INDUSTRIAL APPLICATION OF THREE-DIMENSIONAL ENGINEERING MODELS TO DEVELOPMENT OF PRODUCT DESIGN AND ITS RELATION TO INDUSTRIAL ARTS PROGRAMS

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CHAPTER I

INTRODUCTION

Model making is a very old art dating back to prehistoric times. Archaelogical findings have given evidence that these early forms of models consisted mainly of replicas of humans, animals, birds, and fish. Many of these were hand formed clay figures. The Egyptians as early as 4000 B.C. had intricate models of tomb scenes which were buried with their nobility. They are also given credit for building accurate models of their historic pyramids which date to about the same time (7, p. 283).

The use of a model as a tool of development did not evolve until the Phoenicians began experimenting with models for improving their ships, although the earlier forms of models were partially responsible for this. Where models were used to aid in developing ships, the art progressed rapidly. Models became vital instruments in progressive improvement of ocean-going vessels.

With the tide of industrial developments, models have come to play a necessary role in industry. The model has become an engineering tool. Scale models are used to study design problems and to engineer functions in the developmental process from initial concepts to final prototype. This involves diversified types of models. A wide range of skills and knowledge is necessary in the field of professional model making. Many types of three-dimensional models require a high degree of knowledge in tool and machine operation as well as craftsmanship to solve complicated mechanisms necessary to making the model function. Likewise, a degree of skill is necessary to fabricate the model from a set of working drawings.

Keen industrial competition has spurred the use of engineering models in developing a product because models provide an inexpensive means of studying the product. Depending upon the particular problem involved, the model can be scaled to the appropriate scale and made of easily worked materials, but still have the capacity of illustrating what the actual product would do or what it would look like. Tooling for mass production is expensive, so to assure production of a profitable, functional product, industry relies on an exhaustive development program through the use of scale models. To think of tooling from initial concepts and preliminary designs would be disastrous to industries involved in engineering a product. Therefore, a product is developed from the original idea to manufacturable product by means of models which are studied, analyzed, and in the process, subject to frequent changes.

Statement of the Problem

The problem encountered in this study was threefold:

1. To analyze the field of engineering models used in design studies and identify and define the way in which they are applied to product development.

2. To determine the degree and extent of skills and knowledge necessary for constructing engineering models.

3. To compare the skills and knowledge associated with model building to course content offered in industrial arts.

Basic Assumptions

This study has been made on the basis of the following assumptions:

1. It was assumed that industry will continue its accelerated pace of developing a product through engineering models and that future model uses will be more demanding in their requirements.

2. It was assumed that the knowledge and skills in the field of model construction are attainable by the industrial arts student but that the present industrial arts program could be improved by application of engineering models.

3. It was assumed that industrial arts has neglected this vital part of industry dealing with design and construction of models.

4. It was assumed that not all industrial arts graduates will go into teaching, but that industry will attract a substantial percentage of them.

Limitations of the Study

For the purpose of this study, the following limitations were necessary:

1. The study was limited to three-dimensional engineering models used directly or indirectly in design studies for product development.

2. Information and data obtained through the questionnaire were supplied from the Fort Worth Division of General Dynamics, Fort Worth, Texas.

3. No attempt was made to include all types of engineering models, but only models involving configuration

studies, design aids, mockups, and presentation and display models.

4. The study was further limited to engineering design models used in aircraft development, although the findings should be similar to design model use in other types of industries as well.

5. Comparison of the data obtained from the questionnaire was limited to course descriptions offered by the industrial arts or industrial education departments of five institutions in Texas.

6. Professional literature was reviewed dating back to 1960.

Definition of Terms

For the purpose of clarification of terms within this study, the following are thus defined:

Engineering Model is a three-dimensional object representing an idea, concept, or design which is used in an engineering function requiring a knowledgeable study. The term serves also to identify any model activity with a commercial objective and to distinguish it emphatically from the hobby model.

Design Aid is a type of engineering model used primarily to study the design of the object with regard to functionability, structure, tolerances, relationship, etc.

Presentation Model is an engineering model used primarily as a sales or promotional device and usually stressing keen aesthetics.

Mockup is a full size engineering model, usually made of soft materials such as wood, paper, and cardboard and used to study designs in actual size. Tolerances are not acute.

Prototype is a model representing final design of a product and consisting of actual materials and equipment which will be represented in the ultimate production of the product.

Preliminary Design is an accurate scale drawing of an initial idea or concept.

Set of Lines is a lines drawing of a designated scale which is used in construction of an engineering model of the idea represented by the drawing.

Product refers to an item usually involving a degree of complexity and a number of functional components which ultimately is to be manufactured to serve a designated purpose.

Product Development is the process of developing a product from initial idea to final manufacture and involving many functions, one of which is the application of engineering models.

Design Freeze is the state in which continued changes in design cease so that production may begin.

Need for the Study

Industries actively involved in engineering and development of complex products have for years relied on an extensive engineering model program to aid in the developmental process. In considering industrial arts objectives, the necessity for deriving instructional content from the many ramifications of industry is viewed as a prime objective in the program (1, p. 257). Yet, the application of engineering models in the industrial arts program is relatively non-existent and lies almost unnoticed. Therefore, this study was needed to bring to light this field so that its importance would be noticed and, hopefully, applied to the industrial arts program.

There was also a need to identify the skills and knowledge necessary in this field and through this identification to determine whether or not the present industrial arts program adequately prepared the individual for this type of industrial endeavor. By identifying and defining the many facets of the field of models and careful comparison to the subject matter offered by industrial arts, the extent of knowledge and skills available to the individual would be revealed. Thus, the strengths and weaknesses of the present industrial arts program, relative to the model field, would be viewed with recommendations made relative to the findings.

Lastly, there appeared to be a need to determine whether curriculum development in the field of model use and construction was worthwhile for the total objective of industrial arts.

With the extent of model application to product design so predominant in industry and the use, design, and construction of models relatively non-existent in industrial arts curriculum, the need for study concerning application of model building to the program of industrial arts was evident.

Recent and Related Studies

The search for recent and related studies proved of no success in directly related studies, but several studies indirectly related were located. In a study completed by

Groneman (2), entitled "A Critical Evaluation of the Development of Junior (Model) Aviation Instructional Programs for Schools, Recreational Centers and Model Educational Centers, and Model Enthusiasts," model airplane kits were studied for their value in teaching aviation. La Berge (3) did a study on the use of industrial arts departments of schools for building models during times of emergency, specifically during the period of World War II. In the study undertaken by Shaw (5), and that underway by Steele (6), mere mention was made of models as three-dimensional aids to visualization and understanding of design. Although none of these studies directly applied to this study, all were indicative of the importance of models in their respective uses.

Method of Procedure

Data were obtained from several sources. For the initial analysis of product development through models, the data were secured from current literature, books, journals, periodicals, and films which gave light on the subject. Interviews with design engineers and others considered authorities in the application and the construction of design models were considered necessary to supplement data gathered from literature. This information also helped identify the purposes of models and their application to design (4). A vital source was the American Engineering Model Society, because its direct association with this type of work and information. The data in the chapter concerned with the knowledge and skills required of the professional model builder were secured from a questionnaire which was designed to obtain this type of information. And, finally, data gathered from the previously mentioned questionnaire were compared to course descriptiond offered by the industrial arts departments of five institutions in Texas representing a general geographical spread of the state.

The procedure used for the collection of data was first to review the current literature, journals, periodicals, books, films, and information from professional societies to determine the method of applying engineering models to a development program and to define the area in general terms. Likewise, interviews with persons considered authorities served to promote further understanding of the field. Secondly, after studying, analyzing, and defining the field of model applications, the knowledge and skills for this type of operation were identified by means of a questionnaire with a selected sample of fifty. This questionnaire was submitted to professional model builders and design engineers familiar with the knowledge and skills associated with model making. Further data were obtained from interviews with personnel in supervisory capacities over professional model builders. Finally, the information gathered by the questionnaire was compared to information obtained from five institutions in Texas regarding course content and the subject matter covered by each school in industrial arts.

Data gathered for the initial part of the study were treated descriptively due to the nature of the problem. Careful consideration was given to the need for engineering models, how they were applied to design studies, the different types of models used and their purposes, and future model uses. The results of interviews with authoritative sources were incorporated into this part to substantiate statements made concerning various aspects of the field. Questionnaire data were treated descriptively in an attempt to establish precisely the nature of the skills, knowledge, and craftsmanship necessary for success in this field. The sample size of fifty appeared to insure reliable results. Finally, the comparison of this field with descriptions of courses offered in five industrial arts departments of institutions geographically spread throughout the State of Texas, was done in an effort to identify the background preparation by industrial arts.

Organization of the Study

Chapter I deals with the basic structure of this study, including an introduction, the statement of the problem, basic assumptions, limitations, definition of terms, need for the study, recent and related studies, method of procedure, and the organization.

Chapter II establishes a general background to the field of model making. Model uses are then discussed in an attempt to establish a foundation for their purposes and their essential role in industry. The application of models to actual product development is then dealt with in an attempt to show how a model plays the vital role of design development. Finally, in this chapter, future needs and uses of models are mentioned.

Chapter III is devoted to the analysis of the professional model maker in determining the skills, knowledge, and craftsmanship required of him for accomplishing his assigned task of building a three-dimensional model.

Chapter IV compares the findings of Chapter III to the course content offered by the industrial arts departments of five institutions in Texas in an attempt to determine whether industrial arts adequately prepared an individual for this type of work.

Chapter V presents the summary of the study, including findings, conclusions, and recommendations.

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CHAPTER II

MODEL TYPES AND THEIR APPLICATION TO PRODUCT DEVELOPMENT

Background

Models have been used since the very dawn of civilization as a means of portraying in three-dimension an idea or concept. In ancient history this type of object usually displayed a crude type of craftsmanship and in most cases was regarded as a form of art. Each progressive civilization is evaluated by its standards of development and the extent of its achievements. Many times these achievements were based on art and culture, while others on technological developments. Regardless of the basis, the dominant and greatest were those who were conquerors; be it of nations, of the mind, or of science and technology. Progressive developments usually resulted in the construction of monuments for which each culture is remembered. Yet, few realize that many of the magnificent wonders produced by many early civilizations were preceded by detailed construction of scale models (10, p. 283). The art of drawing was relatively non-existent, so a real need was necessary for building and designing of a model first. The design itself was done through models. Models also provided a means of visualizing what the final results would be like, a basis for planning construction of the structure and determining the materials, and a method to develop the structure which would easily adapt to modifications before actual construction. It would be unrealistic to think that the Egyptians, for example, would develop a monument as magnificent as the pyramids with all its detailed inner compartments by merely starting to pile on one stone after another. They were experts in the use of models (10, p. 289). The models they used assisted in studying the size, shape, and overall design, and ultimately were responsible for the final result.

Model use in the development of ships had most widespread use in early times. It is not known where or when the first boat was built. More than likely different men in different places discovered how to build a boat in their own way and there probably was no first edition (9, p. 17). It probably all began with man's realization that certain objects floated and larger floating objects could sustain him. A single log or a grouping of logs might have been the first means of water transportation. Throughout the world different types of boats began to develop as man progressed. As man ventured further with the development of his water transportation, the need to venture to sea became eminent. The Polynesians were probably the first to take extensive trips across open seas. They employed double canoes as they migrated from Southeast Asia across the equatorial Pacific (9, p. 19). Yet, these boats were not ships capable of carrying a regular economical cargo over seas. It was not until the development of ships to serve in this fashion became necessary that models began to serve an important function in their development.

The earliest known record of ships came from Egypt, a great, civilized nation and perfect place for waterborne commerce (9, p. 21). The art spread to the nearby isle of Crete,where Minoans became the first real seafarers taking voyages to many points around the Mediterranean. The Phoenicians were wider-ranging sailors since they had the materials with which to build and as early as 600 B.C. circumnavigated Africa from east to west. The Greeks, likewise, exploited the art of seafaring commerce with an extensive trade throughout the Mediterranean. But Rome alone, after a costly struggle in a battle with Carthage, learned the real value of ships. In a few decades they had changed a great sea into a Roman lake (9, p. 26).

Through the rise and decline of one civilization after another, the use of ships became more and more necessary. With the discovery of the new world by Columbus in 1492, a new need was realized for ships to be used for discovery and exploration of new lands. Naval power began to be a necessity to European countries and this called for careful validation of the ships' design and construction. Yankee clippers were produced for speed with deep and narrow lines giving a clean cut through the waters. These beauties slipped through calms and rode the wild winds under pyramiding clouds of sail (9, p. 193). The increased speed aided American merchantmen in snatching fat cargoes from under the nodding bows of the slower galleons. The "Golden Age of Sail", climaxed by the square-rigger, ended the fight for commercial sailing perfection. But not so the development of ships. This has continued on to the highly sophisticated and complex ships of the present.

As the progress of shipping and the needs of ships developed from century to century, the use of models to aid in their development became more acute. As complexity and requirements increased, the need for models became even more imminent. The importance for this type of tangible scaled representation of the idea was beginning to be realized as a definite asset to developing and analyzing the design. Britain, in the middle 17th century, was aware of the need for models and made use of their services. She was in a state of developing a strong naval fleet. Problems encountered were, for example, packing three decks of heavy guns into strengthened hulls of her warships. If they were placed too high, they made the ship top-heavy. If placed too low, seas rolled in the open gun ports. But with the judicious application of models, the problems were studied and analyzed to determine the best solution. Many of these models have been preserved in the museums of Great Britain (9, p. 121).

Likewise, the application of models served in a similar fashion to other countries in design and ship construction. Where applied, models accelerated and improved the design of ships. They provided a quick and inexpensive means of studying the problems in a realistic form.

Types of Models

In this study, three types of engineering models will be dealt with because these adequately fulfill the purpose of this particular research problem. Although engineering models could be classified into many categories, for this study only three types of design models within the engineering model group will be identified and discussed. It is believed that these very definitely indicate their value as design tools offering a necessary function to minimizing expenditures in engineering. The three classifications to be studied are (1) design aids, (2) mockups, and (3) display and presentation models, each representative of an important function to design development.

Design Aids

This type of model probably sees more use in engineering as a design tool than any other type. It is, in fact, its only purpose. Design aids are models which are not subject to rigid demands of finish or detail. Keen aesthetics are not necessary. They are not made for their attractiveness, but as three-dimensional aids to design validation. There usually is no extensive expenditure of time to obtain exacting tolerances. The scale employed in design aid models is usually full scale, although it may vary. Full scale may be used because of the actual interrelationship of the parts, but reduced or enlarged scale may be necessary. The object, for example, may be too small to be properly evaluated at actual size, or, it may be much too large to handle in model form. Henceforth, the need for scale. So, depending upon the specific problem, the scale of the design aid is determined so as to be most adequately, accurately, and economically evaluated.

Materials used for this type of model construction are usually paper, plastic, or wood. The ease of construction and hence, speed, are vital factors for a design aid to perform its function. For this reason, the use of soft materials which can indicate what the final product appearance would be, are used. Likewise, the need for constant changes in design and in the model itself demands the use of easily worked materials. To be adequate for use as a design tool and to aid in development of the design, the model must be constructed during and in conjunction with the design stages, or its value is lost (4, p. 102). Thus, in order for it to guide design, it must be made rapidly and with little loss of time. Speed is thus obtained through proper use of soft materials and since finish and detail are relatively insignificant for the purpose a design aid serves, little or no time is lost on that. The use of these materials also readily adapts itself to quick changes, a function as important as rapid initial construction of the model. Engineering calls for continual changes in design as a product is being developed and as it is related to other mechanisms or components (3). This is where the design aid model plays its important role in the engineering model groups. When three-dimensional results are viewed by design engineers immediately after design, validation of design is accelerated, thus allowing for more freedom of experimentation to seek better results (8, p. 80).

Mockups

In the engineering model group, mockups have come to serve a severely needed function. In the past, they served to show in actual size, the interrelationship of components, and a view of size, shape, and some detail. Final engineering drawings were given to mockup builders who constructed from these predetermined drawings. The mockup, then, followed design freeze, that is, after the design improvements were stopped. For this reason, it didn't serve of much value to engineering as a design tool, but was rather a general impression of what the prototype might look like. Changes, of course, were inevitable, and were later reflected in the actual prototype. The mockup itself was not a prototype, but a close resemblance. Mockups were made of widely used materials which were easily worked, while prototypes were indicative of actual hardware.

More recently mockups have come to serve as design aids as well as serving their basic function of full size representation used for testing new concepts of space requirements, control arrangements, and other use factors (7, p. 100). Presently, they are employed in an extensive way, particularly in aircraft development and component interrelationships within the course of aircraft development. Their use is much like that of a design aid, although additionally, they serve in promotional use and thus a high degree of polish accompanies the soft material model. Mockups still are constructed of widely available and easily worked materials such as wood, laminates, plastic, cloth, cardboard, or paper. Their purpose is to serve as a design tool in development of complex components. These are mocked up in a realistic manner, with care taken to obtain relatively close tolerances. Likewise, the demands of the customer have required an incorporation of aesthetic considerations into mockup programs (6). A good finish is applied, with much of the visible area of the mockup simulating actual hardware. For example, the use of hammertone paint on wood gives the illusion of metal to the observer. The ultimate result is to use widely available, inexpensive materials which can be easily worked and changed, yet adequately simulating what actual hardware would look like. The final results are quite pleasing and very realistic.

Mockups serve a definite purpose in engineering and are indicative of distinct advantages over a hard prototype. The mockup provides a means of coordinating the many areas while still in design stages (6). The complexity and extent of the many components demand a careful evaluation of the inter-relationship of each part before construction of hardware is begun. When parts are built for the prototype, changes following become costly because the time in fabrication of metal parts is longer, the material cost is usually higher, and the scheduling at that stage is usually at a state where time-consuming changes cannot be afforded. Changes in a metal prototype are usually quite difficult, too. Soft mockups offer distinctive advantages in ease of construction, faster fabrication, cheaper construction, and less rigid requirements for holding close tolerances (6).

The mockup actually serves a twofold purpose. First, as an aid in design development with necessary changes, which are inevitable in engineering, being easily performed with a minimum of time, thus less expenditure. Secondly, as a sales or promotional device so vital to contract awards.

In construction of current mockups, engineering designers work directly with mockup builders. Since changes are always occurring as design progresses, the direct relationship between these two is a definite asset, since changes may be put into work as they appear. Little time is lost between the drawing boards and the application of the change to the three-dimensional model. Time is also saved by relatively immediate validation of design by design engineers. Changes are made as they are needed.

Most working parts are made functional in mock stages. Seats are made to work and be adjustable, control mechanisms operative, and generally, all moving parts which would be of value to the purpose of the mockup and which would show, are made to work. This does not necessarily mean that they are of equal strength as or of like materials to their prototype. The materials used are evaluated by the individual doing the construction as to their value to the particular situation. If possible, the optimum situation would be to use materials which will simulate the end product, provide necessary strength, yet be easily worked to facilitate construction and economize on time.

Display and Presentation Models

Because of their similarity of construction, use in application to design studies, and because of the requirements of finish and overall detail, both display and presentation models are treated alike in this study.

Display and presentation models are of importance in the development of aircraft design because of the several functions they perform. The terms display and presentation immediately give the impression of sales, promotion, or public relations, and these are precisely what part of their function is. A necessary part of a firm's success depends on sales and the ability to promote its product. If sales are non-existent, then the organization cannot exist. Therefore, an excellent sales device promotes sales security, and insures survival of the organization.

Display and presentation models are engineering models which also serve as design aids, particularly in aircraft configuration studies. Design aids, as described previously, cannot perform the necessary functions needed in configuration analysis. Detail and fine finish are necessary to properly validate design results in these. These qualities can only be obtained by careful, tedious, time-consuming effort on the part of professional model builders. Materials used must be carefully evaluated with regard to their stability, strength, workability, and finishing quality. Precise care is taken to show detail and close tolerance. Final finish is carefully applied with consideration for longevity, durability, maintainability, and excellence in appearance.

The specific difference in display and presentation models is not so much in the nature of the model, but rather in its use or the manner of its application. Display models usually are used where they will be publicly visible. They may be used for program promotion, public relations, or community awareness programs. For these purposes, they demand a high degree of attractiveness and because of the excessive handling, substantial durability. Detail is usually necessary, too. Presentation models require much of the same qualities and usually more. They are used primarily in private sessions where design proposals are submitted to the customer in an effort to win contract awards. They may also serve where groups of engineers are gathered to study the model and the design of the product to determine the course the design is to follow. Often they serve as vital decision-making tools in guiding design (2). Because of the closeness of contact to which they are subjected, a high degree of accuracy, attractiveness, detail, durability and finish is demanded. Usually parts are simulated as realistically as possible, with a minimum of functioning parts, because they tend to be damaged due to the handling, the small scale making them delicate. This may not be true in all cases. There are many cases in which the actual product to be presented may be a complex mechanism which requires moving parts to explain and clarify its function (5, p. 45). The particular object requiring modeling, then, determines to what extent detail, scale, functional parts, and finish must be carried out.

The purposes that display and presentation models serve are the reasons for their extensive use and need. The fact that they are necessary to adequately sell a program cannot be overlooked. Their use as aids in configuration analysis performs an important function to total configuration design. The application of these in engineering is necessary to adequate program development and promotion. They may also serve as valid references to the builder of hard-material wind-tunnel models used for testing airflow patterns. Also, the use of these display and presentation models to familiarize personnel within the structural organization of a firm of the product with which they are directly or indirectly involved in producing, is a useful application of this model group. They, likewise, serve as useful tools in training or familiarization of new personnel, management trainees, or sales personnel (5, p. 42).

Model Application to Product Development

In model use for product design, the engineering model differs radically from the hobby model with respect to its application. The use of an engineering model for aid in developing a product is in direct contrast to the hobby model,which is only for looks or to be used as a toy. An engineering model serves as a design tool and as such, performs an important role in product development (4, p. 102).

The interrelationship of thousands of complex mechanisms into an end product which must be reliable and functional demands a professionalism in engineering. To start with a general concept of what the end result will be and develop a highly sophisticated system of inter-related functional mechanisms having a high degree of reliability is where the professionalism appears. The development and organization of these many complex components into the functional product is not an easy task. To design and develop an individual mechanism to perform a specific function is not always demanding in itself. Engineers may sit down and brood over the problem and develop a solution. The task may take considerable time or it may be relatively simple. When it comes to relating one component to another, both of which might perform an entirely different task yet both vitally necessary to the functional whole, the application of engineering models become especially useful and necessary (1). This use of models to develop a product of inter-related components and mechanisms is referred to as model application in product development.

As many problems in engineering differ, so the use of engineering models to develop and design these parts are varied. Oftentimes, though, a sad mistake is made through little or no use of models being applied to design. In such cases, design is done on paper and if volume representation is necessary, as is usually the case, it is done by illustrations. Isometric drawings are employed to illustrate three-dimension in these cases. Yet, few realize the additional cost of this approach. This type of illustration is very difficult, requiring many projections, and this is time-consuming and costly (4, p. 101). When a model is applied to such a problem, the advantages far outweigh the use of illustrative means. In such a case, the use of a model as a design tool would offer distinct man-hour economy because of the less time involved in producing the design aid model, the ease of design validation because of a tangible three-dimensional object, and because of the lack of time spent on finishing due to the small importance on aesthetic appearance at this stage in design. The function of such a model is to assist; guidance and control of design are much easier when a model is employed (4).

The costly mistake of engineering on paper alone should be cause of concern to those aware of it. The application of design aids is so simple, and yet, the results are so vital to economic product development. Oftentimes, when three-dimensional objects are omitted from product design, the resulting idea goes directly to construction of prototype hardware, in which case if changes are needed, the cost is excessive (8, p. 80) and very time-consuming. Much of this can be avoided if judicious use of models as design tools is incorporated throughout the development of design.

Engineering models serve in a special capacity when the design requirements call for interrelationship of complex components. When many mechanisms are involved, the use of drawings alone cannot adequately and economically fulfill the job. With the application of three-dimensional models, relationships and clearances may be validated realistically and the necessary changes carried back to the drawing boards. With the growing rate of system complexity, the probability of error slipping through design stages into prototype becomes more and more possible. Likewise, the way into which management breaks up design responsibilities into smaller subsystems has increased this risk (8, p. 80). But, with the proper application of engineering models, errors are virtually screened out. This is because the model serves as a tangible three-dimensional representation of the design and affords a realistic and valid reference readily adaptable to change.

Somewhere along the line of design development, there must be a point where design changes must cease in order that production may begin. This point in the design progress is referred to as design freeze. There is always a better way to make anything, but scheduling dictates a stopping point (2). At this point the line drawings of the product may be turned over to personnel responsible for building the product, relating it to other mechanisms, and ultimately, for fabricating a prototype. After design changes are stopped, parts constructed from line drawings no longer serve as design tools. If changes are necessary, they are expensive and costly in man-hours (4, p. 102). The use of models prior to the freezing of design is imperative to minimize this costly mistake. In this manner, the design may be properly validated prior to hardware construction and its ability to function properly in the space-relationships determined.

Design freeze does not necessarily imply that there will be no more changes. Change, in fact, is inevitable because without it there would be no improvement in the product. The optimum situation is to produce as good a design as can be achieved. In such a case the results will call for less changes in the future because of good engineering to begin with. The basis for good engineering is the application of design aids to provide sound design in the development period. The final result will be a product requiring few future improvements or modifications, yet costing a minimum in materials, time, and man-hours. If this is realized, effective and economical engineering has been the result.

In application of models to product design, the presentation and display models probably offer less adaptability to change than other types of models. The reason for this is primarily the cost of refinishing. Finish and detail are innate qualities of these models and changes call for a high degree of refinishing and intricate detail, which is costly. But changes are inevitable as in design aids and mockups and often must be handled by extensive re-work of the model with the necessary changes. Good appearance has its part in product development and through the use of presentation and display models, evaluation of appearance is more adequately performed than if a simple design aid were to be applied to the product. This type of model, then, is applicable to product development more in terms of aesthetic validation than the actual function or relationship of the product to other parts.

Design aids and mockups, on the other hand, concern themselves with design functionability, and, except for special cases, they would not concern themselves with aesthetics and keen appearance. The primary use of a design aid model in particular, in the application to product engineering, is for evaluation of its functional relationship to other parts. The ease and speed of construction at which this is carried out further indicates how well it will serve in this capacity. When speed is inherent and rapid validation is obtained, then the model serves as a guide to design. This, probably, is the most important function of any engineering model, for it is engineering in itself.

Future Needs in Models

With the trend of technological developments progressing to more sophistication and complexity, the need for a critical evaluation of management personnel toward product development is acute. Technology is advancing at a fantastic rate and in order to keep pace, three-dimensional aids in engineering are essential because of their attributes of accelerating and improving design. In order to be an asset they must, of course, be applied at the appropriate stages in design and of the appropriate types for the particular problem, in which case they become design tools.

The future holds new and different objectives for engineering model application, much of which cannot be predetermined from past experiences. There are, for example, newly emerging fields such as that of advanced composites which are rich in totally new concepts needing three-dimensional representations. Likewise, other fields, new in their endeavors or constantly seeking new techniques and methods, may have problems needing three-dimensional models to study, analyze, and evaluate design problems. Oftentimes, these may require an entirely new approach in model design and construction.

So, the field of engineering models is rich in potential and extensive in application. The accent of increased complexities only insures more use of models in the future in order to integrate the program (2). Model application will likely continue to be applied to product design to facilitate design development, to analyze the functionality of the product, and to accelerate the design process, in areas where they are presently used as well as in areas where they are non-existent.

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CHAPTER III

THE SKILLS AND KNOWLEDGE EXPECTED OF THE PROFESSIONAL MODEL BUILDER

Questionnaire Procedure

In this portion of the study a questionnaire was developed to determine the relative range of knowledge and areas of skill concentration of the individuals employed in construction of models used in design development. No attempt was made to cover fields of structural models, mathematical models, or test models, but instead these areas were avoided because of the limitation of the study to models used in the development of product design. Fifty questionnaires were distributed among model builders actively involved in construction of this type of model and engineers who applied these to their task of designing. Thirty-seven questionnaires were answered by model builders and thirteen by engineers. Since the number of professional model makers within the facility was limited, supplemental questionnaires were completed by design engineers. Specifically, design engineers were selected because of their extensive use of models in designing. Design engineers also work directly with the model builder during the construction phases of the model because of the usual changes in design which are noted as a result of the three-dimensional model, thus better design may be incorporated into the model. It was believed that because of this close contact with model builders, design engineers would be familiar with the degree of knowledge and skills associated with the model building art and that the comparison would present an analogy which might point out some interesting observation in itself.

Actual use of design engineers was limited. Supervisors were personally approached with the purposes of the study and the function of the questionnaire, but most, although willing to help, were skeptical because of the time loss involved. It was then agreed upon to take several design engineers out of each area within the design group to be representative of the entire group. The selection, for example, in preliminary design, consisted of two or three engineers from configuration design, armament, landing gear design, and structural design.

A similar situation arose when the supervision of various model building groups was approached with the questionnaire. Once again a thorough explanation of the purposes of the study and function of the questionnaire were covered. A personnel interview preceded the request for assistance from each individual in filling out a questionnaire. Supplemental verbal instructions were given each participant so he would be aware of the objectives of the study and the nature of the questionnaire. Since so much of the information was dependent upon the particular type of model being considered and the purposes it was to serve, each was instructed to answer as he was involved in dealing with models or model building and use. This was to include design aids, mockups, and display and presentation models as they applied to design development. By this means, it was believed that the answers would give an indication of each individual's area of concentration within the model making field. Comments following the completion of the questionnaires varified that the information given was entirely dependent upon the particular type of model being considered. For this reason, most of the findings are indicative primarily of design models in the aircraft industry.

Of those who completed the questionnaire, thirty-seven were professional model builders ranging in experience from twenty-six years to nine months. These were classified as supervisors, design engineers, engineering illustrators, and mockup builders. Of the thirteen not involved in construction of models, but rather their direct application, experience ranged from twenty-eight years to two years. Job classifications within this group were design engineers, design group engineers, project design engineers, and senior engineers. Of both groups, several overlapped from the use of models in design studies and model construction. Areas of overlap resulted primarily in the fields of aircraft crew station design. The individuals in this area were involved in both construction of models and evaluating their design. The models were made primarily of cardboard for quick construction and, consequently, rapid evaluation of the design. This was a process of designing in three-dimension by creating new concepts, determining functions, and detailing design of aircraft crew stations in model form from nothing but a creative imagination and a possible sketch. In later stages of the crew station design the process was reversed and models were made from drawings. This overlap applied almost exclusively to crew station preliminary design and not to other areas where design is not as complex and the evaluation of human factors so essential.

Questionnaire Results

The craftsman has been defined as, "...one who practices some trade or manual occupation, an artificer or artisan" (1). Relative to model building, this term appears applicable because of the manual effort and the skilled use of the hands model building involves. Craftsmanship was supported by the questionnaire. Since it was noted from observations that model building required some degree of craftsmanship on the part of the individuals constructing them, the degree of craftsmanship was sought. Craftsmanship was found to be of a high degree. That is, in general terms, the model building occupation requires the refined skills of a craftsman.

The art of model building almost always involves more than one material and often the application of many. This was indicated by all those questioned. Generally, in design models, the most widely used material is wood. This is easily obtained, worked, and reworked as needed, and readily finished. The type of model and the purposes it is to serve dictate the material used and the extent of its use. Wood most generally filled the need for this type of model construction.

Model construction involved a degree of judgement in consideration of the properties of the material selected to determine the best material for each given problem. Four basic properties were mentioned in the questionnaire. The most important, according to the results of the question, was the workability of the material, that is, how workable it is. Finishing characteristics of the material selected were considered as second in importance followed by strength and lastly, material hardness. It was evident from the results of this question that all properties were essential to the professional model builder in order that proper judgement be made in selection of the best materials to be applied for each particular model problem.

Likewise, an understanding of engineering drawing and its prinicples as well as competence in engineering drawing skills was necessary to the model builder. The questionnaire revealed that all respondents felt the necessity of a basic understanding of engineering drawing and the majority indicated the need for competence in drawing.

In order to determine the knowledge in areas relative to model building and the degree of improtance of each area, a list of areas definitely requiring knowledge for model making as well as areas with possible relation to the model making trade were incorporated into the questionnaire. Table I shows these areas and the percentages of responses indicating whether the area required extensive knowledge, moderate knowledge, or none at all relative to model building.

TABLE I

THE DEGREE OF KNOWLEDGE NEEDED BY THE PROFESSIONAL MODEL BUILDER AS REPORTED BY FIFTY RESPONDENTS

Area	Degree of Knowledge		
	High*	Moderate*	None*
Woodturning	64	32	4
Woodcarving	82	16	2
Patternmaking	40	60	0
Adhesives	36	64	0
Fasteners	62	36	2
Finishing	56	44	0
Cabinet making	8	76	16
Furniture making	4	76	20
Carpentry	14	42	44
Upholstery	38	28	34
Laminating	6	88	6
Lettering	10	84	6
Sketching	44	52	4
Machine drawing	44	52	4

*Numbers indicate percentages.

TABLE I--Continued

Area	Degree of Knowledge		
	High*	Moderate*	None*
Design	48	50	2
Blueprint reading	56	44	0
Architectural drawing	40	46	14
Engineering drawing	82	18	0
Electrical drawing	2	72	26
Structural drawing	6	90	4
Sheet metal	6	90	4
Machining	10	88	2
Etching	2	24	74
Heat treating	0	34	66
Foundry	2	74	24
Welding	4	86	10
Brazing	4	88	8
Soldering	6	92	2
Plating	0	22	78
Metal spinning	0	20	80
Silk screening	8	50	42
Photography	2	52	46
Sheet plastics	76	44	0
Liquid plastics	80	20	0
Vacuum forming	78	22	0
Injection molding	66	82	12
Casting	14	84	2
Hand tools	94	6	0
Portable power hand tools	88	12	0
Abrasives	78	18	4
Maintenance	70	26	4
Safety	88	10	2

*Numbers indicate percentages.

The importance of thorough knowledge was noted by the majority in the areas of woodturning, woodcarving, fasteners, finishing, blueprint reading, engineering drawing, sheet plastics, liquid plastics, vacuum forming, hand tools, portable power hand tools, abrasives, maintenance and safety. Knowledge of a lesser degree of importance was indicated by the majority in the areas of patternmaking, adhesives, cabinet and furniture making, laminating, lettering, sketching, machine drawing, design, electrical drawing, structural drawing, sheet metal, machining, foundry, welding, brazing, soldering, photography, injection molding, and casting. In the areas of etching, heating-treating, forging, plating and metal spinning, the respondents indicated in a majority that no knowledge in these areas was necessary for the professional model builder. It was evident from the large number of positive responses to most of the areas mentioned that the knowledge needed by the professional model builder was quite varied and widespread.

Essential skills were determined in much the same manner as knowledge. Areas in which it appeared that definite skills were needed to perform the task of model building as well as areas where possible skills might be needed were listed. Table II shows in percentages the opinions expressed by the respondents relative to the extent of skill needed in each area for model making. Some areas listed in Table I were omitted in Table II because it was believed that a knowledge might be beneficial but skill in the area irrelevant. Forging was an example.

TABLE II

THE DEGREE OF SKILL NEEDED BY THE PROFESSIONAL MODEL BUILDER AS REPORTED BY FIFTY RESPONDENTS

Area	Degree of Skill		
	High*	Moderate*	None*
Woodturning	80	20	0
Woodcarving	88	12	0
Patternmaking	80	20	0
Fastening	36	60	4
Finishing	96	4	0
Cabinet making	6	82	12
Upholstery	0	84	16
Carpentry	12	80	8
Lettering	8	86	6
Sketching	14	84	2
Designing	18	82	0
Engineering drawing	72	26	0
Blueprint reading	86	14	0
Sheetmetal working	8	88	4
Welding	2	80	18
Brazing	10	80	10
Soldering	10	90	0
Machining	10	86	4
Milling	6	78	16
Foundry	0	80	20
Architectural drawing	4	82	14
Graphic illustrating	10	84	6
Structural drawing	0	94	6
Heat-treating	0	42	58
Silk screening	14	42	44
Photography	2	52	46
Vacuum forming	16	80	4
Mold making	26	74	0
Casting	20	80	0

*Numbers indicate percentages.

The figures showed that the majority felt that a high degree of skill was necessary in the areas of woodturning, woodcarving, patternmaking, finishing, engineering drawing, and blueprint reading. Moderate skills were necessary in the areas of fastening, cabinet making, upholstery, furniture making, carpentry, lettering, sketching, designing, sheetmetal working, welding, brazing, soldering, machining, milling, foundry, architectural drawing, graphic illustrating, structural drawing, silk screening, photography, vacuum forming, mold making, and casting. Data showed that no skill was necessary in heat-treating. In most areas the figures presented in this table showed that the large majority rated the area specifically as either high, moderate, or none. But in some areas there was diversification of opinions as to whether the area was high-to-moderate, moderate-to-none, or as in the case of silk screening, a full range of answers from high to none. In this instance it was noted that the majority lay between the moderate skills and none at all, but that 14 per cent felt it as a skill needing a high degree of refinement, so it was treated as a moderate skill.

Along with the array of knowledge and skill areas, it was deemed important to determine the relative knowledge and skill needed by the professional model builder in the operation and use of machine tools. Table III shows in percentages the respondents' opinions regarding the knowledge, then skill, in the operation and use of seventeen common machine tools.

TABLE III

THE KNOWLEDGE AND SKILL NEEDED BY THE MODEL BUILDER IN THE OPERATION AND USE OF MACHINE TOOLS AS REPORTED BY FIFTY RESPONDENTS

Machine Tool	Knowledge*	Skill*
Bandsaw	98	96
Jigsaw	96	94
Table saw	96	94
Radial-arm saw	74	72
Mortiser	18	12
Shaper	84	70
Jointer	82	74
Planer	90	82
Sander	98	96
Drill press	98	94
Wood lathe	96	96
Metal lathe	92	96
Metal shaper	20	2
Metal planer	16	4
Grinder	94	84
Metal cut-off saw	22	12
Mill	42	10

*Number indicate percentages.

Data from this table showed that most woodworking machines received a majority of responses indicating the need for knowledge and skill in the use of these. The exception was the mortiser. Only 18 per cent of the respondents felt a need for knowledge about this machine and only 12 per cent the need for skill in its operation and use. Of metalworking machines only two were of significance to the model builder, in the opinions of the respondents. These were the metal lathe and the grinder. Of the other metalworking machines, both skill and knowledge were considered essential by only a small percentage of the respondents.

In an effort to determine the extent of the knowledge and skill needed by the professional model builder in the operation of portable power hand tools, a list of some of the common power hand tools was included in the questionnaire. Table IV shows the positive results of the respondents opinions concerning each tool.

TABLE IV

THE KNOWLEDGE AND SKILL NEEDED BY THE MODEL BUILDER IN THE OPERATION AND USE OF PORTABLE POWER HAND TOOLS

Tool	Per Cent of Respondents
Drill	98
Saw	94
Sabre saw	68
Disc sander	94
Dremel	90
Belt sander	96
Router	86
Orbital sander	72

The results showed that in the majority of the respondents opinions, knowledge and skill in the operation and use of all of the portable hand tools listed were necessary to the model builder.

Knowledge and skill of hand tools needed in model making were determined by listing an array of common and specialty hand tools in the questionnaire. Table V shows this list of tools and the number of responses indicating a need of each particular tool as well as the per cent of the total the responses represent.

TABLE V

THE SKILLS AND KNOWLEDGE OF HAND TOOLS NEEDED BY THE PROFESSIONAL MODEL BUILDER

Hand Tools	Number of Respondents	Per Cent of Respondents
Hand saw	48	96
Combination square	48	96
Center head	41	82
Scribe	48	96
Center punch	46	92
Awl	39	78
Woodcarving chisels	48	96
Mat knife	48	96
X-acto knife	49	98
Scissors	45	90
Clamps	47	94

TABLE V--Continued

Hand Tools	Number of Respondents	Per Cent of Respondents
Tweezers	44	88
Pliers	46	92
Wire cutter	45	90
Wrenches	43	86
Marking gauge	47	94
Syringe	39	78
Coping saw	42	84
Scale	48	96
Woodturning chisels	48	96
Nail set	42	84
Hammer	48	96
Brace and bit	40	80
Dividers	44	88
Inside calipers	43	86
Outside calipers	48	96
Micrometer	44	88
Gauge blocks	35	70
Plane	44	88
Spoke shave	44	88
File	48	96
Mitre-box saw	11	22
Sharpening stone	48	96
Level	40	80
Pallet knife	43	86
Scrapers	40	80
Glass cutter	36	72
Screwdriver	47	94
Mallet	46	92

The results showed that all the hand tools listed, with the exception of the mitre-box saw, were necessary to model building, in the opinion of the majority of the respondents. In essence then, the model maker must be equipped with a wide range of knowledge of hand tools and possess the ability to skillfully manipulate them.

The areas of maintenance of tools and equipment, along with safety in the operation or manipulation of them, were proposed in the questionnaire in order to resolve if these were areas of importance to the model builder. The results of both of the questions revealed the majority were strongly in favor of both safety as a factor of importance as well as proper knowledge and skill in the maintenance of tools and equipment.

In order to obtain information on the feeling of individuals questioned about the overall background of a prospective model builder, the question was asked whether they would select an individual for a model building postion with a theoretical background, a practical experience background, or some theory and practical experience in their background. Of those questioned, 60 per cent indicated a background of theory and practical experience and 40 per cent strictly practical. Of those indicating strictly practical backgrounds, it was noted that all were mockup builders, with exception of two design engineers. This could support the belief of some that for mockup alone, a practical background would be sufficient. But, when modeling becomes an integrel phase of engineering design studies, theory is needed in conjunction with practical experience. The task becomes more than mere manipulative skills but rather a task of understanding problems associated with the particular design. Changes are not always needed, but when complex shapes are incorporated into design, it often is easier to design with the model rather than on paper. In such cases, the model builder needs familiarization with the design functions and purposes. This often demands a relatively deep knowledge in many phases of engineering itself.

As a final question in the questionnaire, comments were requested concerning knowledge and skills not previously dealt with in the questionnaire but which may be necessary to successful model making. Some interesting observations and comments were brought out.

The application of knowledge and skill of tools and materials in combination with requirements the particular problem had to illustrate was one of the observations. To possess knowledge and skills, yet being unable to apply them to the problem makes the knowledge and skills of little usefulness.

Others observed that proper mental attitude was desirous. The job could be very tedious and intricate at times and added to that, changes seemed to occur in the most inopportune times. This could result in continual frustration if the proper mental attitude was not retained. Changes would occur continually, in most cases, for that was the necessary function of models.

Along with the proper mental attitude, ability to visualize what the end product would look like was necessary. Many times this was difficult, but often as the model progressed, it aided because three-dimensional visualization became a reality. Thus the three-dimensional model actually helped the model builder in the fabrication phases as well as the design engineer in studying the design.

Speed was indicated by some as a necessary function not mentioned by the questionnaire. This was especially true in design models because of the need to have relatively immediate design validation. Without speed in model construction, design could not proceed effectively. Often decisions concerning the direction design was to follow were determined by the model. For this reason, skill in producing such a model in the fastest means possible was vital to the professional model builder.

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CHAPTER IV

EXPERIENCES IN INDUSTRIAL ARTS COURSE WORK AVAILABLE IN AREAS RELATING TO MODEL BUILDING

In the previous chapter a questionnaire was used to gather data and information concerning model building in an attempt to identify and define the knowledge and skills associated to this field. Data showed that the knowledge and skill areas of model building were widespread and that the background or preparation for this field required training in both theory and practical experience. It was noted, too, that many of the skills were refined to a point of a high degree of craftsmanship with experience, but that basic knowledge and skills of a widespread field of industrial processes, applications, tools, and materials were needed.

In Chapter I, two of the basic assumptions made in this study stated that "...the knowledge and skills in the field of model construction are attainable by the industrial arts student..." and that "...industry will attract a substantial percentage of them." Because of these assumptions, this portion of the study dealt with a view of what five institutions in Texas offered in the way of instruction in areas relative to model making. By this means data would show whether the industrial arts curricula provided sufficient knowledge and practical experience for graduates to be employed in positions involved in fabrication of engineering models following graduation.

This was done by separating all institutions in the state of Texas having industrial arts or industrial education departments and selecting of these five. The geographical location was considered as one of the requirement in the selection. The number of courses offered as well as the diversification of these courses were also considered in selecting the five schools from which data would be treated. Of the institutions considered, the five selected were North Texas State University, East Texas State University, Texas A&M University, Southwest Texas State College, and Abilene Christian College. These institutions had fairly large industrial arts or industrial education departments with rather diversified course offerings and each provided in their general bulletin fairly descriptive accounts of the courses offered.

Following the selection of institutions, a list was drawn up of areas in which data from the questionnaire revealed that skills and knowledge were essential to the professional model building trade. The process then involved taking each area found necessary to model building and analyzing each institution's course descriptions offered by the industrial arts or industrial education departments of the respective institution to determine whether or not experiences were offered in the particular areas. Table VI shows the results obtained from the analysis.

TABLE VI

KNOWLEDGE AND SKILL AREAS FOUND NECESSARY TO THE PROFESSIONAL MODEL BUILDER IN WHICH EXPERIENCE MAY BE AVAILABLE AT THE INSTITUTIONS LISTED

Knowledge and Skill Areas Found Essential to Model Building	Institutions Providing Experience *					
	NTSU	ETSU	T A&M	STSC	ACC	Total
Woods	X	X	X	X	X	5
Woodturning	X	X	X	X	X	5
Woodcarving	. .	. .	. .	. .	. .	0
Laminating	X	X	. .	. .	. .	2
Patternmaking	X	. .	X	. .	. .	2
Adhesives	X	X	X	X	X	5
Abrasives	X	X	X	X	X	5
Fasteners	X	X	X	X	X	5

*Source: Bulletins of the institutions.

TABLE VI--Continued

Knowledge and Skill Areas Found Essential to Model Building	Institutions Providing Experience*					
	NTSU	ETSU	T A&M	STSC	ACC	Total
Welding	X	X	X	X	X	5
Brazing	X	. .	. .	X	. .	2
Soldering	. .	. .	X	. .	. .	1
Foundry	X	X	X	X	X	5
Machining	X	X	X	X	X	5
Milling	X	X	X	X	X	5
Casting	X	X	X	X	X	5
Plastics	X	X	X	X	X	5
Sheet plastics	X	. .	X	. .	. .	2
Liquid plastics	X	X	X	. .	. .	3
Vacuum forming	X	. .	X	. .	. .	2
Injection molding	X	. .	X	. .	. .	2
Mold making	X	. .	X	. .	. .	2
Photography	. .	. .	. .	. .	X	1
Maintenance	X	X	X	X	X	5
Safety	X	X	X	X	X	5
Silk screening	X	. .	. .	X	X	3

*Source: Bulletins of the institutions.

TABLE VI--Continued

Knowledge and Skill Areas Found Essential to Model Building	Institutions Providing Experience*					
	NTSU	ESTU	T A&M	STSC	ACC	Total
Finishing	X	X	X	X	X	5
Cabinet making	X	. .	X	X	X	4
Furniture making	X	. .	X	X	X	4
Carpentry	. .	X	X	X	X	4
Upholstery	X	X	X	X	X	5
Drawing	X	X	X	X	X	5
Engineering drawing	X	X	X	X	X	5
Architectural drawing	X	X	X	X	X	5
Electrical drawing	X	X	X	X	. .	4
Structural drawing	X	. .	X	X	X	4
Machine drawing	X	X	X	X	X	5
Sketching	X	X	X	X	X	5
Lettering	X	X	X	X	X	5
Blueprint reading	X	X	X	. .	. .	3
Design	X	X	X	X	X	5
Graphic illustrating	X	X	. .	X	. .	3
Metals	X	X	X	X	X	5

*Source: Bulletins of the institutions.

TABLE VI--Continued

Knowledge and Skill Areas Found Essential to Model Building	Institutions Providing Experience *					
	NTSU	ETSU	T A&M	STSC	ACC	Total
Stationary wood equipment	X	X	X	X	X	5
Stationary metal equipment	X	X	X	X	X	5
Portable power hand tools	X	X	X	X	X	5
Hand tools	X	X	X	X	X	5
Totals	42	33	40	36	32	. .

*Source: Bulletins of the institutions.

Resulting from the analysis of this table, data showed that of the areas found necessary to model building in the previous chapter, most were provided for by each of the industrial arts departments studied. Of the forty-six areas in which skills and knowledge believed to be essential to the model builder, North Texas State University (3) provided experiences in the largest number of areas, totaling forty-two. Texas A&M University (5) indicated forty areas of instruction relative to the model building areas. The other institution's course descriptions appeared to show availability of instructional experiences in the majority of areas, with Southwest Texas State College (4) having thirty-six, East Texas State University (2) offering thirty-three, and Abilene Christian College (1) providing for thirty-two. From these figures it is evident that each of the institutions offered experiences in at least some form in the majority of the areas found necessary to model building.

Several areas had contrasting emphasis, though. Plastics were probably the more predominant. Data from the previous chapter indicated a wide range of knowledge and skills needed in plastics. Emphasis was indicated in vacuum forming, mold making, casting, and liquid and sheet plastics. This was noted as an area of particular importance to the model builder. A similar importance was not noted by the over-all course descriptions offered by the industrial arts departments of the institutions reviewed in this phase of the study. Only North Texas State University (3) and Texas A&M University (5) had courses devoted to the field of plastics and in which appropriate experiences compatible to the modeler's needs might be provided for. But of the other institutions studied, mere mention was made of plastics, generally in the crafts courses of the respective institutions.

There were other areas shown in the table in which less emphasis appeared to be placed by industrial arts as noted by the course descriptions reviewed. These included silk screening, photography, slodering, brazing, graphic illustrating, blueprint reading, patternmaking, laminating, and woodcarving. Of these, only patternmaking and woodcarving need to be noted because these two areas were found to be particularly important skill and knowledge areas to the model builder. This was contrasted to indications from the course offerings of the institutions reviewed. Of these institutions only North Texas State University (3) and Texas A&M University (5) mentioned patternmaking in their course descriptions. None of the institutions studied listed woodcarving in their course offerings. These general deficiencies were in contrast to the apparent needs of the model builder. Data in Chapter III showed that these two areas were areas in which essential skills and knowledge of a high degree or extent of refinement were needed.

In general, though, of the five institutions from which data were obtained, all provided experiences in the majority of the areas found necessary to model building. Some areas appeared to have a lesser degree of emphasis but most seemed adequately provided for.

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CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

From the very earliest civilizations, three-dimensional replicas have been evidenced. In fact, much of the early way of life of these prehistoric civilizations can only be traced by the models they left. The Egyptians especially, left vivid and extensive carvings on stone tablets along with perfectly preserved models buried with their nobility which give clear indications of what their life was like as far back as 4000 B.C. They were also experts in using models for designing and building their monumental wonders, particularly the pyramids.

Models did not serve as design tools until their use was applied to the development and improvement of ships. Where models were applied to ship design and design problems associated with ship building, the process was accelerated and development improved to a large extent. Through the centuries the application of models to ship building was particularly emphasized because of the importance of this type of transportation and the continual need of improving it. The use of models offered the necessary instrument for analysis of design and consequently, a vital tool for improving design.

The intial part of this study concerned itself with the study of industry's application of three specific types of engineering models to design development, particularly in the aircraft industry. These included design aids, mockups, and display and presentation models. Each was described and its function discussed. The application and use of each type was covered in an attempt to define the purpose they serve.

Secondly, the study presented and treated data gathered through the use of a questionnaire to determine the knowledge and skills in the model building field. The questions were presented in an effort to cover as wide a range of experiences and knowledge definitely or possibly associated to the field of model building.

Finally, the study presented data that indicated that many of the skills and knowledge believed to be essential to the model building field can be acquired through courses available in industrial arts departments at five institutions in Texas.

Findings

As a result of this study, the findings are presented as follows:

1. It was found that a design aid model is particularly useful to an engineer as a design tool because of the time required for initial construction of the model as well as the ease of making changes. These factors are both vital to product design because they allow for almost immediate validation of the design, thus providing tools to influence and guide design.

2. Mockups serve a necessary function particularly in aircraft development where there is an interrelation of thousands of complex, yet functional components. The mockup serves much as a design aid in illustrating in full size and three-dimensionally the space requirements, control arrangements, and limited functional parts. Its purpose is to illustrate and co-ordinate the many subsystems and divisions while design is still in the development process. This calls for a model made of widely available materials which can be easily worked and adaptable to rapid changes. The mockup offers a definite advantage over the prototype during design stages because of the lower cost of construction, faster fabrication, and less ridgid tolerances. This results in an over-all savings in both time and costs.

3. It was found that display and presentation models are necessary to design studies, especially in evaluation of aesthetics. Because of the nature of their use, they demand careful and tedious work on the part of the model builder in obtaining detail, close tolerances, and excellent finish. They also serve as design aids when used in aircraft configuration analysis. Further, they are used as promotional devices for public relations, community awareness programs, and as vital sales tools.

4. It was found that the use of models in design studies is necessary to economical product development, especially when the product involves complexity, many mechanisms, and the need for keen aesthetics.

5. It was found that a relatively high degree of craftmanship is essential in model building.

6. It was found that two or more materials are usually applied in model making, the most widely used being wood.

7. It was found that knowledge of engineering drawing principles and competence in engineering drawing skills are essential to the professional model maker.

8. It was found that an extensive knowledge of many phases of industry itself is needed.

9. It was found that a wide range of knowledge of machine tools is needed by the model builder, as is skill in their operation.

10. It was found that a degree of skill and knowledge in the operation and use of all major portable power hand tools is necessary to the professional model builder.

11. It was found that a thorough knowledge of many hand tools, both common and specialty, is essential in model making, as is the skill in manipulating them.

12. It was found that both maintenance and safety are areas of needed knowledge and skill in model building.

13. It was found that the general background training needed for employment in the construction of design study models involves one of both practical and theoretical training.

14. It was found that industrial arts offers a basic educational background which is believed to be applicable to what is needed for the field of model building.

15. It was found that industrial arts course experiences appeared to parallel the skill and knowledge areas found necessary to the model builder with exception of the areas of plastics, patternmaking, and woodcarving.

16. It was found that the use of engineering models, similar to those used in design and development of complex

products, is not applied in a like manner in project design in industrial arts programs.

Conclusions

Based upon the findings of this study, the following conclusions were presented:

1. It was concluded that models offer definite advantages in development and design of a product.

2. It was concluded that the interplay between three-dimensional models and product design is vital to effective development of complex mechanisms.

3. It was concluded that the field of model design and construction is rich in potential and virtually unlimited in possibilities due to the increased amounts, the added diversification, and the complexity of new products.

4. It was concluded that the field of model building is a professional trade, demanding in the knowledge and skills necessary of a craftsman.

5. It was concluded that industrial arts adequately provides an educational background compatible to that needed by model building.

6. It was concluded that industrial arts lacks this phase of industry in its curriculum.

Recommendations

From the results of the findings and conclusions of this study, several recommendations are presented. They are as follows:

1. It is recommended that engineering models continue to be applied to design of products and more extensive use made, especially when the end product is complex and where there must be interrelationship of mechanisms.

2. It is recommended that industries involved in the development of complex products evaluate current applications and incorporate models in all phases of design.

3. It is recommended that industries seek potential model builders from industrial arts graduates.

4. It is recommended that industrial arts departments evaluate their programs with regard to incorporation of engineering models into the curriculum.

5. It is recommended that further research be conducted to define and determine the nature of other types of models in the field of engineering models.

APPENDIX A

INTERVIEW QUESTIONNAIRE

DATE ______________________________

NAME ____

POSITION OR TITLE ____

YEARS EXPERIENCE ______________

To what extent do you use models in your job? If you don't presently, would their use be of any value to you?

Is three-dimensional visualization acute and necessary in product development? Explain.

INTERVIEW QUESTIONNAIRE --Continued

Are models an asset to engineering and if so, in what sense?

Should models be applied concurrent with design or should they follow-up design?

Do models afford a necessary function as design tools if used at the appropriate time in the design sequence?

INTERVIEW QUESTIONNAIRE --Continued

Is the application of a three-dimensional design aid to product development an asset to the design validation by accelerating the process?

Is speed in construction of a design aid critical in order for it to be an effective tool of design?

In what way do mockups serve an engineering purpose and what is their advantage over a hard prototype?

INTERVIEW QUESTIONNAIRE --Continued

What was the use of mockups in the past as compared to the present uses?

What of changes in design and their relation to a mockup?

What purposes does a presentation model serve? Is it necessary in aircraft development?

INTERVIEW QUESTIONNAIRE --Continued

What are necessary elements of presentation models with regard to detail, finish and functionability?

What advantages can be realized when models are used in design analysis rather than isometric illustrations?

Could a product as complexed as an airplane be realized without the use of models in any form (excluding prototype)?

INTERVIEW QUESTIONNAIRE --Continued

Should model building be an integral part of engineering? If so, is there room for expansion of these services in this facility or is the present program adequate?

Do you forsee any need for continued use of models? If so, how, when, where, and why?

What is your feeling of future needs in models and the purposes they will serve?

APPENDIX B

SURVEY QUESTIONNAIRE

Directions: The following questionnaire is designed to obtain information concerning knowledge and skills necessary in model building. This information will serve for a graduate study in model application to product design. All answers will be kept in the strictest confidence. Check appropriate answers and fill in areas where explanations are needed:

Name ______________________________

Position/Title ______________________________

Years Experience ______________________________

Department ______________________________

1. Does your job involve:

_____ a. actual construction of models?

_____ b. use of models in design studies?

_____ c. other? Explain.

2. Craftsmanship associated with professional model making may best be expressed as (check only one):

_____ a. a high degree

_____ b. a moderate degree

_____ c. very little

_____ d. other.

3. Does model construction usually involve application of two or more different materials? _____ yes _____ no.

4. Indicate which of the following materials is most widely used in model making. (check only one)

   _____ a. metal

   _____ b. plastic

   _____ c. wood

   _____ d. paper or cardboard

   _____ e. other

5. In model construction which of the following properties of a material would be essential knowledge.

   _____ a. the finishing characteristics

   _____ b. the workability

   _____ c. the strength

   _____ d. the hardness

6. Is an understanding of engineering drawing and its principles necessary for model building? _____ yes _____ no.

7. Is competence in engineering drawing skills necessary? _____ yes _____ no.

8. To perform the job of professional model building, a degree of <u>knowledge</u> in certain areas may be necessary. Indicate the degree of knowledge necessary by checking the appropriate column. (Check all that may apply)

Areas	Degree of Knowledge: High	Moderate	None
Woodturning	____	____	____
Wood carving	____	____	____
Patternmaking	____	____	____
Adhesives	____	____	____
Fasteners	____	____	____
Finishing	____	____	____
Cabinetmaking	____	____	____
Furniture making	____	____	____
Carpentry	____	____	____
Upholstery	____	____	____
Laminating	____	____	____
Lettering	____	____	____
Sketching	____	____	____
Machine drawing	____	____	____
Design	____	____	____
Blueprint reading	____	____	____
Architectural drawing	____	____	____
Engineering drawing	____	____	____
Electrical drawing	____	____	____
Structural drawing	____	____	____

Areas	Degree of Knowledge		
	High	Moderate	None
Sheet metal	____	____	____
Machining	____	____	____
Etching	____	____	____
Heat-treating	____	____	____
Foundry	____	____	____
Forging	____	____	____
Welding	____	____	____
Brazing	____	____	____
Soldering	____	____	____
[illegible]	____	____	____
[illegible]	____	____	____
[illegible]	____	____	____
[illegible]	____	____	____
[illegible]	____	____	____
[illegible]	____	____	____
[illegible]	____	____	____
[illegible]	____	____	____
[illegible]	____	____	____
[illegible]	____	____	____
[illegible]	____	____	____

Areas	Degree of Knowledge: High	Moderate	None
Portable hand tools	____	____	____
Abrasives	____	____	____
Maintenance	____	____	____
Safety	____	____	____
Others (list):	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____

9. What degree of skill is needed by the model maker in each of the following areas? (Check all that may apply)

Areas	Degree of Skill: High	Moderate	None
Woodturning	____	____	____
Wood carving	____	____	____
Pattern making	____	____	____
Fastening	____	____	____
Finishing	____	____	____
Cabinet making	____	____	____

Areas	Degree of Skill: High	Moderate	None
Upholstery	____	____	____
Carpentry	____	____	____
Lettering	____	____	____
Sketching	____	____	____
Designing	____	____	____
Engineering drawing	____	____	____
Architectural drawing	____	____	____
Graphic illustrating	____	____	____
Structural drawing	____	____	____
Blueprint reading	____	____	____
Sheet metal working	____	____	____
Welding	____	____	____
Brazing	____	____	____
Soldering	____	____	____
Machining	____	____	____
Milling	____	____	____
Foundry	____	____	____
Forging	____	____	____
Heat-treating	____	____	____
Metal spinning	____	____	____

Areas	Degree of Skill: High	Moderate	None
Silk screening	____	____	____
Photography	____	____	____
Vacuum forming	____	____	____
Mold making	____	____	____
Casting	____	____	____
Others (list)	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____

10. General <u>knowledge</u> of which of the following machine tools would be necessary to the professional model makers? (Check all that apply)

____ bandsaw	____ jointer	____ metal shaper
____ jigsaw	____ planer	____ metal planer
____ table saw	____ sander	____ grinder
____ radial arm saw	____ drill press	____ metal cut-off saw
____ mortiser	____ wood lathe	____ mill
____ shaper	____ metal lathe	____ other (specify)

11. <u>Skills</u> in operation of which of the following would be essential? (Check all that apply)

____ bandsaw	____ jointer	____ metal shaper
____ jigsaw	____ planer	____ metal planer
____ table saw	____ sander	____ grinder
____ radial arm saw	____ drill press	____ metal cut-off saw
____ mortiser	____ wood lathe	____ mill
____ shaper	____ metal lathe	____ other (specify)

12. Knowledge of and skills in the use of which of the following portable power tools are <u>needed</u> by the model maker? (Check all that apply)

____ drill	____ belt sander
____ saw	____ router
____ sabre saw	____ orbital sander
____ disc sander	____ other (specify)
____ dremel	

13. Skills and knowledge needed in the use of hand tools for model making are <u>necessary</u> of which of the following items listed? (Check only those which apply)

____ saw	____ wood carving chisels	____ pliers
____ combination square	____ mat knife	____ wire cutters
____ center head	____ Xacto knife	____ wrenches
____ scribe	____ scissors	____ marking gauge
____ center punch	____ clamps	____ syringe
____ awl	____ tweezers	____ coping saw

13. (Continued)

____ scale	____ micrometer	____ level
____ woodturning chisels	____ gauge blocks	____ pallet knife
____ nail set	____ plane	____ scrapers
____ hammer	____ spoke shave	____ glass cutter
____ brace	____ file	____ screwdriver
____ dividers	____ mitre-box saw	____ mallet
____ inside calipers	____ sharpening stone	____ other (specify)
____ outside calipers		

14. Could proper knowledge and skill in the maintenance of tools and equipment be considered essential to a good model builder? ____ yes ____ no.

15. Is safety a factor needing the attention of the model maker? ____ yes ____ no.

16. If you were to interview interested individuals seeking employment in model building, which of the following backgrounds would you most likely be interested in?

    ____ a. Strictly theoretical

    ____ b. Strictly practical

    ____ c. Some theory and practical application

    ____ d. Other (Explain)

17. Are there areas in which knowledge or skills necessary to model making have been omitted in this survey? Explain.

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