, since it needed to cut single layers and often laid up 55 layer plies. It intended to keep single layer cutting to give maximum scope to designers. The raw material cost in broadgoods form, which it also calculated at a 10 percent total cost differential from tape, was a factor; but it seemed likely that McDonnell could eventually begin to make its own broadgoods in the 12-foot long bites that seemed optimum for the type of nesting McDonnell typically did.

McDonnell's immediate reason for non-adoption of the General Dynamics or other tape layers was its dissimilar manufacturing philosophy. In time, when high volume composites production becomes commonplace, McDonnell could well invest in some form of tape layer to fabricate small components, but for the present the main capital investment will continue to be in the broadgoods area.

Northrop

Northrop, McDonnell's partner in the F-18 program, came to composite production in the mid-1970s, later than the other companies. As a result, it was in a position to choose between tape and broadgoods. It has a low volume of composite components to make, and they are fairly small in size. Although it is known as a low-cost producer, Northrop also places a very high priority on flexibility and it judges broadgoods to be consistent with that philosophy. Consequently it has not pursued the idea of a tape layer. Like Grumman it has received AFML support for an integrated composites production facility, but its approach to the concept has been much different.

In 1976 Northrop gathered a group of people from several levels of management to visualize what a composites factory might look like in 1990. From that point its engineering department assembled a series of building blocks to achieve this objective gradually. Instead of the laser cutter which will cut only single plies, it has adopted the Gerber cutter which will handle multiple plies. It has added to that other equipment that has been used successfully outside the industry but has hitherto been unfamiliar in air frame manufacturing. In general the characteristic approach Northrop has taken to manufacturing innovation is to adopt feasible technology from any industry and adapt it for its purposes.

Northrop's reason for non-adoption of the General Dynamics equipment is the clearest example of a mismatch in manufacturing philosophies, to the point that Northrop did not consider the tape laying concept at all.

Composite Tape Laying Chronology

1965	General Dynamics begins mechanization of composite tape laying
1966-67	First AFML contract results in Conrac machine
1969	The AFML holds the Scottsdale conference and publicizes expectations for future automation in composites.
1970	Grumman builds Flintstone machine for F-14 program to handle larger F-14 mylars in anticipation of B-1 horizontal stabilizers.
Early 1970s	Composites become available in broadgoods form.
1972-73	General Dynamics has AFML contract to improve Conrac head.
1974	McDonnell commits to broadgoods and laser.
1975-76	Grumman develops Integrated Laminating Center (ILC) using LTV tape head concepts.
1976	The AFML sponsors General Dynamics in another tape laying head improvement, this time under heading of integrated composite production.
1977	Grumman gets contract from the AFML for application of ILC ideas to B-1 stabilizer and Northrop receives support for its IFAC (Integrated Fabrication for Advanced Composites).