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MANUFACTURING COST/DESIGN GUIDE (MC/DG) FOR AEROSPACE APPLICATIONS

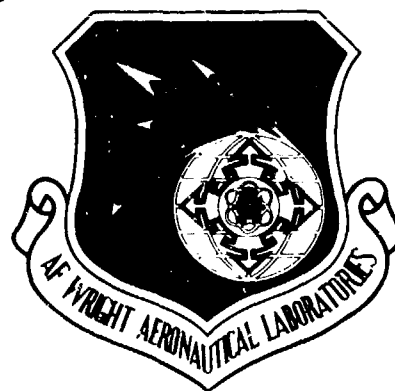
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May 1988

Final Report for Period July 1985 — September 1987

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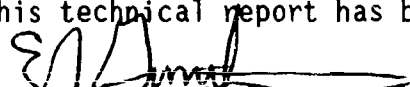
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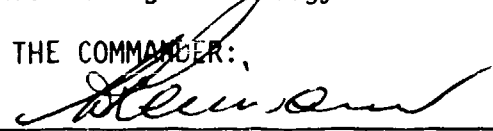
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Project Technical Manager
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1 Dec 87
Date

FOR THE COMMANDER:



Chief
Computer Integrated Manufacturing Br.
Manufacturing Technology Division

1 Dec 87
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The Manufacturing Cost/Design Guide (MC/DG) enables conceptual and detail designers of airframes to minimize cost by conducting trade-off analyses between the aircraft system performance objectives and specific manufacturing complexities over which the designers have control. This report describes this design tool which documents the relationships between airframe design features and producibility of both metallic and composite discrete parts and assemblies. The MC/DG highlights cost-drivers associated with various structural designs and also the costs associated with competing manufacturing processes. The current program, discussed in this report, expands the two demonstration MC/DG sections, i.e., composites and assemblies, developed previously. This program also enabled development of a new MC/DG section for superplastic formed titanium			
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airframe parts. The man-hours associated with test, inspection, and evaluation are frequently a cost-driving factor when conducting realistic trade-off studies; therefore, such data are also presented for use in the design process.

It is emphasized to designers that prior to utilizing any data presented, it is essential to recognize that, first, with certain emerging technologies the available facilities may be classed as experimental and therefore significant variations may occur between the practices at different companies and, second, the general and detailed ground rules included in this report must be studied for each technology to assure consistency with the materials required, production quantities, etc. of the aerospace system under development. The development of the designer oriented formats identifying the cost-drivers satisfy specific criteria and readily enable incorporation of company data for emerging technologies such as superplastic forming or thermoplastics.



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FOREWORD

This Final Report covers the work performed under Contract No. F33615-85-C-5016 from July 26, 1985 through September 30, 1987. This program was sponsored by the Computer Integrated Manufacturing Branch, Materials Laboratory, Air Force Wright Aeronautical Laboratories (AFWAL/MLTC). The Air Force Project Manager was Lt. Eric J. Gunther.

Battelle's Columbus Division (BCD) was the prime contractor. Mr. Bryan R. Noton was the program manager for this effort.

The airframe company team members and participating staff in this program to extend the MC/DG for composite materials and mechanically-fastened assemblies and to develop a section for superplastic forming are listed below.

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This report is published for information only and does not necessarily represent the recommendations or conclusions of the Air Force.

TABLE OF CONTENTS

		<u>Page</u>
SECTION 1.	INTRODUCTION.	1-1
1.1	Scope	1-1
1.2	Objectives.	1-3
1.3	Designer-Oriented Format Design Criteria.	1-7
1.3.1	Emphasize Cost-Drivers.	1-8
1.3.2	Be Simple to Use.	1-8
1.3.3	Use Designer-Oriented Language.	1-8
1.3.4	Instill Confidence.	1-8
1.3.5	Be Economical	1-9
1.3.6	Be Accessible	1-9
1.3.7	Be Maintainable	1-9
1.4	Data Presentation Methodologies	1-10
1.5	Data Generation	1-11
1.5.1	Recurring Costs	1-11
1.5.2	Nonrecurring Tooling Costs.	1-11
SECTION 2.	REFERENCES.	2-1
2.1	Applicable Documents.	2-1
2.2	Terms and Abbreviations	2-3
2.2.1	Glossary.	2-3
SECTION 3.	COST-DRIVERS IN DESIGN AND MANUFACTURE.	3-1
3.1	Adhesive Bonding.	3-1
3.2	Castings.	3-2
3.3	Composite Structures.	3-2
3.4	Diffusion Bonding	3-3
3.5	Extrusions.	3-4
3.6	Filament Winding.	3-4
3.7	Forging	3-5
3.8	Fusion Welding.	3-5
3.9	Mechanically Fastened Assembly.	3-6
3.10	Sheet-Metal Discrete Parts.	3-6
3.11	Superplastic Forming/Diffusion Bonding (SPF/DB)	3-7
3.12	Weldbonding	3-7
SECTION 4.	HOW MC/DG IS USED	4-1
4.1	Manufacturing Cost/Design Guide Design Process Interaction	4-1
4.2	Procedure to Conduct Airframe Trade-Off Studies Utilizing MC/DG	4-3
4.3	Utilization of Learning Curve	4-6

TABLE OF CONTENTS (Continued)

		<u>Page</u>
SECTION 4.	HOW MC/DG IS USED	
4.4	Ground Rules	4-9
4.4.1	General Ground Rules.	4-9
4.4.2	Detailed Ground Rules	4-9
4.5	Cost Worksheet for Airframe Designers	4-11
4.5.1	Instructions for Use of Cost Worksheet.	4-11
4.6	Interaction with Other Air Force Programs for Cost Analysis	4-14
4.6.1	Design-MC/DG Interaction.	4-14
4.6.2	Advanced Composite Fabrication Guide (ACFG)- MC/DG Interaction	4-14
4.6.3	Design-Advanced Composite Fabrication Guide (ACFG) Interaction.	4-16
4.6.4	Advanced Composites Fabrication Guide (ACFG)- Cost Estimating System Interaction.	4-16
4.6.5	MC/DG-Cost Estimating System Interaction.	4-16
4.6.6	Design-Cost Estimating System Interaction	4-16
SECTION 5.	COMPOSITES FABRICATION SECTION.	5-1
5.1	Format Selection Aids	5-1
5.2	Examples of Utilization	5-3
5.2.1	Carbon/Epoxy Channel with Sine-Wave Web	5-4
5.2.2	Carbon/Epoxy J-Section with Sine-Wave Web	5-5
5.2.3	Carbon/Epoxy I-Section with Sine-Wave Web	5-6
5.3	Composite Materials Data.	5-7
SECTION 6.	SUPERPLASTIC FORMING.	6-1
6.1	Format Selection Aids	6-1
6.2	Example of Utilization.	6-3
6.2.1	Problem Statement	6-3
6.3	Airframe Parts.	6-7
SECTION 7.	MECHANICALLY FASTENED ASSEMBLY.	7-1
7.1	Format Selection Aids	7-1
7.2	Example of Utilization.	7-3
7.2.1	Utilization Example of Aluminum First Level Assembly.	7-3
7.3	Airframe Assemblies	7-6a
7.4	Manufacturing Data for Airframe Assemblies.	7-6b

TABLE OF CONTENTS
(Continued)

	<u>Page</u>
APPENDIX A	
GROUND RULES FOR COMPOSITE STRUCTURES	A-1
APPENDIX B	
GROUND RULES FOR MECHANICALLY-FASTENED METALLIC ASSEMBLIES.	B-1
APPENDIX C	
GROUND RULES FOR SUPERPLASTIC FORMING/DIFFUSION BONDING (SPF/DB). . .	C-1

LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1-1	Decaying Impact of Decision on Cost.	1-5
1-2	Aerospace System Design Team Priorities.	1-5
1-3	MC/DG Section Selection Aid.	1-6
4-1	MC/DG Design Process Interaction	4-2
4-2	Design Engineering-MC/DG-Fabrication Guide- Cost Estimating System Interaction for Composites.	4-15
6-1	MC/DG Format Selection Aid for SPF & SPF/DB Fabrication	6-2
6-2	A Discrete Part Ready for Assembly	6-4
6-2A	Approximate Thickness after SPF.	6-6
6-2B	Tooling Arrangements	6-7
6-3	Example of Diaphragm Preferred Fabrication for SPF Design Guidance.	6-8
6-4	Example of SPF Sinewave Web.	6-9
6-5	Example of SPF Beaded Web.	6-9
6-6	Example of SPF Stiffened Web	6-10
6-7	Example of SPF Stiffened Web with Integral Flange.	6-10
6-8	Example of SPF Formed Intercostal Structural Member.	6-11
6-9	Example of SPF Formed Frame Stiffened by Beads	6-11
6-10	Female versus Male Beads for SPF Parts	6-12
6-11	Example of SPF and SPF/DB Concepts	6-13
7-1	Format Selection Aid for Mechanically Fastened Assemblies. .	7-2
7-2	Aluminum (2024) First Level Assembly	7-5

LIST OF TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
1-1	MC/DG Volume Contents: Manufacturing Technologies for Airframes.	1-2
4-1	Typical Industry Learning Curves	4-7
4-2	Factors to Convert the MC/DG 200th Unit Cost to the Cumulative Average Cost for the Design Quantity and Learning Curve Involved.	4-8
4-3	Designer' MC/DG Cost Worksheet	4-13
4-4	Detailed Cost Analysis	4-13

SECTION 1.0 INTRODUCTION

1.1 Scope

With its step-by-step approach to attaining optimum performance at minimum cost, this "Manufacturing Cost/Design Guide" (MC/DG) is a tool developed expressly for designers. The need for such a guide has long existed. The MC/DG presents easy-to-use formats that provide designers with manufacturing cost data developed from industry-wide practice. It allows the user (design, manufacturing, and procurement personnel) to quickly make the trade-offs necessary to achieve lowest acquisition cost with confidence. During the design phase, designers with different levels of experience can conduct simple trade-offs between manufacturing processes for metallic and composite airframe components and assemblies. The MC/DG also establishes data at a level that complements and is conducive to computer-aided design and manufacturing systems.

The MC/DG was developed by establishing a model for its contents. Manufacturing cost-drivers and data requirements were identified. Designer-oriented formats were recommended for conventional and emerging technologies while meeting specified criteria. Based on this model, three MC/DG sections were developed to determine the effectiveness of the overall concepts. These concepts, focusing on sheet metal aerospace discrete parts and first-level mechanically fastened assemblies, were demonstrated and proven. Applicability of the concept to the fabrication of composites was also studied, and, while a broad data development effort was not initiated, the concept was again demonstrated and proven.

Designers from major aerospace companies have used the data and formats to conduct trade-off studies of structural performance and manufacturing costs of fuselage panels in aluminum, titanium, and composites. The results provided significant measurable benefits and the subsequent expansion of the guide to include sections on forgings; castings; extrusions; superplastic forming; and test, inspection, and evaluation (TI&E) of sheet metal, composites, castings, machining, and assembly. The MC/DG includes formats providing manufacturing cost data and detailed instructions for their use.

Table 1-1 lists the functional data sections of the "MC/DG for Airframes."

TABLE 1-1.

**MC/DG VOLUME CONTENTS:
MANUFACTURING TECHNOLOGIES FOR AIRFRAMES**

I	II	III	IV	V	VI
PROCURED ITEM COSTS	MATERIAL REMOVAL COSTS	DETAIL FABRICATION COSTS	MATERIAL TREATMENT COSTS	ASSEMBLY COSTS	TEST, INSPECTION AND EVALUA- TION COSTS
EXTRUSIONS CASTINGS FORGINGS	MACHINING	SHEET METAL COMPOSITES SUPERPLASTIC FORMING	HEAT TREATMENT SURFACE TREATMENT	METALLIC STRUCTURES NON- METALLIC STRUCTURES	SHEET METAL ASSEMBLY CASTINGS FORGINGS MACHINING COMPOSITES

CATEGORIES - PROCURED ITEM COSTS, ETC.
SECTIONS - FORGINGS, ETC.
SUBSECTIONS - MACHINING, ETC.

1.2 Objectives

The MC/DG study identified in 1.1 was initiated to further aid in attaining the objectives of the Computer Integrated Manufacturing (CIM) program.

The CIM objectives are to

- (1) Reduce aerospace systems cost
- (2) Provide leadership to industry
- (3) Increase competence in aerospace manufacturing
- (4) Provide for CIM technology transfer
- (5) Improve the USAF's mobilization position
- (6) Demonstrate the capability for a totally integrated manufacturing system.

The MC/DG project objectives are directed at reducing the cost of airframes and electronics in the design phase. The specific objectives include

- (1) Provide urgently needed, quick, simple, and quantitative cost comparisons of manufacturing processes to designers.
- (2) Emphasize design orientation of MC/DG formats and manufacturing man-hour data for use at all phases of the design process, i.e., preliminary and detail design--to increase emphasis on cost as a vital design parameter.
- (3) Enable more extensive manufacturing cost trade-offs to be conducted on airframe components and aerospace electronics fabrication and assembly.
- (4) Emphasize potential cost advantages of emerging materials and manufacturing methods to accelerate the transfer of these technologies to production hardware.
- (5) Guide the designer to the lowest cost manufacturing process early in the design phase.
- (6) Identify cost-driving manufacturing operational sequences, which provide targets for future CIM efforts.

The varying leverage to reduce cost at various stages during the airframe design process is shown in Figure 1-1. In an effort to achieve minimum cost, the performance of the design engineer is today evaluated on the factors shown in Figure 1-2.

To provide an overview of the MC/DG sections and contents, a generalized selection aid is shown in Figure 1-3.

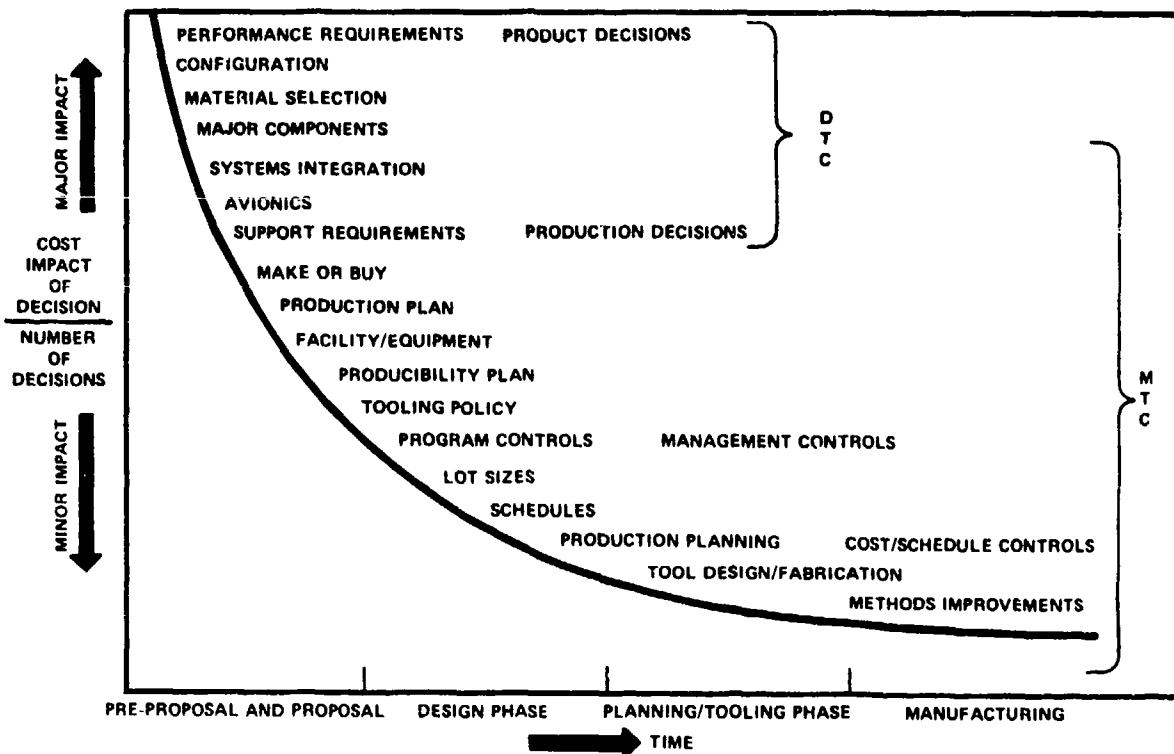


FIGURE 1-1. DECAYING IMPACT OF DECISION ON COST

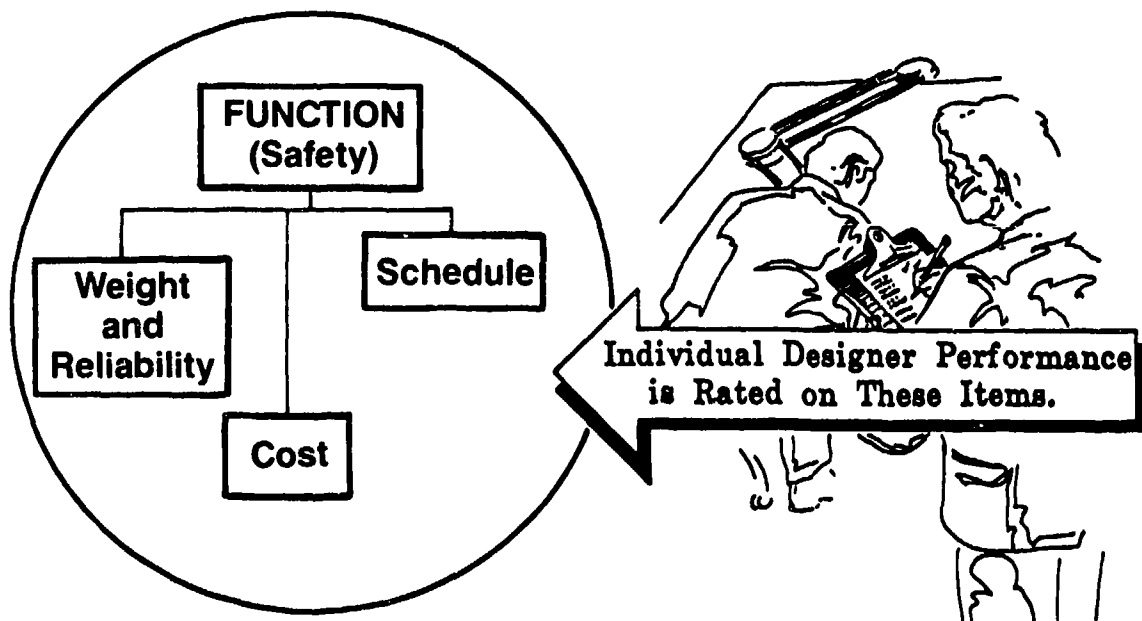
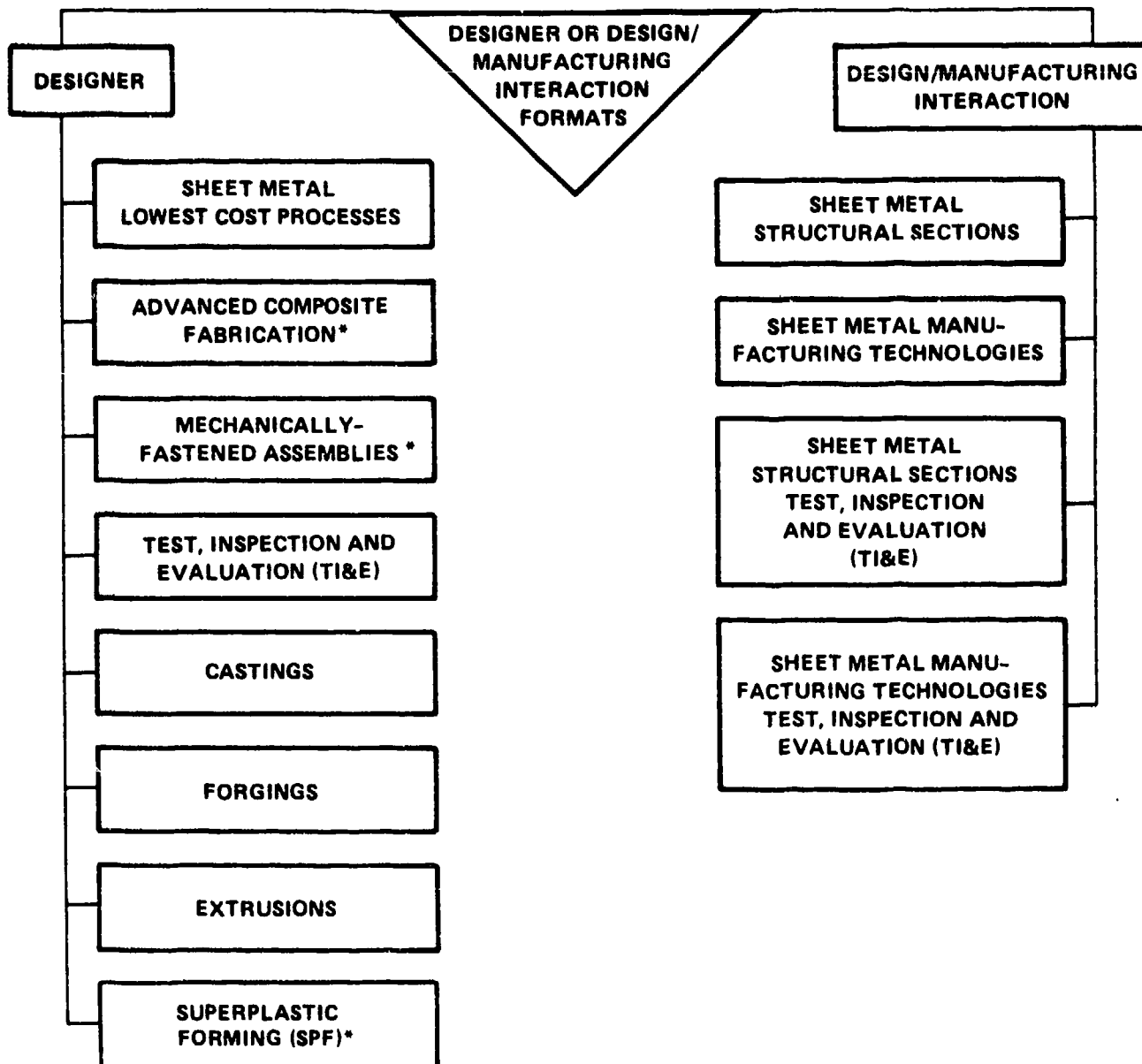


FIGURE 1-2. AEROSPACE SYSTEM DESIGN TEAM PRIORITIES

MC/DG SECTION SELECTION AID



*These MC/DG Sections represent program reported herein.

FIGURE 1-3

1.3 Designer-Oriented Format Design Criteria

The formats and methodologies developed for the MC/DG concept (AFML-TR-76-227) were used as the basis for format development in the MC/DG for Airframes and also Electronics Fabrication and Assembly. Each project manager in industry was responsible for having the following categories of staff members review the data requirements and formats:

- Management (concurrence necessary to assure MC/DG utilization, i.e., achieve technology transfer)
- Engineering (design and support)
- Manufacturing (fabrication, tooling, and quality control).

Futhermore, designer surveys of the MC/DG resulted in the following feedback:

- Must be simple whenever possible
- Must not be time consuming to use in the design process
- Complicated calculations should be avoided
- Manufacturing data are urgently needed but must have designer orientation
- No single airframe company can provide all manufacturing cost data required due to varying expertise
- Designers are more concerned that it is the lowest cost rather than what it costs; i.e., qualitative comparisons are also important.

It was, therefore, agreed by the team that the MC/DG formats must meet the following criteria:

- Emphasize cost-drivers
- Be simple to use
- Use designer-oriented language
- Instill confidence
- Be economical

- Be accessible
- Be maintainable.

The following is a detailed explanation of the above format development criteria.

1.3.1 Emphasize Cost-Drivers

The MC/DG will emphasize sensitive factors, which by minor variation in selection can cause major increases or decreases in manufacturing cost. The degree of impact on manufacturing cost during the design, developed through the selection of materials, manufacturing, and fabrication processes, must be depicted in formats and data that will make the designer readily aware of those elements of design (cost-drivers) that pose manufacturing cost hazards.

1.3.2 Be Simple to Use

The cost-driver effects (CDE) and cost-estimating data (CED) formats used to guide designers will require little or no arithmetical calculations to determine the cost comparisons of design/manufacturing alternatives. The cost impact formats and graphics will provide more direct readout of man-hours through maximum use of simple curves and tables.

1.3.3 Use Designer-Oriented Language

The primary purpose of the MC/DG is to display manufacturing process capabilities and costs in a manner that will permit designers to select the most economical manufacturing approach. The formats must be developed through a close working relationship with design personnel at all the team member companies and through constructive recommendations submitted during the development of the MC/DG. The charts and terminology included with the formats must be common to the engineering community and be of the types which are recognized and employed by the designer in his daily engineering tasks.

1.3.4 Instill Confidence

The designer must have a high degree of confidence in the CDE and CED formats and manufacturing man-hour data if the MC/DG is to serve as a useful working tool for design. The formats developed will be related to

practical and meaningful cost trades that are illustrative of airframe design decisions made every day by designers. The formats must clearly provide an MC/DG for making trade-off decisions between manufacturing technologies with both comparative and quantitative cost data. It is recognized that the degree of accuracy of manufacturing man-hour data integrated into the formats will be significant in determining the confidence and degree of utilization of the MC/DG in industry.

1.3.5 Be Economical

Minimizing acquisition and maintenance costs of the data and formats is a high priority item in the development of the MC/DG.

1.3.6 Be Accessible

The MC/DG must be readily available at all designer locations. This will be handled differently within each company, but along similar lines. Copies of the MC/DG can be issued to individual designers or small engineering groups. The wider the distribution of the MC/DG to individual users, the more extensive use can be expected. Computerization will greatly enhance the accessibility.

1.3.7 Be Maintainable

The formats must be developed to facilitate maintenance of the MC/DG. In today's highly fluid technical and economic environment, the useful life of the MC/DG will depend upon the flexibility of the formats to accept revised or new data. One approach is through computer preparation of individual pages of loose-leaf volumes. The data would be stored in the central data bank and, for user accessibility, transmitted via telephone connections to remote terminals to each company for printout and multiple distribution. This is discussed in Volume III of report number AFWAL-TR-80-4115 dealing with MC/DG computerization.

1.4 Data Presentation Methodologies

Throughout the presentations of MC/DG data requirements and formats, the following two terms are frequently used:

COST-DRIVER EFFECTS (CDE)

COST-ESTIMATING DATA (CED)

The objectives of the CDE and CED methodologies are:

- | | | |
|---|---|-----------|
| ● To develop a simple approach for use of formatted data by designers to achieve lower fabrication costs during design phases; both CDE and CED. | } | DIRECTION |
| ● To provide qualitative cost guidance to perform simple trade-offs to achieve lowest fabrication cost; CDE. | | |
| ● To provide the designer with the capability to perform simple trade-offs to achieve quantitative rough-order-of-magnitude (ROM) estimated fabrication costs; CED. | } | COST |
| | | |

The CDE and CED methodologies provide the designer with cost guidance for achieving lower manufacturing costs at the preliminary detailed design phase:

CDE achieves qualitative results

CED provides quantitative results.

The CDE approach enables preliminary and production designers to

- Identify the intensive cost-drivers that increase the manufacturing cost of the design
- Determine the relative cost effects of cost-drivers over which they have control
- Determine pertinent cost data that allow them to perform simple trade-offs leading to comparative costs for those configurations evaluated.

The CDE approach motivates designers. They can obtain low cost designs, providing they take full advantage of the CDE data and use the

lower end of the cost range wherever possible, while satisfying the performance and reliability requirements.

The CED approach provides preliminary and detail designers with the ability to perform cost-estimates through the use of simplified formats and data. CED values are both quantitative and comparative.

1.5 Data Generation

1.5.1 Recurring Costs

Throughout the MC/DG, team average production man-hours are given. Direct material costs are not included. The direct factory labor costs for manufacturing base-parts and designer-influenced cost elements (DICE) were generated by the participating aerospace companies using their own time standards, excluding personal fatigue and delay (PF&D) allowances. In developing data for recurring costs for base-parts and DICE, general and detailed ground rules were formulated by the coalition to assure consistent results. Elements that affect the costs, such as lot release, program quantity, and learning curves, were included in the generation of data.

Direct factory labor recurring costs consist of setup (SU) time and run time. The SU time is that time required to prepare for a production operation. The SU time is required once for each manufacturing lot of parts.

The production run time is that time required to produce a single part from the raw stock to part completion ready for storage or use in assembly. The direct factory labor time per part is obtained by dividing the SU time by the lot size, e.g., 25, as an industry average, and then adding the run time per part.

To facilitate the use of the MC/DG, the direct factory labor and man-hours per part have been adjusted to reflect the part cost in man-hours at unit 200. To achieve this, each company has applied its own proprietary learning curves.

1.5.2 Nonrecurring Tooling Costs

Standard tools are used, when available, to fabricate the base-part and to incorporate the DICE. Nonrecurring tooling costs are documented in man-hours.

As used in the MC/DG, the NRTC includes the cost of those contract tools required to make the part. Examples are forming tools, trim tools, and templates (check, drill, or router templates, etc.). The tools required to produce the tools were not included, e.g., tooling templates, tooling masters, and mock-ups. Tool material costs are included only when significant.

SECTION 2.0
REFERENCES

2.1 Applicable Documents

<u>Item</u>	<u>Description</u>
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8	"Superplastic Forming of Aluminum Airframe Components," Rockwell International, North American Aircraft Operations. Briefing to U.S. Army Aviation Systems Command in Los Angeles, California, January 28, 1986.

- 9 "Superplastic Forming of Aluminum Airframe Components",
Rockwell International, North American Aircraft Operations.
Briefing to U.S. Army Aviation Systems Command in Los Angeles,
California, January 28, 1986.

2.2 Terms and Abbreviations

2.2.1 Glossary

Auxiliary Operations: Additional processing to the forging to obtain shapes, surface conditions, or other properties not obtainable in the regular forging operation.

Base-part: A detailed or discrete part in its simplest form, i.e., without complexities.

Base-part Cost: The standard hours to fabricate the base-part projected on an improvement curve to unit 200. (The base cost is derived by applying the learning curve factor to the sum of the standard hours required for the complete fabrication of the base-part.)

Beading: A forming operation in which a ridge or elongated projection is raised on sheet metal.

Bender: The portion of the dies which forms the metal so that the longitudinal axis is in two or more planes.

Bend Radius: The radius measured on the inside of a bend which corresponds to the curvature of a bent specimen or the bent area in a formed part.

Blank: The piece of sheet metal, produced in cutting dies, that is to be subjected to further press operations. A blank may have specific shape developed to facilitate forming or to eliminate a trimming operation subsequent to forming (see Blank Development).

Blank Development: The process of determining the optimum size and shape of a blank for a specific part.

Blank Holder: That part of a forming die which holds the blank by pressure against a mating surface of the die to control metal flow and prevent wrinkling. The blank holder is sometimes referred to as "Hold Down." Pressure may be applied by mechanical means, springs, air, or fluid cushions.

Blanking: The act of cutting a blank.

Blast Cleaning: A process for removing the oxide surface, or scale, from forging by propelling grit or shot at high velocity at the work to clean it.

Blocking: A forging operation which imparts to the forging its general but not exact or final shape.

Blocking Impression: The impression which gives the forging its general shape.

Blow: The impact or other pressure produced by the moving part of any forging unit.

Boss: A projection on the main body of the forging.

Box Anneal: An annealing process whereby the steel to be annealed is packed in a closed container to protect the surfaces from oxidation.

Brake Forming: A forming process in which the principal mode of deformation is bending. The equipment used for this operation is commonly referred to as a press brake.

Brake Press: A form of open frame, single action press comparatively wide between the housings, with bed designed for holding long narrow forming edges or dies. It is used for bending and forming strips and plates.

Check: A crack in a die impression, usually in a corner, generally due to forging strains localized at some relatively sharp corner.

Clean: The operation of removing the oxide coating, or scale, from the surface of the forging.

Coining: The operation of applying heavy pressure in a coining press to a surface to obtain closer tolerances or smoother surfaces. In the strict sense, the term used should be sizing.

Coining Dies: Dies in which the coining or sizing operation is performed.

Cold Shut: A forging defect caused by the meeting of metal surfaces without welding and within the die impression.

Consumed Weight: The weight of received material expended, divided by the number of forgings accepted by the customer. All scrap rejects and material loss from any cause is included.

Contract Tools: Tools that are chargeable to a specific part or contract and are unique to that contract.

Cut Off: A blanking operation in which cutting is performed along a line so that no scrap is generated.

Cut-Off Die: Sometimes called a trimming die. The cut-off die can be the last die in a set of transfer dies which cuts the part loose from the scrap, or it can be a die which cuts straight sided blanks from a coil for later use in a draw die.

Cutoffs: A pair of blades either milled in the corner of a pair of forging dies, or inserted in the dies, used to cut away a forging from the bar after the finishing blow.

Cut Weight: The weight of material necessary at the machine to fabricate one forging. This equals the net weight plus flash, sprues, tonghold, and scale loss.

Designed Tools: Tools of such a complex type that a design effort is required to ensure proper end results.

Designer-Influenced Cost Elements: Those designer-influenced cost elements (DICE) which might include joggles, holes, bends, lightening holes, and special tolerances that add cost to the base-part configuration. These additional costs are due to the increased operations required over the standard manufacturing method (SMM).

Detailed or Discrete Part: The lowest form to which an airframe structure can be broken into its elemental unites, i.e., base-part with complexities.

Developed Blank: A flat blank with a shape that will produce a finished part with the desired configuration with a minimum of trimming operations.

Die: (a) A complete tool used in a press for any operation or series of operations such as forming, impressing, piercing, and cutting. The upper member or members are attached to the slide (or slides) of the press, and the lower member is clamped or bolted to the bed or bolster, the die members being so shaped as to cut or form the material placed between them when the press makes a stroke. (b) The female part of a complete die assembly as described in (a).

Die Clearance: The space, on each side, between punch and die.

Die Holder or Shoe: A plate upon which the die components are mounted.

Die Set: A standardized unit consisting of a die holder or lower shoe, punch holder or upper shoe, and guide pins or posts.

Die Shift: The movement of the dies from their proper place in relation to each other.

Draft: The amount of taper on the side walls of die impressions to aid the removal of the forging from the dies. Applied also to the metal on a forging caused by this taper.

Draft Angle: The taper of the draft expressed in degrees.

Drawing: Reheating after hardening to a temperature below the critical range, followed by any desired rate of cooling.

Drawing: A sheet metal deformation process in which plastic flow results in a positive strain (e_1) in one direction in the plane of the sheet surface and a negative strain (e_2) at 90° to (e_1) in the sheet surface. Drawing can only occur when sheet metal flow under the blank holder is permitted. The term drawing is sometime loosely used to describe a wide variety of press forming operations which are actually stretch forming operations or a combination of stretching and drawing.

Drop Forging: A forging made in a drop hammer (see Forging).

Edger: The portion of the die that distributes the metal in a general proportion of the shape to be forged.

Fabrication Planning Function (Methods): The effort required to generate the standard manufacturing method (SMM) and complexities and additional operations required for part fabrication.

Faying Surfaces: Joining surfaces in contact, e.g., bond area of adhesively bonded joints.

Fillet: A radius imparted to inside meeting surfaces.

Fin: See Flash.

Final Yield: The quotient from dividing the net weight by the consumed weight.

Flanging: A bending operation in which a narrow strip at the edge of a sheet is bent down along a straight or curved line. It is used for edge strengthening, appearance, rigidity, and the removal of sheared edges. A flange is often used as a fastening surface.

Flash: The metal that is in excess of that required to fill out the final impression in a pair of dies and moves out as a thin plate around the parting line of the dies. Also called fin.

Flash Pan: The portion of the die which has been machined to permit the excess metal to flow through.

Forging: The product of work on plastic metal formed to a desired shape by pressure. Forgings are formed in dies in a drop hammer, forging machine, or forging press. The forging hammer imparts intermittent impact pressure, and the forging machine (upsetter) and the forging press impart squeeze pressure. While some metals, including a few steels, can be cold forged, the majority of metals are made plastic by heating for forging.

Forging Strain: A strain that has been set up in the metal by the process of forging. It may be relieved by a subsequent annealing or normalizing.

Fuller: That portion of the die used for reducing the cross section of the stock.

Gathering Stock: Any operation whereby the cross section of a portion of the stock is increased above its original size.

Grain Flow: The direction of flow lines.

Grain Size: The size of crystals in metal when measured with some standard.

Gross Weight: The weight required to produce one forging. May have the meaning of Cut Weight or Multiple Bar Weight or Consumed Weight. See those definitions.

Gutter: The portion of the die which has been relieved to provide for the excess metal after it passes through the flash pan.

Handling Holes: Holes drilled in opposite ends of the die block to permit handling by the use of a crane or bar.

Hardening: A method of increasing the hardness of a metal by controlled heating and cooling.

Hardness: Generally, the resistance of metal to deformation by mechanical force. Also refers to the hardness numbers obtained in testing for hardness by any of the several hardness tests.

Heat: Temperature of the metal, or the operation of increasing the temperature of the metal for heat treating or forging purposes.

Heat Treatment: Any operation or operations of heating metal and cooling it to bring out desired physical properties.

Hub: A boss which is in the center of the forging and forms a part of the body of the forging.

Impression: That portion of the dies which has been machined so as to produce the shape of the forging.

Insert: A piece of steel which is removable from a die. The insert may be used to fill a cavity, or to replace a portion of the die with a grade of steel that is better adapted for service at that particular point.

Insert Die: A small die containing the impression of a forging and which is fastened in a master block.

Inspection: The process of checking a forging for possible defects or deviations from the standards given in the specifications. Chemical inspection is the determination of the chemical analysis of the metal. Physical property inspection is the determination of the resistance of the metal to deformation against the application of force in several forms. Hardness testing is the determination of the relative hardness of the metal against a standard hardness when tested by one of several hardness tests. Cold inspection is a visual inspection of the forgings for visible defects, dimensions, weight, and surface condition. Hot inspection is a visual inspection of the forging for visible defects during the time the forgings are in the heated state.

Iron: A press operation used to obtain a more exact alignment of the various parts of a forging, or to obtain a better surface condition.

Lap: A surface defect in the forging caused by the folding of metal in a thin plate on the surface.

Layout: The transference of drawing or sketch dimensions to templates or dies for use in sinking dies. Also checking a forging or a lead cast (see below) to determine whether its dimensions are in accordance with those given in the specifications.

Lead Cast: A reproduction in lead, or a lead alloy, of the die impression, obtained by clamping the two dies together in alignment and pouring molten metal into the finished impression. Also called a lead proof.

Learning or Improvement Curve: A system for establishing unit part costs to reflect the impact of quantity.

Learning or Improvement Curve Factor: A factor applied by an individual company to determine the base-part cost at a specific unit of production.

Lock: One or more changes in the plane of the mating faces of the dies. A compound lock is one where two or more changes are in the mating faces. A counterlock is a lock placed in the dies to offset a tendency for die shift caused by a necessarily steep lock.

Lot Release: The total number of parts released for fabrication at one time.

Machine Forging: The product of the forging machine, or upsetter.

Manufacturing Equipment: Facilities used to fabricate parts, e.g., brakes, rolls, and presses.

Manufacturing Process: The operations using chemicals, heat treatment, etc., to meet required functional properties of the part such as strength and corrosion resistance.

Matched Edges: The machined surfaces of the dies at the parting plane at right angles to each other from which all measurements are determined. Sometimes called match lines or matched faces.

Methods Code: A means to identify a particular standard manufacturing method. Required complexities or additional operations to the base-part will be included.

Minimum Bend Radius: That radius about which a metal can be bent without exhibiting fracture. It is often described in terms of multiples of sheet thickness.

Mismatch: The misalignment of a pair of forging dies. Also applied to the condition of the resulting forging.

Multiple Bar Weight: The cut weight plus loss in cutting as saw cut or torch burn. Crop ends from shearing may or may not be included.

Net Weight: The average shipping weight of all forgings shipped from one die sinking. Equals shape weight plus die wear and size tolerances.

Nondesign Tools: Tools of such simple or standard configuration that no design work is required.

Nonrecurring Costs: One-time costs incurred by planning, tooling, engineering, etc.

Normalize: Heating steel to above its critical range, holding it at that temperature for the required time, and cooling it in still air.

Normalized Part Cost: The base-part cost and cost of complexities submitted to Battelle Columbus Division (BCD) by the team members are normalized or averaged by Battelle Columbus Division (BCD) for integration into the Manufacturing Cost/Design Guide (MC/DG) formats.

Part Cost: Base-part cost with cost of any complexities.

Parting Line: The intersection of the surface of the impression and the parting plane. Also the flash line on a forging.

Parting Plane: The dividing plane between the two halves of a pair of forging dies.

PF&D: "Personal Fatigue and Delay." The nonproductive portion of a worker's daily labor which includes attending to personal needs, equipment failures, and other idle time.

Pickling: Chemical treatment to remove scale from metal.

Piercing: Forming a hole in sheet metal with a pointed punch with no metal slug fallout.

Planish: Rolling a forging, or some portion of a forging, in a pair of dies to remove the trim line or to obtain close tolerances. Generally a cold press or hammer operation, but performed at a low temperature at times.

Planning Function/Methods: The procedures by which the operational sequence for fabricating tooling is established.

Platter: The entire mass of metal upon which the hammer performs work, including the flash, sprue, longhold, and as many forgings as are made at a time.

Performing: A forming operation to prepare the sheet metal for subsequent operations.

Press Forging: A forging produced by a mechanical or a hydraulic press.

Pressing: The product or process of shallow drawing sheet or plate.

Processing Equipment: Facilities used to process parts by chemical treatment, heat treatment, painting, etc.

Product Assurance: The planned interdisciplinary and systematic establishment and application of all quality assurance, quality control, reliability and maintainability actions necessary to provide adequate confidence on an independent basis that requirements are properly

specified; that the design will achieve these requirements; that adequate tests, inspection and evaluation systems are established to detect nonconformance; and that the final product will perform the intended function(s) in the operational environment for the designed life cycle.

Proof: Any reproduction of a die impression in any material (see Lead Cast).

Punch: The operation of shearing out a slug in a forging to produce a hole.

Punch: The part of a tool that forces the metal into the die during blanking, coining, drawing, embossing, forging, powder molding or similar operations.

Punching: A process in which a hole is produced in a metal part by penetration of a punch through the metal into a fitted matching die.

Punch Press: (a) In general, any mechanical press. (b) In particular, any end-wheel, gap-frame press with a fixed bed used in piercing.

Punch Section: A section of the punch used in cutting, forming, or flanging operations which is fastened to other sections to make up the complete punch working edge.

Quality: The composite of all the attributes or characteristics including performance of an item or product.

Quality Assurance: The planned and systematic establishment of all actions (management/engineering) necessary to provide adequate confidence that nonconformance prevention provisions and reviews are established during the design phase and performed throughout the product manufacturing and life cycle phases.

Quality Control: The planned and systematic application of all actions (management/Technical) necessary to control raw materials or products and detect nonconforming material or products through the use of test, inspect, evaluate, and audit techniques.

Quench Aging: A phenomenon that occurs naturally in materials following rapid cooling from an elevated temperature. The result is usually an increase in hardness and a decrease in ductility.

Realization Factors or Variance: Those factors which account for the percentage difference between standard hours and actual shop performance in the airframe industry. Realization factors represent elements, which are generally applied as multipliers to the base standard hours, to arrive at an "estimated real-time" total cost to manufacture a part.

Recurring Tooling Costs: Costs incurred by planning and tool maintenance.

Restrike: Subsequently striking a forging in dies to align its several components.

Roller: A preparatory operation in a set of drop forging dies, designed to move bar forging stock into various forms of revolution so that the metal is distributed suitably for further forging in drop forging dies.

Roll Forming: A process in which coil sheet or strip metal is formed by a series of shaped rolls into the desired configuration.

Rolling Edger: An edger and a roller combined for the distribution of metal for further forging in drop forging dies.

Run Time: Base standard hours for the repetitive elements comprising the job or operation.

Sandblast: To clean forgings by propelling sand at high velocity by air pressure.

Scale: The oxide film that is formed on hot metal by chemical action of the surface metal with the oxygen in the air.

Scale Pit: A surface depression formed on the forging due to scale in the dies during the forging operation.

Setup Time: The standard hours required to make ready or to prepare for the performance of a job or operation. These hours also include teardown or cleanup efforts to return the areas and equipment to that condition necessary to undertake a different operation normally assigned to the work place or equipment.

Shank: That portion of a tool by which it is held in position during use.

Shape Weight: The weight of material contained in the geometric volume to the specified dimensions.

Shearing: A cutting operation in which the work metal is placed between a stationary lower blade and movable upper blade and severed by bringing the blades together. Cutting occurs by a combination of metal penetration and actual fracture of the metal.

Shoe: A holder required as a support for the stationary portion of trimming or forging dies.

Shotblast: Cleaning forgings to free them of scale by propelling fine steel shot at high velocity through centrifugal force on the surface of the forging.

Shrinkage: The contraction of metal when cooled.

Sink: The specialized operation of machining impressions into forging dies.

Size: The operation in a press to obtain closer tolerances on portions of a forging.

Sizing: A metal forming operation in which a formed part is more accurately shaped by restriking between an accurately fitted punch and die.

Slotting: A stamping operation in which elongated or rectangular holes are cut in a blank or part.

Soaking Heat: Holding the metal at a desired temperature sufficiently long so as to permit the metal to reach a uniform temperature.

Sprue: The portion of the die which is machined out to permit a connection between multiple impressions or between the impression and the forging bar. Sometimes called gate.

Standard Hours: The industrial engineering base standard hours (IEBSH) to perform a specific factory task, operation, or work element. This does not refer to any specific industrial engineering methods and time measurement systems.

Standard Manufacturing Method: The factory operations and facilities used to fabricate parts to the required configuration or shape.

Standard Tools: Common shop tools that are not chargeable to a specific contract. Examples of such tools are perishable items such as drills, reamers, cutters, files, etc.; and portable equipment such as drill motors, rivet guns, squeezers; and brake and joggle dies, etc.

Straighten: Decreasing misalignment between various sections of a forging.

Strain Aging: A phenomenon that occurs in some materials following plastic deformation. In low carbon steel sheet, strain aging results in a return of discontinuous yielding, and increase in yield strength and hardness, and a decrease in ductility without substantial change in tensile strength.

Strain Hardening: An increase in hardness and strength caused by plastic deformation at temperatures lower than the recrystallization temperature. Sometimes referred to as work hardening.

Stretch Forming: A process in which a sheet section is formed over a block of the required shape while the blank is held in tension.

Support Function Modifier: Supplemental costs or man-hours, other than factory labor, added by the Manufacturing Cost/Design Guide (MC/DG) industry user to the base-part cost to account for elements such as planning, quality control and assurance, manufacturing engineering, and graphics.

Support Functions: Planning, quality control and assurance, and other functions which are not hands-on efforts, but are often charged as direct labor to the cost of producing the part. This depends on individual company policy.

Swage: Operation of reducing or changing the cross-sectional area of diameters by revolving the stock under fast impact blows.

Tempering: See Drawing.

Template: A gage or pattern made from a sheet and used to lay out or check dimensions on forgings or dies.

Test, Inspection, and Evaluation (TI&E): TI&E are three techniques utilized to carry out quality control activities. Specific techniques are used to determine whether materials, components, and/or end items conform to specified standards, specifications, and/or requirements. The TI&E techniques are normally addressed with specific detail in the quality control inspection plan or equivalent documents.

Tolerance: The permissible deviation from the specifications.

Tonghold: The portion of the stock by which the operator grips the stock with tongs during the forging operation.

Tool Engineering/Tool Planning Function: The effort required to establish the plan for construction of project tools.

Tool Fabrication Costs: Man-hours or costs to make a tool.

Tool Family: The tools required to fabricate a particular detailed part.

Total Tool Costs: Man-hours or costs to fabricate a tool, including materials, design, and planning costs.

Trim: To remove the flash or excess metal from a forging by a shearing operation. May be done hot or cold.

Trimmer: The dies used to remove the flash or excess stock from the forging.

Trimming Shoe: The holder used to support the trimmer.

Tumbling: A process for removing scale from forgings by impact with each other, together with jacks, sawdust, and abrasive material in a rotating container.

Type: A hardened block machined to the shape of a portion of the required forging and tapped in that part of the die impression to determine its shape.

Undercut: Sections which would lock themselves into an impression and prevent removal without distortion if driven into the impression while the metal was hot.

Underfill: The portion of a forging which does not have its true shape due to insufficient metal in the die.

Upset: Working metal so that the cross-sectional area of a portion or all of the stock is increased.

Upset Forging: A forging in which the metal has been placed in the die so that the direction of the fiber structure is at right angles to the faces of the die.

Weight: See Shape Weight, Net Weight, Gross Weight, Cut Weight, Multiple Bar Weight, Consumed Weight.

Weld: Uniting metal by the application of heat.

Yield: The quotient from dividing the net weight or the shape weight by the gross weight (see Final Yield).

SECTION 3.0

COST-DRIVERS IN DESIGN AND MANUFACTURE

While opportunities to reduce cost must always be pursued by designers, the ability to do so will depend largely on how advanced the aerospace system is. For example, some materials must be used for temperature or corrosion resistance, yet these materials may be associated with cost-drivers related to forming or machining. However, a knowledge of cost-drivers for various manufacturing technologies is important to designers in this quest to minimize cost. Being aware of cost-drivers at the conceptual design phase will, in particular, enable designers to address these prior to the form, fit, and function requirements that become evident at the detail design phases. Furthermore, a knowledge of the various cost-drivers will improve interaction with materials engineering, manufacturing engineering and test, inspection and evaluation (TI&E) specialists.

Of particular concern at the conceptual design phase are those designer influenced cost elements (DICE) that increase the manufacturing cost of the parts, assemblies or installation over a lower cost design which may meet the vehicle structural requirements. Designer influenced cost elements are frequently sensitive factors, which by minor variation or selection, can cause major increases or decreases in manufacturing cost. However, there are many cost-drivers over which the designer has little or no control and these must be addressed in the process of strengthening design/manufacturing. Examples of cost-drivers for various manufacturing technologies are provided below. These are intended to stimulate awareness on the part of the designer and during the interactions with materials and manufacturing technology engineers. For many of the cost-drivers, manufacturing man-hour data and relative costs are presented in cost-estimating data (CED) and cost-driver effect (CDE) formats, respectively, to first, guide the designer to the lowest cost component and/or assembly and second, enable trade-off analyses to be conducted. Examples of cost-drivers in the various technologies are listed below.

3.1 Adhesive Bonding

- Material types and combinations
- Number of detail parts
- Panel size
- Complexity
- Tolerances
- Skin padding
- Honeycomb core
- Number of bonding stages

- Curing methods
- Tooling
- Equipment requirement
- Quality assurance.

3.2 Castings

- Material type
- Casting processes
- Size
- Structural classification
- Complexity
 - Isolated masses
 - Fillet radii
 - Length/diameter ratios
 - Through and blind holes
 - Web thicknesses and configurations
- Heat treat condition
- Quantity
- Cast condition vs. required finish
- Subsequent machining required
- Test, inspection and evaluation requirements.

3.3 Composite Structures

- Part size and configuration
- Material type and form
- Tape width
- Design allowables
- Number of plies
- Ply orientation
- Inserts/cutouts
- Doublers
- Tabs or clips
- Surface requirements (influencing tooling)
- Resin type
- Curing cycle (multi-stage or cocuring)

- Debulking requirements
- Layup method (manual or automatic)
- Tape cutting (manual or automatic)
- Edge treatment requirements
- Tolerances
 - Base part configuration
 - Laminate thickness
 - Minimum radii
 - Fit-up
- Coatings
- Lightening protection
- Assembly of discrete parts
 - Mechanical fastening
 - Adhesive bonded
 - Cocuring
- Test, inspection and evaluation
 - Receiving and storage (certification, chemical verification, age control, etc.)
 - In-process handling and layup (ply preparation, orientation and count, discrepancy frequency, etc.)
 - Cure cycle (preparation and monitoring)
 - Laminate (quality/voids/porosity).

3.4 Diffusion bonding

- Complexity
- Size
 - Available equipment capacity
 - Support tooling
- Equipment costs
- Cross-sectional characteristics
 - Thick/thin sections
 - Nonuniform thicknesses
 - Thin webs with large bosses
 - Angular surfaces and closed angles

- Weight
 - Available heating and pressure capacities
- Dimensional and surface tolerances
- Material lead-time
- Material utilization.

3.5 Extrusions

- Extrusion Material
 - Aluminum alloy/titanium
 - Quantity
 - Shape--solid/semi-hollow/hollow
 - Extrusion factor ($\frac{\text{Perimeter}}{\text{Lb/ft}}$)
 - Tolerances
 - Surface finish.
- Extrusion Fabrication
 - Trim
 - Joggles
 - Contour--cylindrical/noncylindrical
 - Heat treatment
 - Stretch percentage
 - Surface finish.

3.6 Filament Winding

- Certain fibers, e.g., graphite
- Certain resins
- Material losses (resin remaining at end of shift)
- Component shape and diameter
- Laminate thickness
- Bosses, holes and inserts
- Surface finish requirements
- Sealing requirements
- Lot sizes
- Tooling (mandrels and autoclaves)
- Quality control of materials

- Pressure proof testing
- Test, inspection and evaluation.

3.7 Forging

- Materials
- Forging process
- Size
- Tolerances
- Quantity
- Complexity
 - Section thicknesses
 - Length/width/height relationships
 - Draft angle
 - Corner radii
- Part specifications
- Quantity, lead-time, and lot release
- Quality requirements
- Metallurgical properties and test, inspection and evaluation (TI&E).

3.8 Fusion Welding

- Material
- Type of joint
- Weld classification
- Length and number of passes
- Path complexity, e.g., straight, curved, irregular
- Pre- and post-weld processing (heat treatment and straightening)
- Size of assembly
- Welding process
 - Manual
 - Mechanized
 - Automatic
- Tooling complexity

- Equipment
- Inspection
- Proof loading
- Weld repair.

3.9 Mechanically Fastened Assembly

- Manual

- Accessibility
- Materials joined
- Number of parts
- Stack-up of parts
- Number and type of fasteners
- Close tolerances
- Sequencing
- Sealing
- Assembly size
- Quantity.

- Automatic

- Accessibility
- Part count
- Tapered fasteners
- Blind fasteners
- Multi-part fasteners
- Sealing requirements
- Shimming requirements
- Connectors/harnesses installed
- Equipment costs
- Low production rates
- Design changes.

3.10 Sheet-Metal Discrete Parts

- Material cost
- Joggles
- Flanged holes
- Beads

- Non-standard tolerances
- Lineal trim
- End trim
- Cutouts without flanges
- Routing and milling of titanium
- Hot forming
- Solution heat treatment/check & straighten
- Finish (irridite, anodize).

3.11 Superplastic Forming/Diffusion Bonding (SPF/DB)

- Plan area
- Flat vs. formed parts
- Number of sheets in configuration
- Configuration of core members
- Part salvage
- Fabrication cycle
- Equipment costs
- Tooling.

3.12 Weldbonding

- Lineal inches of faying surface
- Size (influences tooling costs)
- Quantity
 - Setup time
- Assembly classification (primary or secondary structure)
- Spotwelding (sheet thickness criteria)
- Adhesive type
- Curing cycle
- Sealing requirements
- Cleaning requirements
- Quality assurance tests.

SECTION 4.0
HOW "MANUFACTURING COST/DESIGN GUIDE" IS USED

4.1 "Manufacturing Cost/Design Guide" Design Process Interaction

It is recognized that the needs of designers at different levels, the primary users of the "Manufacturing Cost/Design Guide" (MC/DG), dictate the organization, structure, and formats of the guide sections. Therefore, a comprehensive analysis of the design process was performed in order to relate the interaction of the MC/DG with the design process.

The analysis revealed that part shape and material type would be two of the initial primary design considerations. Design factors relating to the base-part shape include loads, weight, space, and adjacent assemblies. Design factors related to the material types used for the base-part include temperature, operating environment, galvanic compatibility, available space, material allowables, heat-treatment, fracture mechanics, and fatigue considerations.

The function of the MC/DG is shown in the flow diagram in Figure 4-1, by the heavy, black-bordered boxes, while the designer functions are indicated by the broken-line blocks. The flow diagram includes the negotiable and nonnegotiable design factors. The nonnegotiable design factors are those over which the designer has little control, e.g., adjacent assembly, with regard to discrete-part design. The negotiable design elements may influence the manufacturing costs, e.g., joggles and lightening holes. The MC/DG will assist the designer in providing the lowest-cost manufacturing process for the cost/weight and performance trade-off studies.

The flow diagram depicts the relationship of the part shape and material type in the design process and follows the process through the trade study to the discrete-part selection based on lowest cost.

An analysis of the design process illustrated in the flow diagram emphasizes that the organization and formats of the MC/DG sections be structured by part shape and material type. The formats provided to the designer therefore

- (1) Show cost effect of comparable shapes
- (2) Show cost effect of material types
- (3) Give continuity and uniformity for each part shape in order to enable the designer to make quick comparisons, meeting the established MC/DG design criteria.

Designers will be reluctant to use MC/DG if they are required to readjust each time they change structural section or shapes.

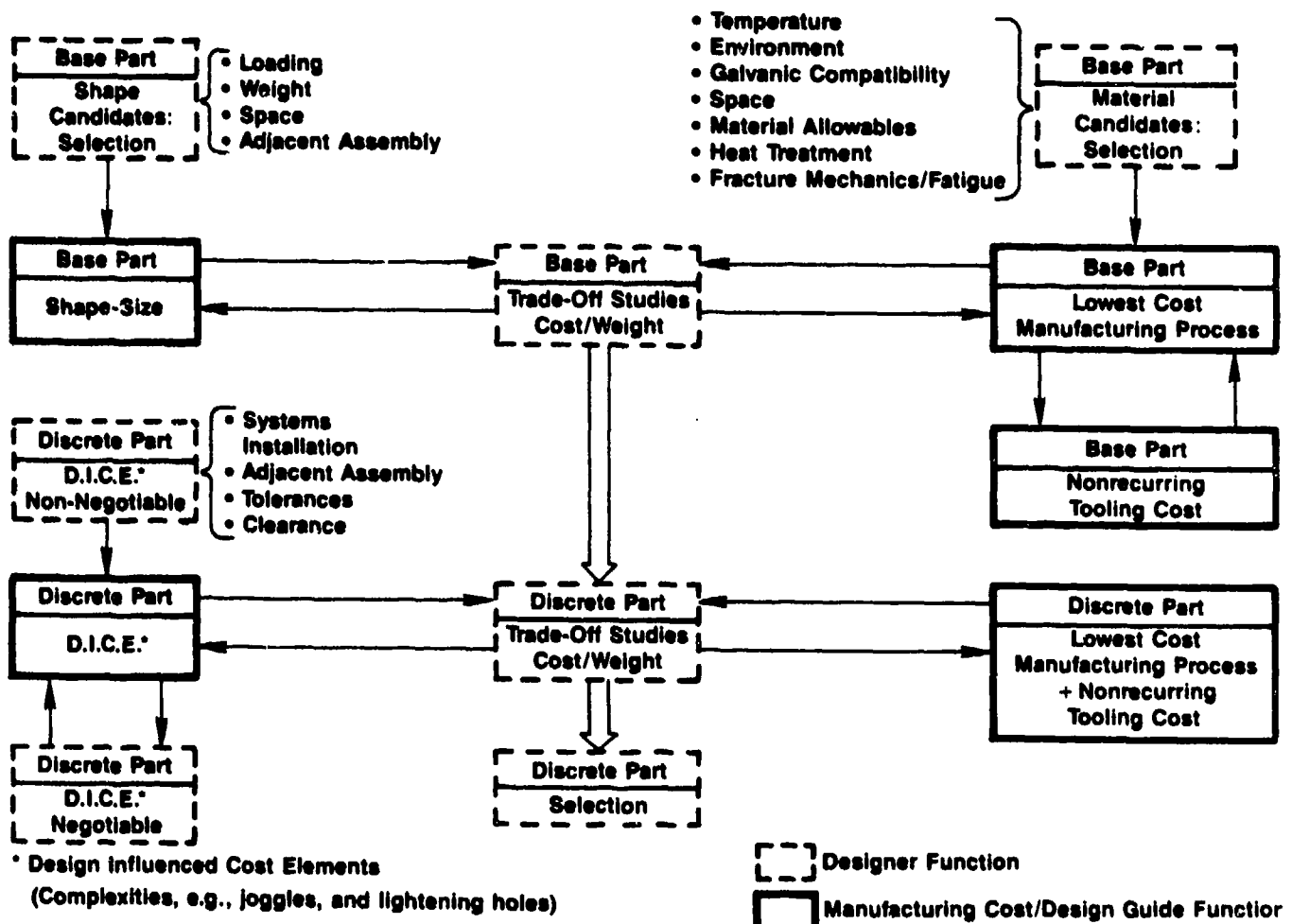


FIGURE 4-1. MANUFACTURING COST/DESIGN GUIDE DESIGN PROCESS INTERACTION

4.2 Procedure to Conduct Airframe Trade-Off Studies Utilizing MC/DG

The objectives of the MC/DG are to point the designer to the lowest cost structural candidate while meeting the design objectives, which may include

- Strength and stiffness
- Minimum weight
- Satisfactory performance at elevated temperature
- Fatigue strength
- Low maintenance
- Crashworthiness
- Corrosion resistance
- Damage tolerance
- Ease of repair.

The designer uses the following procedure to conduct manufacturing cost trade-off studies:

- (a) Develop concepts which, in the case of a fuselage panel, will require selecting or determining the
 - material
 - skin panel sizing
 - frame shape
 - number of frames required
 - stringer shape
 - number of stringers required
 - joining methods, e.g., bonding versus rivets
 - candidate manufacturing methods for each discrete part in the assembly
- (b) Determine manufacturing costs for each panel configuration

- (c) Determine assembly cost for each configuration
- (d) Determine test, inspection, and evaluation (TI&E) costs
- (e) Determine total manufacturing costs, which include materials and tooling
- (f) Determine weight of each panel assembly
- (g) Present manufacturing man-hours or costs and structural weight in summary tables and also, if appropriate, on design charts that show structural weight on the ordinate versus manufacturing cost on the abscissa.

The designer and management can then select the optimum structure (discrete part, subassembly, or assembly) with respect to structural weight and other design factors and manufacturing costs. If a manufacturing facility is committed to manufacture of other components or if a facility is not available, decisions to procure parts from outside or to utilize a more costly manufacturing method can be made quickly.

The designer, having developed candidate structural configurations to meet all design requirements, such as those listed above, then utilizes the MC/DG. The following steps are typical of those taken to arrive at a lowest manufacturing cost design:

- Step 1: After selecting materials that meet corrosion, elevated temperature, or other requirements, review the section ground rules for those materials, e.g., titanium sheet metal, or graphite/epoxy.
- Step 2: Review the ground rules of the MC/DG to determine the discrete part and assemblies analyzed.
- Step 3: Record on the designer's worksheet the Concept Number, Part Number, description, labor rate, number of parts per aircraft, design quantity, and date. Use one worksheet for each part when conducting the trade-off between parts or a separate worksheet for each subassembly.
- Step 4: Consult the overview selection aid of MC/DG showing various sections.
- Step 5: Select sections of MC/DG representing the material types and/or joining methods, e.g., sheet metal or mechanically fastened assemblies.
- Step 6: Study selection aid for each MC/DG section to be used. The selection aid will indicate the cost-driver effects (CDE) formats, cost-estimating data (CED) formats for the

manufacturing methods, and also the TI&E methods for the materials and parts analyzed in the MC/DG in accordance with the ground rules.

- Step 7: Review CDE formats providing relative cost information for the materials, parts, and assemblies being analyzed. These CDE formats will provide qualitative information leading to the lowest cost.
- Step 8: Utilize the format selection aid to determine the lowest cost manufacturing process and select the format to use. Selection aids precede the formats.
- Step 9: Study CED formats for the base parts and any required designer-influenced cost elements (DICE) using the required dimensions, e.g., length for sheet metal stringers or area for panels. Note on the designer's worksheet the total labor man-hours/part (including applicable DICE) on the cost worksheet for each discrete part in the assembly.
- Step 10: Check for applicable DICE. The format will indicate which DICE are applicable and in some cases DICE will be incorporated in the manufacturing methods for the base-part.
- Step 11: Apply the learning curve tables in the MC/DG as required. The manufacturing man-hours for each part and assembly in the MC/DG is the average value for the aerospace industry. In most cases, the average value will be sufficiently accurate for comparisons between candidate concepts meeting the design requirements. However, when a company considers it has greater or less experience than the industry average, or if the quantity is greater or less than the 200th unit analyzed in the MC/DG in accordance with the ground rules, the learning curve tables may be required.
- Step 12: From the CED chart selected, read the value (man-hours) for the nonrecurring tooling costs (NRTC). Note again that these values are for 200 parts or assemblies. Record the man-hours divided by 200 on the designer's worksheet.
- Step 13: Record the current manufacturing labor rate, including direct labor fringe benefits, and overhead charges, on the designer's worksheet.
- Step 14: Using the same procedure as for manufacturing methods, determine TI&E manufacturing man-hours from that section

of the MC/DG and record the TI&E recurring and nonrecurring tooling costs on the designer's worksheet.

Step 15: Insert the cost of materials based on furnished data in the company and enter that cost per part in dollars on the designer's worksheet.

Step 16: Consult instructions accompanying the designer's worksheet to determine aerospace vehicle program cost for the discrete part and assembly.

Step 17: Compare results from the designer worksheets for each part and/or subassembly and, if desired, enter on a diagram (graph) showing weight versus manufacturing cost and compare each concept. In the case of a supersonic aircraft, management and the customer may elect to sacrifice some manufacturing cost for improved performance or, in the case of a low-speed aircraft, to sacrifice some performance for lower manufacturing cost.

Using this procedure, the designer will have compared different design concepts, possibly using different materials, e.g., sheet metal versus composites or castings versus a built-up metal assembly. With each analysis conducted in accordance with the same general ground rules, e.g., lot sizes and design quantity, the designer and management can be confident in the results.

4.3 Utilization of Learning Curve

The learning curve (LC) theory, developed from historical manufacturing cost data, is a mathematical means of expressing the reduction in manufacturing labor as an aerospace program proceeds through the production phase. The LC theory states that "as the production quantity doubles, the labor required to produce a unit is reduced by a constant percentage." For example: for an 80-percent LC, the labor required to produce the second unit is 80 percent of that required to produce the first unit; the labor required for the fourth unit is 80 percent of that required for the second unit; etc. Table 4-1 provides examples of typical aerospace industry learning curves. Table 4-1 is useful for those designers for whom an individual company learning curve is not available.

The application of the learning curve varies among companies and the percent may be varied as a program progresses. A 70-percent LC may be used in the early phases with a change to 85 percent as production progresses. Toward the end of the program, labor turnover can result in a man-hour increase and produce a negative learning curve.

TABLE 4-1. TYPICAL INDUSTRY LEARNING CURVES

OPERATION	TYPICAL INDUSTRY LEARNING CURVE
Assembly, Controls	85%
Assembly, Electrical	80%
Assembly, Hydraulics, Pneumatic, etc.	85%
Functional Installation	65%
Plastic Fabrication	85%
Machining - Conventional	90%
Machining - Numerical Control	95%
Structural Assembly - Bench	85%
Structural Assembly - Floor	75%
Structural Assembly - Final	70%
Sheet Metal Fabrication	90%

NOTE: The above table has been included for use by designers who may not have company learning curve values readily available.

Use the above appropriate learning curve in Table 4-2 to obtain learning curve factor for design quantity involved.

**TABLE 4-2. FACTORS TO CONVERT THE MC/DG 200TH UNIT
COST TO THE CUMULATIVE AVERAGE COST
FOR THE DESIGN QUANTITY AND
LEARNING CURVE INVOLVED**

DESIGN QUANTITY	LEARNING CURVE-%						
	95	90	85	80	75	70	65
1	1.48	2.25	3.48	5.50	9.00	15.00	27.00
10	1.33	1.79	2.47	3.48	5.04	7.53	11.67
25	1.25	1.59	2.05	2.71	3.68	5.13	7.43
50	1.19	1.44	1.79	2.22	2.85	3.76	5.14
100	1.13	1.30	1.52	1.80	2.18	2.73	3.51
200	1.08	1.17	1.30	1.45	1.66	1.95	2.36
350	1.04	1.08	1.14	1.22	1.33	1.48	1.70
500	1.01	1.02	1.05	1.09	1.15	1.24	1.38
750	0.98	0.96	0.96	0.96	0.97	1.01	1.09
1000	0.96	0.92	0.89	0.87	0.87	0.88	0.91

4.4 Ground Rules

In developing MC/DG data, ground rules were important to promote understanding and to ensure consistency, uniformity, and accuracy in generating and integrating data into formats. The ground rules are in two categories, general and detailed, with the composite structures listed below.

4.4.1 General Ground Rules

The major categories of the general ground rules are

- (a) Advanced Composite Parts
- (b) Advanced Composite Materials
- (c) Manufacturing Technology
- (d) Tooling
- (e) Facilities/Equipment
- (f) Test, Inspection, and Evaluation
- (g) Interaction With Other Air Force Programs (See Section 4.6)
- (h) Data Generation - Recurring Costs
- (i) Data Generation - Nonrecurring Costs
- (j) Data Compilation and Presentation.

4.4.2 Detailed Ground Rules

The major categories of detailed ground rules are

- (a) Structural Parts
- (b) Materials
- (c) Tolerances
- (d) Support Functions.

The general and detailed ground rules for each technology being analyzed in this program are covered in Appendixes A through C.

The LC has a different slope for the various manufacturing technologies, e.g., sheet-metal, machining, joining, and bench assembly. The learning curve factor used in cost-estimating depends on both the LC percentage and the design quantity. For example, the engineering cost analysis group at the California Division, Lockheed Aircraft Systems Company, uses the historically determined LC percentage for the technology involved and also uses a design quantity, the number of airplanes to be built, regardless of the number of identical parts per airplane. Occasionally, departmental realization (standard man-hours/actual man-hours) is used instead of the LC to analyze costs of high usage operations (such as riveting and nutplate or fastener installation) that are common to many parts or assemblies.

When comparing a proposed design to an existing design in production, reductions in labor that occur during the "prior production" must be considered. For example

Design quantity - 200 airplanes

Prior production - 100 airplanes

The cost analysis would compare the cost of "existing design" units 101 through 200 to the cost of the "proposed design" units 1 through 100.

Aerospace labor costs are normally collected by cost centers, each representing a different manufacturing technology, and are not traceable to individual parts or assemblies. Labor costs are for a production lot representing a "mix" of single usage and multiple usage parts or assemblies. From these data, learning curve slopes (%) are established for the various cost centers. When estimating the cost of aerospace parts or assemblies, the appropriate learning curve factor, provided in Table 4-2, is selected by the learning curve percentage for the technology involved and the design quantity, regardless of the quantity of parts or assemblies per airplane.

4.5 Cost Worksheet for Airframe Designers

Airframe designers can utilize the MC/DG data in a number of ways. When it is necessary to determine the total cost of an aircraft subassembly, the Cost Worksheet, shown in Table 4-3, has been developed and can be used at the discretion of the designer. This table enables the program recurring and nonrecurring costs to be determined and also the cost per aircraft. A table for recording the details of the cost analysis is also provided (Table 4-4).

4.5.1 Instructions for Use of Cost Worksheet

The following are instructions for using the Cost Worksheet.

Step No.	Worksheet Column	Input	Procedure
1		Part no.	Enter identification, if available.
2		Description	Enter brief description, e.g., Stiffener, Zee, J section, etc.
3	1	Manufacturing Labor	From Cost-Estimating Data (CED) Section, determine man-hours per part at 200 units.
4	2	Learning curve (LC) factor	Based upon LC percentage and design quantity. Factor provided by user company.
5	3	Test, Inspection, and Evaluation (TI&E) labor	From "Manufacturing Cost/Design Guide" (MC/DG), enter recurring costs (RC) for TI&E (man-hours).
6	4	Labor rate	Current manufacturing labor rate including direct labor fringe benefits and overhead charges.
7	5	Labor RC	Product of Column 1 times Column 2 plus Column 3 times Column 4.
8	6	Material cost	Based upon furnished data in company utilizing MC/DG, enter material cost per part in dollars.
9	7	Recurring cost per part	Total of Columns 5 and 6.

Step No.	Worksheet Column	Input	Procedure
10	8	Parts per aircraft	Number of identical parts per aircraft.
11	9	Design quantity	Number of aircraft to be manufactured.
12	10	Program RC	Product of Column 7 times Column 8 times Column 9.
13	11	Nonrecurring tooling cost (NRTC)	From MC/DG, enter NRTC in man-hours.
14	12	NRTC for TI&E	From MC/DG, enter NRTC for TI&E in man-hours.
15	13	Labor rate	See Column 3.
16	14	Program NRTC	Columns 11 plus 12 times Column 13.
17	15	Program cost	Sum of Column 10 and Column 14.
18	16	Design quantity	See Column 9.
19	17	Cost per aircraft	Column 15 divided by Column 16.

DESIGNERS' MC/DG COST WORKSHEET

TABLE 4-4.

DETAILED COST ANALYSIS

PAGE 2 OF 2

4-13

4.6 Interaction with Other Air Force Programs for Cost Analysis

The Advanced Composites Cost-Estimating Manual (ACCEM) and Advanced Composites Fabrication Guide (ACFG) were used in generating manufacturing data. The ACCEM was a source of developing raw man-hour data for the overall data. The man-hours from the ACCEM were evaluated and modified as necessary to reflect each company's production experience and the data development ground rules.

The ACFG was used to provide background information on the manufacturing methods selected. It was used to develop standard operational sequences and to define the various tooling concepts.

The interactions among the various programs are illustrated in Figure 4-2 and detailed in the following sections.

4.6.1 Design-MC/DG Interaction

The design-MC/DG interaction

- Provides cost guidance through designer-oriented formats and data
- Identifies manufacturing cost drivers
- Permits trade-off studies by designers to determine the lowest manufacturing cost of composite structural components and/or assemblies.

4.6.2 Advanced Composite Fabrication Guide(ACFG)-MC/DG Interaction

The ACFG-MC/DG interaction

- Provides guidance in selection of structural components and assemblies for the purpose of developing designer-oriented formats and manufacturing cost data, and enables identification of the following cost-drivers on which data are required:
 - Manufacturing methods
 - Processes
 - Fabrication planning operation
 - Factory equipment
 - Tooling
 - Quality assurance.

DESIGN ENGINEERING—MC/DG—FABRICATION GUIDE—COST ESTIMATING SYSTEM INTERACTION FOR COMPOSITES

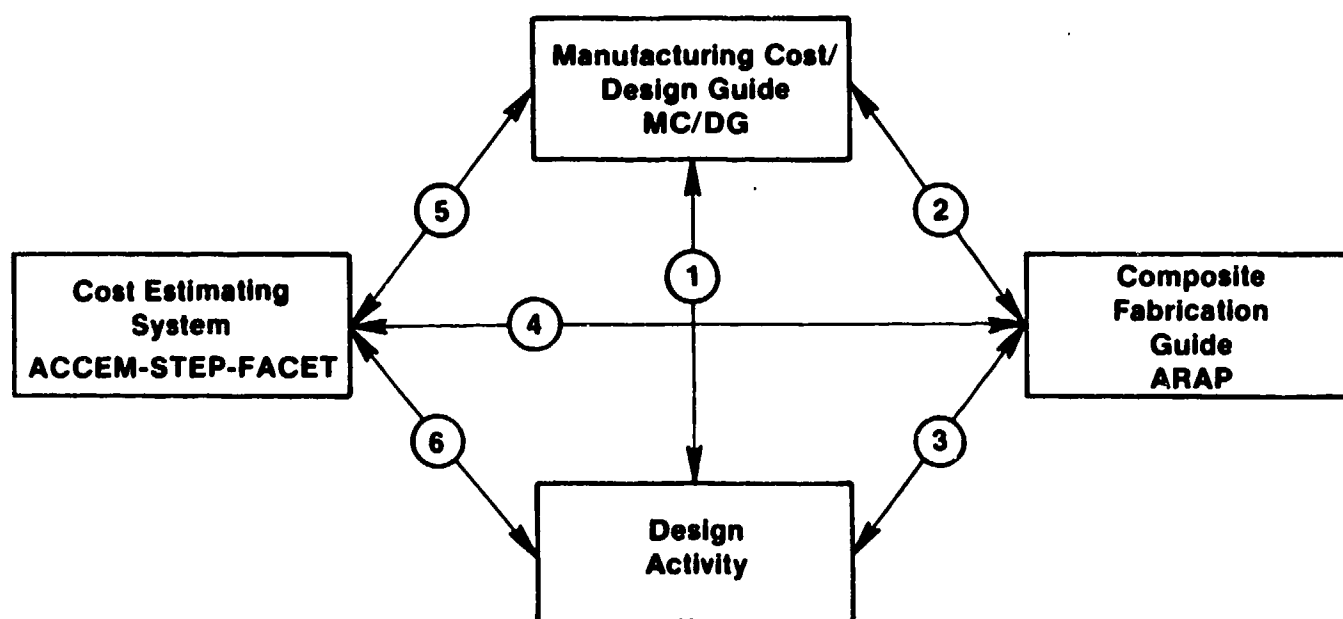


FIGURE 4-2. INTERACTIONS AMONG AIR FORCE COST ANALYSIS PROGRAMS
FOR COMPOSITE STRUCTURES AND AIRFRAME DESIGN

4.6.3 Design-Advanced Composite Fabrication Guide (ACFG) Interaction

The design-ACFG interaction

- Provides designers with manufacturing data, such as
 - Manufacturing methods
 - Processes
 - Fabrication operations (planning)
 - Tooling concepts
 - Test, inspection, and evaluation

for use in assuring that structural composite components and assemblies are designed at the lowest cost.

4.6.4 Advanced Composites Fabrication Guide (ACFG)-Cost Estimating System Interaction

The ACFG-cost estimating system interaction

- Provides manufacturing data for development of the cost-estimating data base for composite structural components and assemblies.

4.6.5 MC/DG-Cost Estimating System Interaction

The MC/DG-cost estimating system interaction

- Provides cost estimates for MC/DG data development for composite structural components and assemblies for integration into and development of designer-oriented MC/DG formats.

4.6.6 Design-Cost Estimating System Interaction

The design-cost estimating system interaction

- Provides data for cost analysis of structural configurations being considered in trade-off studies, for engineering decision making and for design-to-cost target cost programs.

SECTION 5.0 COMPOSITES FABRICATION SECTION

This section contains format selection aids, identification of the types of parts analyzed for data to determine the manufacturing man-hour data, examples of how the data are utilized in airframe design and a set of composite MC/DG formats. These formats include CDE, CED, and DICE.

5.1 Format Selection Aids

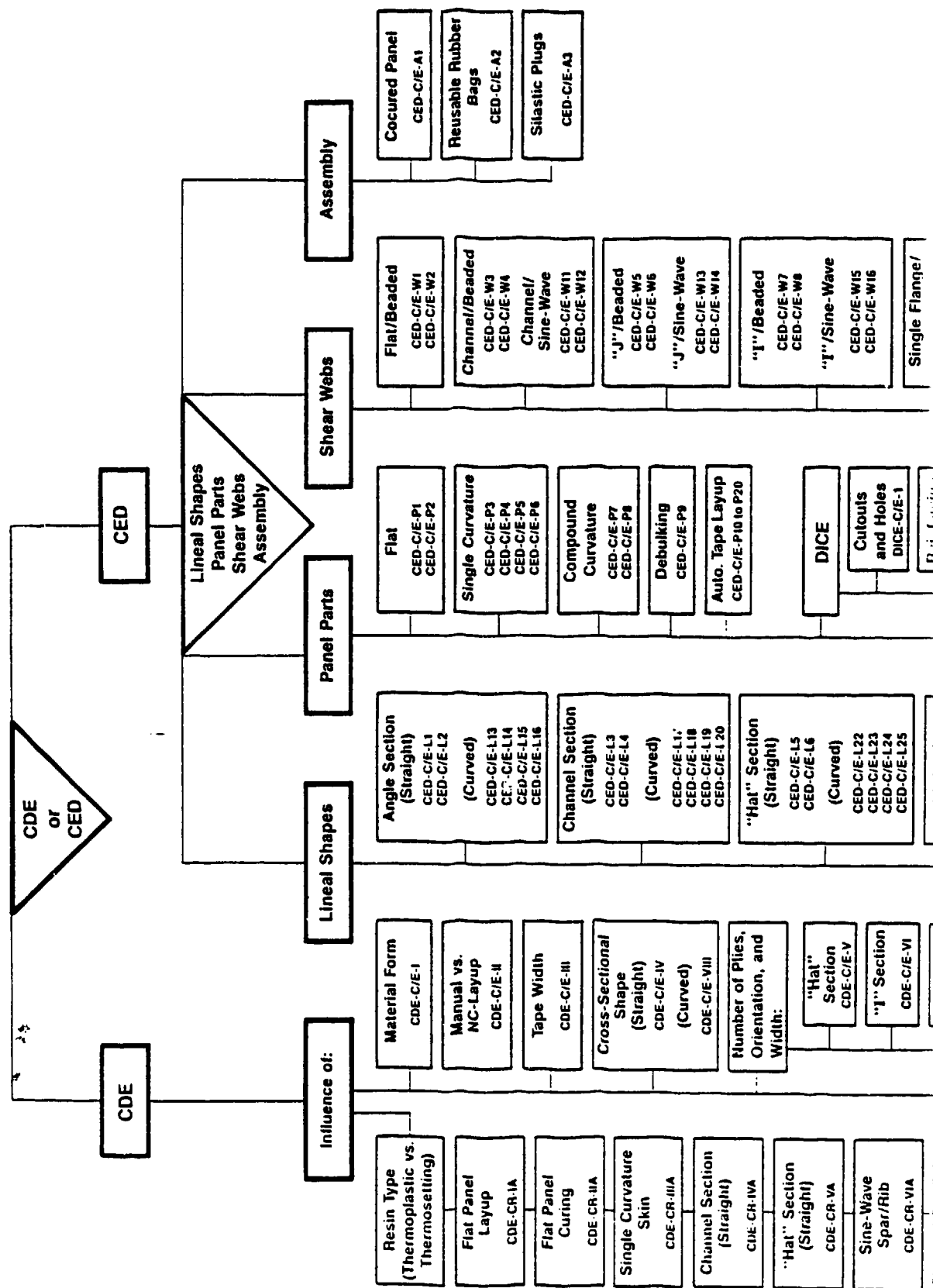
Format selection aids are presented to provide the user with a building-block approach to determine manufacturing cost data for alternative designs or processes. The designer can review the format selection trees and identify those areas that have an impact on his design. The formats provide CDE for qualitative guidance to lowest cost and CED in man-hours for conducting trade-offs.

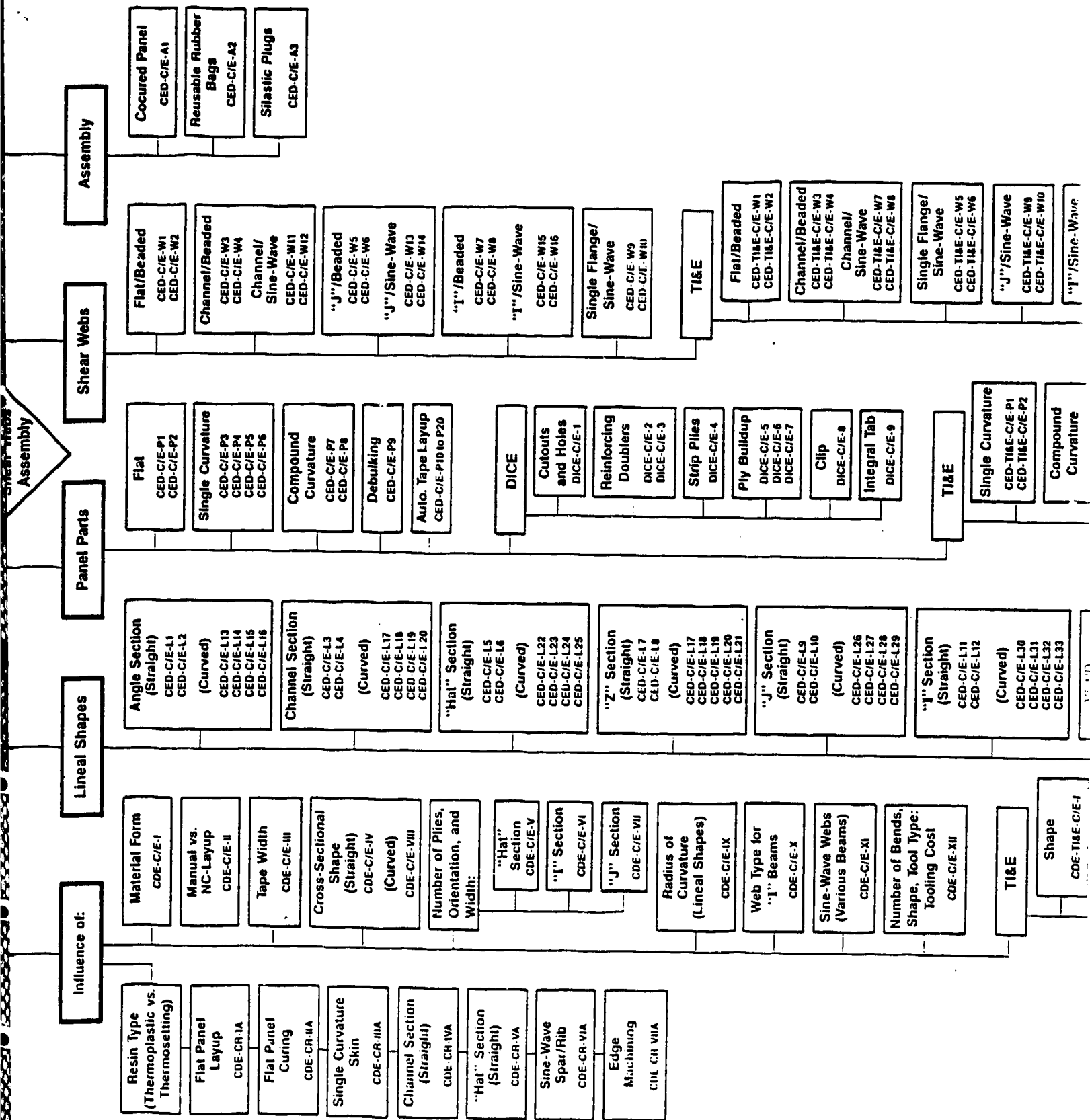
The CDE formats for designer guidance show the cost effect of material form, tape width, radius of curvature, number of plies, etc., for broad groups of airframe discrete parts and assemblies representative of aircraft types that are in production or in the design phase.

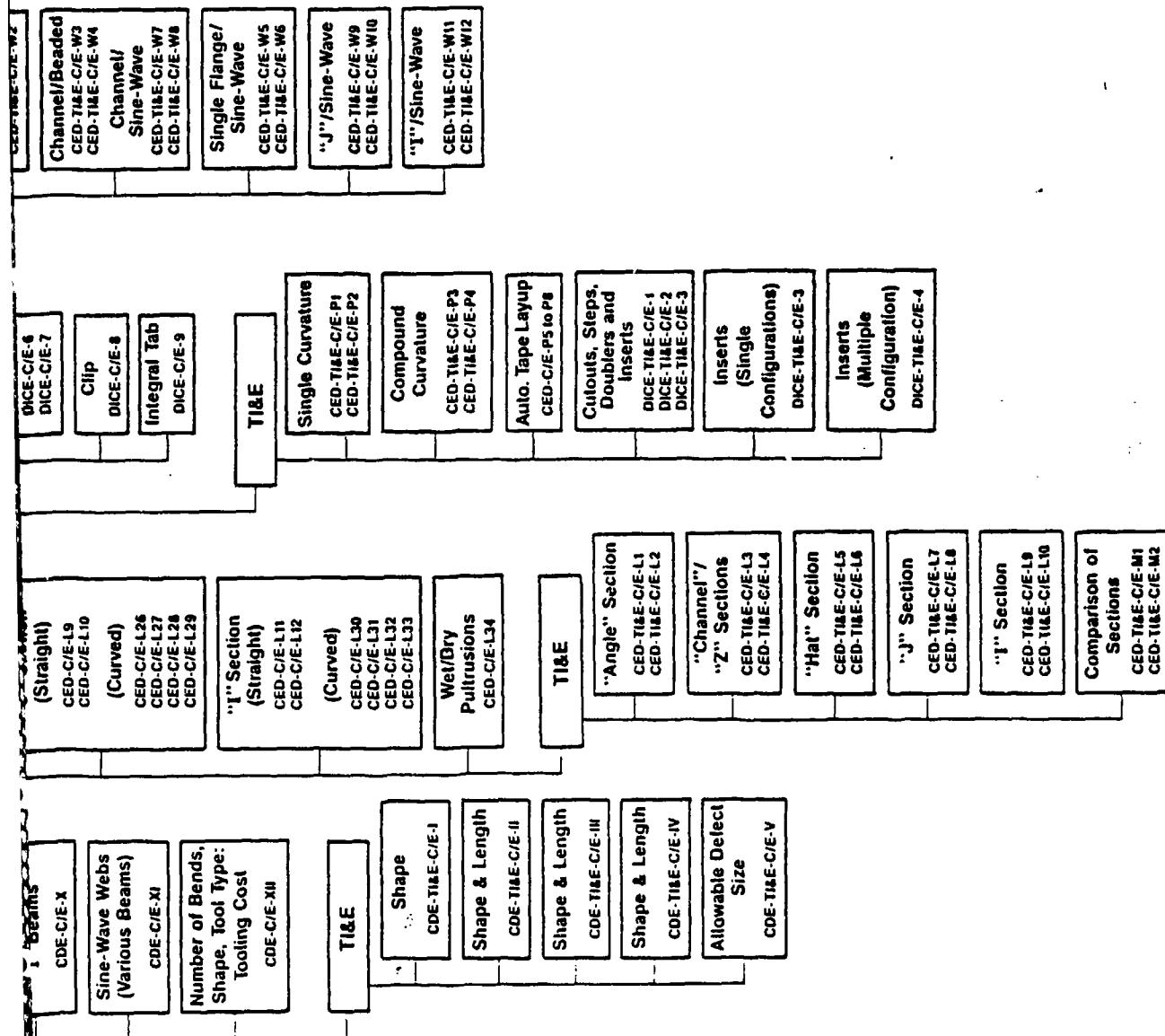
The CED formats used for cost trade-offs are included for lineal shapes, panels, and also assembly. The DICE formats shown on the Selection Aid, include strip plies, cutouts, and doublers.

FORMAT SELECTION AID

Advanced Composite Fabrication





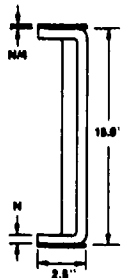


5.2 Examples of Utilization

These examples demonstrate how the data generated are utilized on specific design problems. The examples show how to identify applicable formats and extract data from the formats, and indicate how the data are used to determine the part cost in man-hours or dollars.

5.2.1 Carbon/Epoxy Channel with Sine-Wave Web

Graphite/Epoxy
Sine-Wave Web



- N = 20 Plies, L = 12 feet
- Design Quantity (DQ) = 100 parts
- Reuseable Rubber Bags
- 85% Learning Curve Assumed
- Developed Width = $(2 \times 2.5") + 15.0" = 20.0"$
- Single Channel with 2 Strip Plies

Total Cost/Part = Learning Curve (LC) Factor x Recurring Cost + Nonrecurring Costs/Design Quantity (DQ)

	<u>Recurring (MH/Part)</u>	<u>Nonrecurring (MH/DQ)</u>
(1) Lay-Up of Channel Use formats: CED-C/E-W1 & W2	21.0 MH	605 MH
(2) Lay-Up of Strip Plies (2) Use format: DICE-C/E-4	1.4 MH	
(3) Cure Strip Plies/Channel Use formats: CED-C/E-A1 & A2	4.4 MH 0.3 MH	76 MH
(4) Test, Inspection, & Evaluation (TI&E) Use formats: CED-TI&E-C/E-W7 & W8	<u>3.25 MH</u>	<u>225 MH</u>
Total:	30.4 MH	906 MH

Total Cost/Part = $(1.52 \times 30.4 \text{ MH}) + (906 \text{ MH}/100 \text{ Parts}) = 55.3 \text{ MH/Part}$.

Assuming that 1 MH Cost is equivalent to \$50, then,

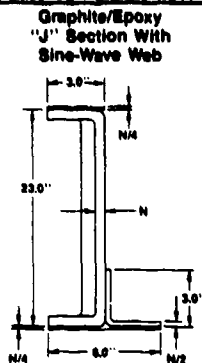
Total Cost (\$) = $55.3 \text{ MH/Part} \times 50 \text{ $/MH} = \underline{\$2,765/\text{Part}}$.

Learning Curve Factors

<u>Density Quantity</u>	<u>LC Factor</u>	<u>Density Quantity</u>	<u>LC Factor</u>
1	3.48	200	1.30
10	2.47	350	1.14
25	2.05	500	1.05
50	1.79	750	0.96
100	1.52	1000	0.89

85% Learning Curve Factor to Convert Unit 200 Format Cost to Cumulative Average Cost for Various Design Quantities.

5.2.2 Carbon/Epoxy J-Section with Sine-Wave Web



- N = 20 Plies, L = 20 feet
- Design Quantity (DQ) = 100 parts
- Reuseable Rubber Bags
- 85% Learning Curve Assumed

Total Cost/Part = Learning Curve (LC) Factor x Recurring Cost + Nonrecurring Costs/Design Quantity (DQ)

	Recurring (MH/Part)	Nonrecurring (MH/DQ)
(1) Lay-Up of Channel Use formats: CED-C/E-W3 & W4	28 x <u>0.84</u> (B-Stage) 23.5 MH	720 MH
(2) Lay-Up of Angle Use formats: CED-C/E-L1 & L2	13 x <u>0.84</u> (B-Stage) 10.9 MH	480 MH
(3) Lay-Up of Strip Plies Use format: DICE-C/E-4	0.8 + 0.7 = 1.5 MH	
(4) Cure Strip Plies/Angle/Channel Use formats: CED-C/E-A1 & A2		
● Bagging Time	9.2 MH	
● Expandable Tooling	1.0 MH	
● Handling/Prefit	0.5 MH	
● Reuseable Rubber Bags		170 MH
(5) Test, Inspection, & Evaluation (TI&E) Use formats: CED-TI&E-C/E-W9 & W10	<u>9.5 MH</u>	<u>680 MH</u>
Total:	56.1 MH	2,050 MH

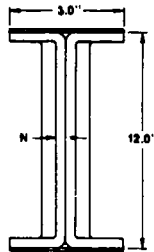
Total Man-Hours (MH)/Part = (1.52 x 56.1 MH) + (2,050 MH/100 Parts) = 105.77 MH/Part.

Assuming that 1 MH Cost is equivalent to \$50, then,

Total Cost Per Part (\$) = 105.77 MH/Part x 50 \$/MH = \$5,289/Part.

5.2.3 Carbon/Epoxy I-Section with Sine-Wave Web

Graphite/Epoxy
"I" Section With
Sine-Wave Web



- N = 32 Plies, L = 9 feet
- Design Quantity (DQ) = 100 parts
- Reuseable Rubber Bags
- 85% Learning Curve Assumed
- Developed With (Channel) = 12" + 2 (1.5") = 15"
- 2 Channels with 2 Strip Plies

Total Cost/Part = Learning Curve (LC) Factor x Recurring Cost + Nonrecurring Costs/Design Quantity (DQ)

	Recurring (MH/Part)	Nonrecurring (MH/DQ)
(1) Lay-Up 2 Channels Use formats: CED-C/E-W11 & W12	2 x 22.5 = 45 x 0.84 (B-Stage) 35.8 MH	450 MH
(2) Lay-Up 2 Strip Plies Use format: DICE-C/E-4	2 x 0.8 = 1.6 MH	
(3) Cure Strip Plies/Channel Use formats: CED-C/E-A1 & A2		
• Bagging Time	3.0 MH	
• Expandable Tooling	0.54 MH	
• Unit Cost	0.48 MH	
• Reuseable Rubber Bags		44 MH
(4) Test, Inspection, & Evaluation (TI&E) Use formats: CED-TI&E-C/E-W11 & W12	7.0 MH	575 MH
Total:	48.32 MH	1,069 MH

Total Man-Hours (MH)/Part = (1.52 x 48.32 MH) + (1,069 MH/100 Parts) = 84.1 MH/Part.

Assuming that 1 MH Cost is equivalent to \$50, then,

Total Cost/Part (\$) = 84.1 MH/Part x 50 \$/MH = \$4,205/Part.

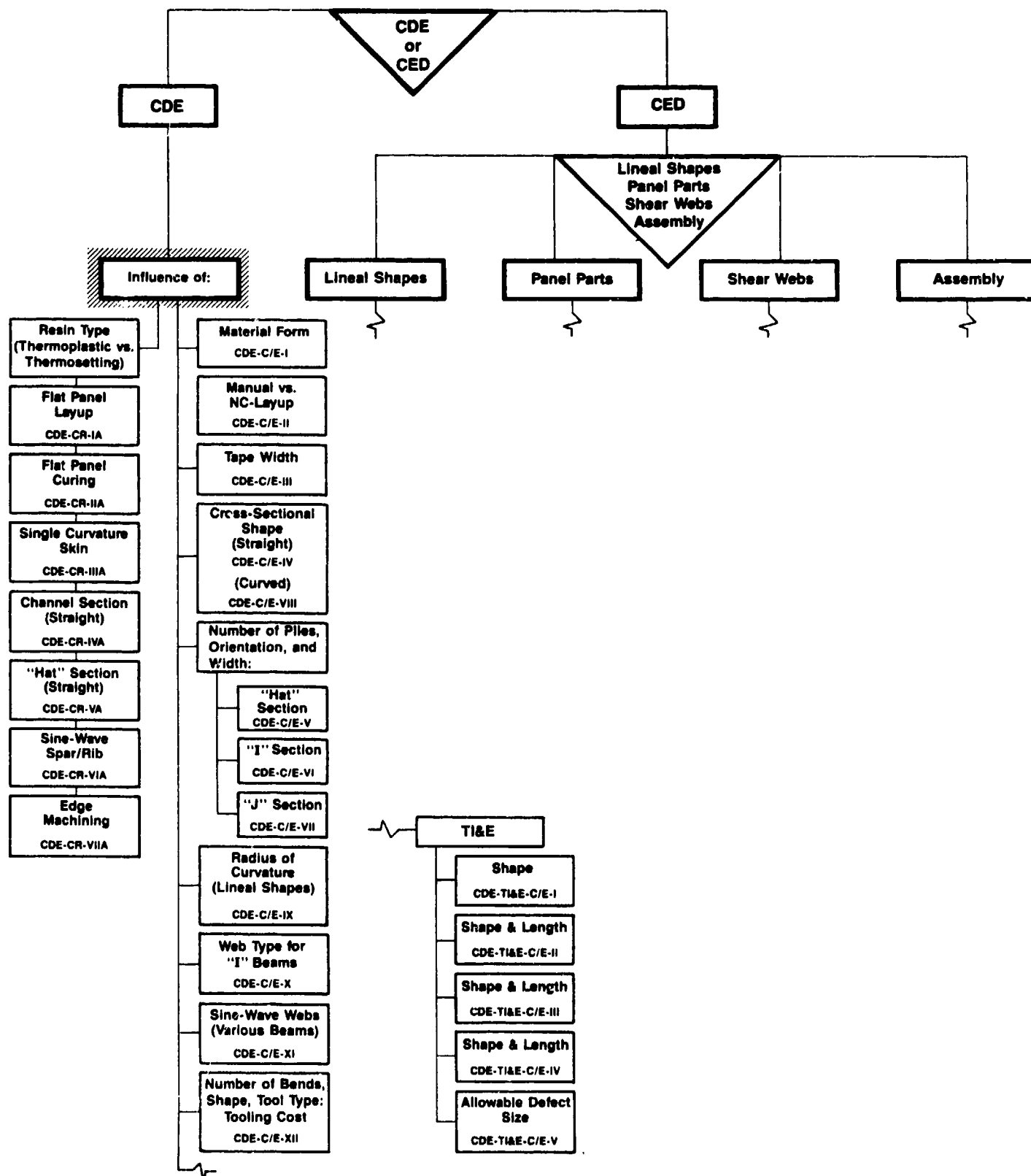
5.3 Composite Materials Data

Data/formats on the following pages identify generic part shapes studied and provide the applicable cost and charts for conducting cost trade-off studies.

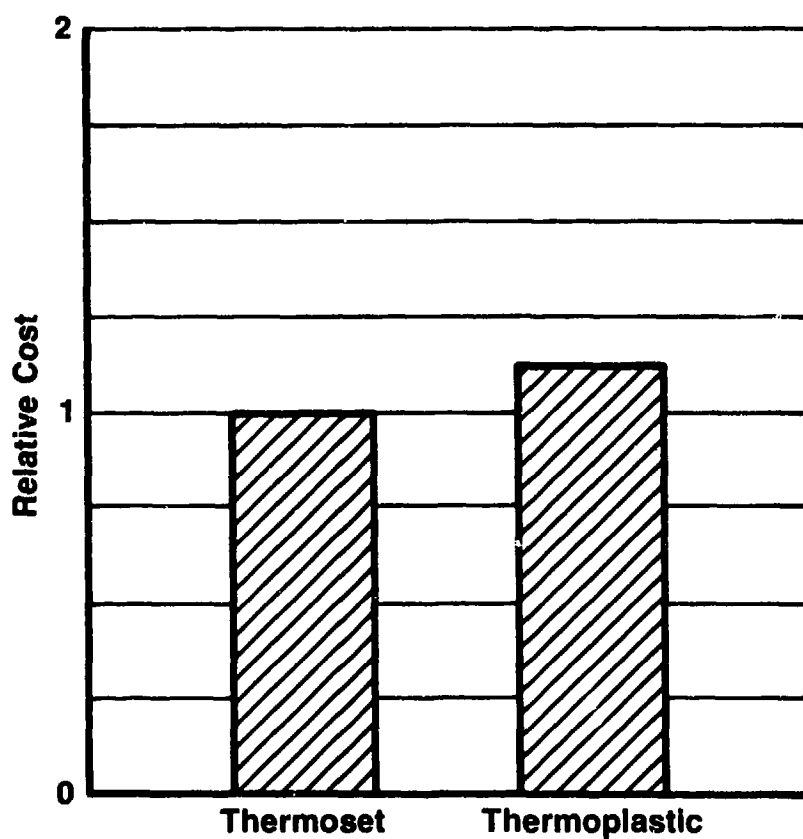
The data for lay-up of carbon/epoxy cloth and also for automated tape lay-up, varied significantly. The principal reason for the scatter in data for the latter method is the differences in installed tape-laying equipment. Such machines are still the focus of much development. Designers are therefore cautioned and recommended to utilize the formats to represent data for the specific equipment installed in their own company. The format designs will prove very useful in presenting such data to enable trade-off studies to be conducted rapidly.

FORMAT SELECTION AID

Advanced Composite Fabrication

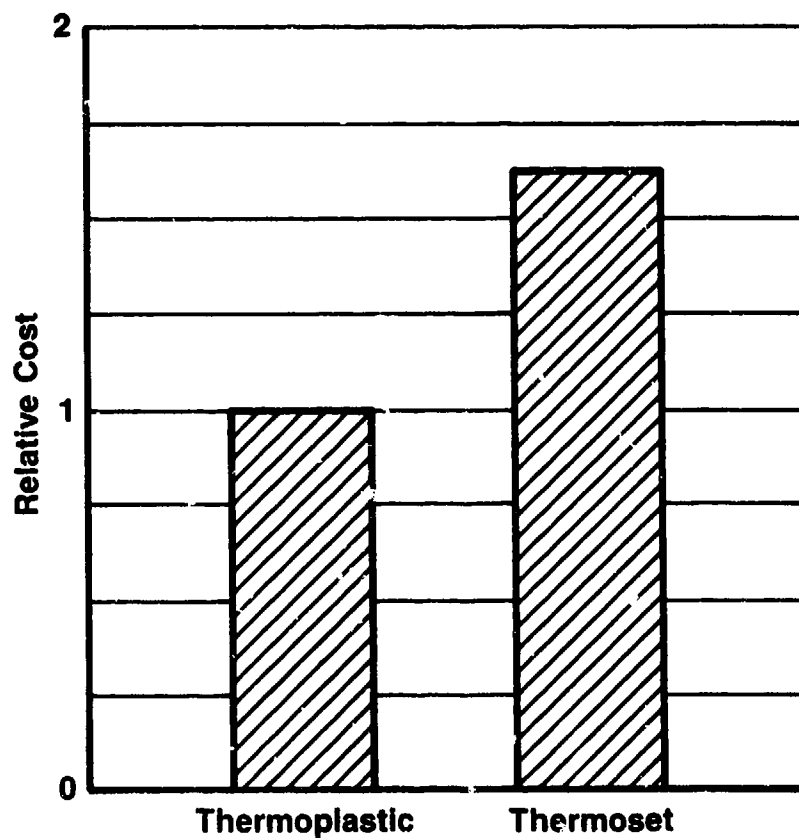


LAYUP OPERATION* OF FLAT PANELS; THERMOPLASTIC VS. THERMOSETTING MATRIX

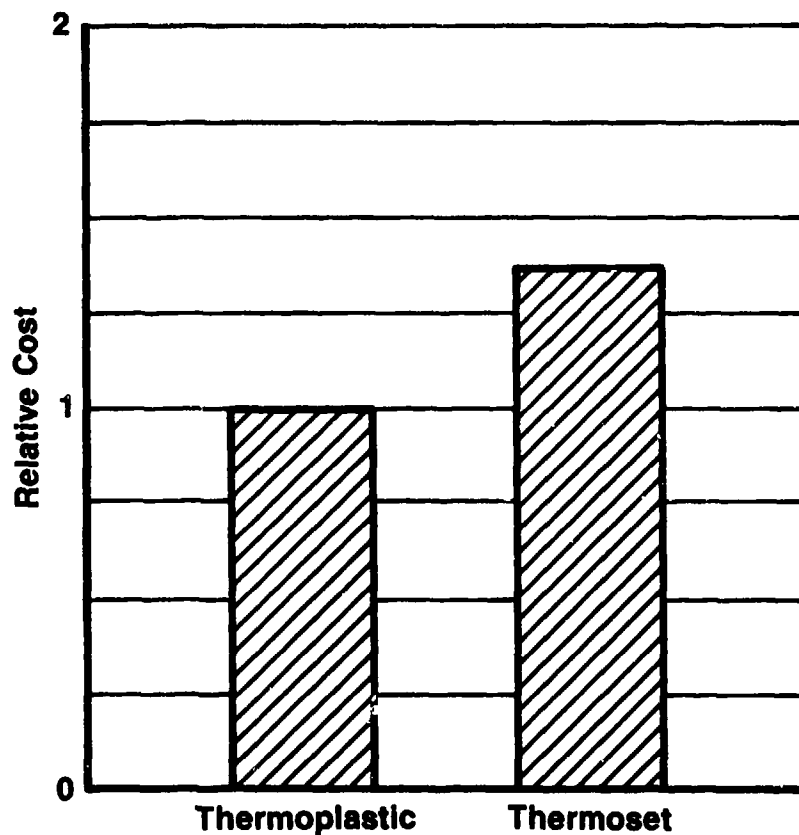


*Comparison limited to layup operation only. For complete process, see CDE-CR-IIA.

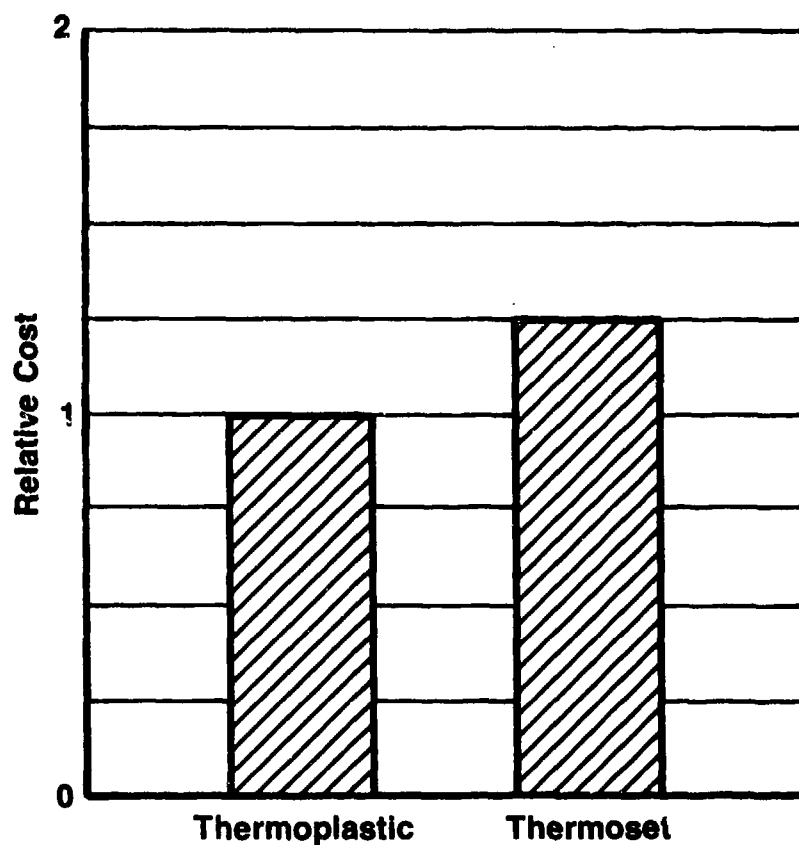
COMPLETE MANUFACTURING PROCESS FOR COMPOSITE FLAT PANELS; THERMOPLASTIC VS. THERMOSETTING MATRIX



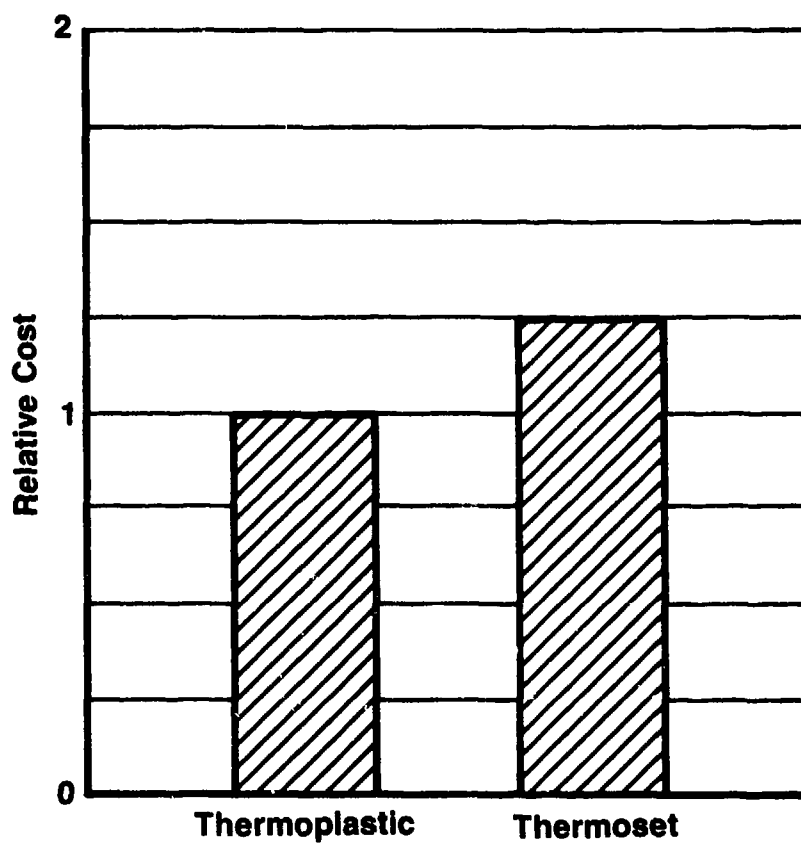
COMPOSITE SINGLE CURVATURE SKIN (TYPICAL OF LARGE FUSELAGE PANEL); THERMOPLASTIC VS. THERMOSETTING MATRIX



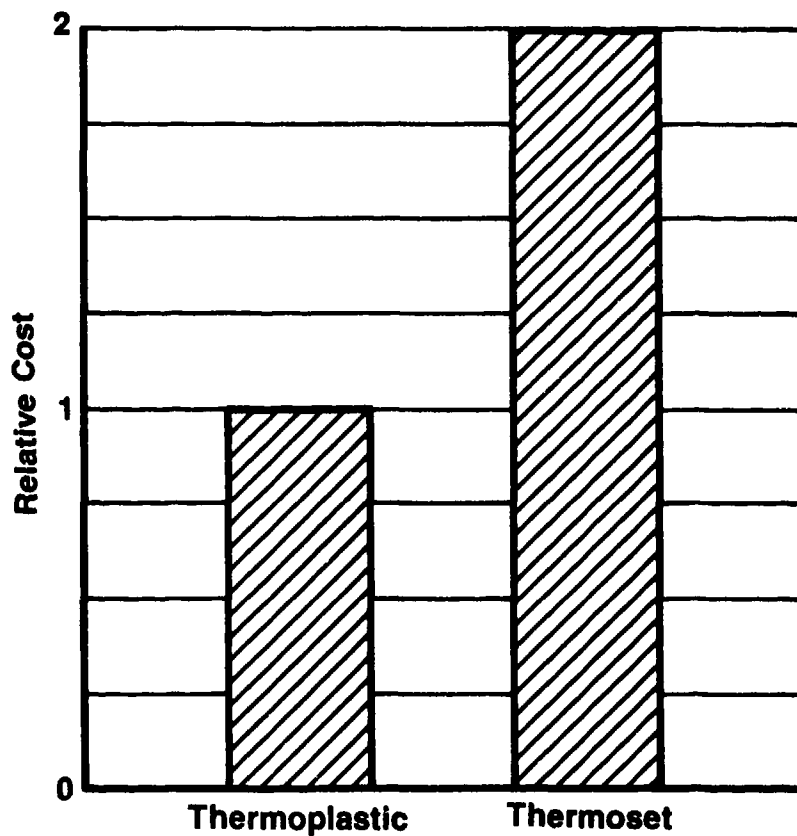
COMPOSITE STRAIGHT CHANNEL SECTION; THERMOPLASTIC VS. THERMOSETTING MATRIX



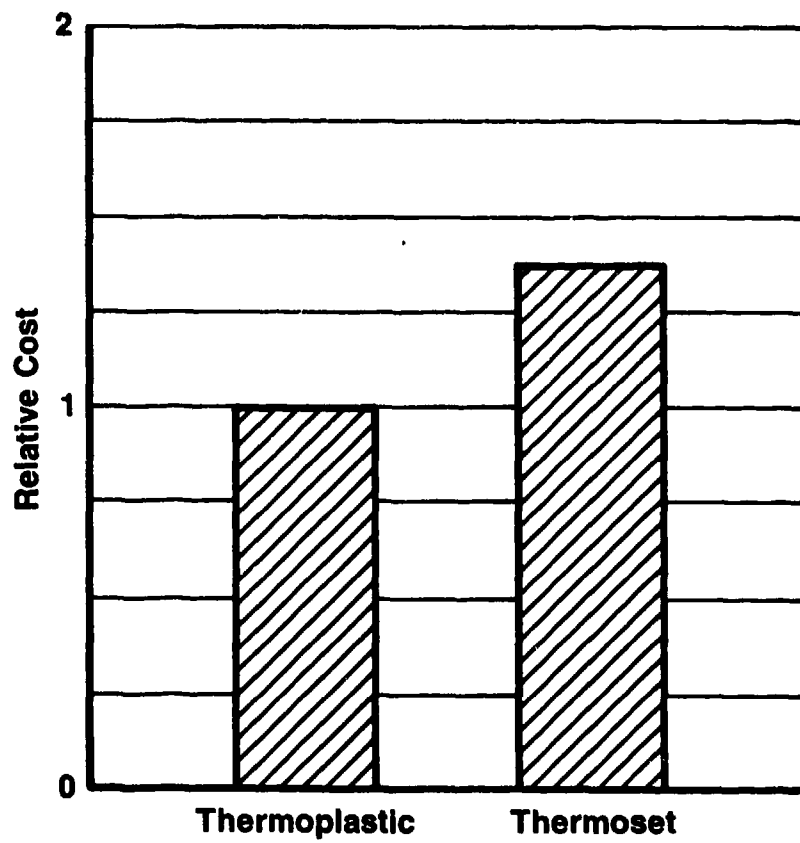
COMPOSITE STRAIGHT HAT SECTION; THERMOPLASTIC VS. THERMOSETTING MATRIX



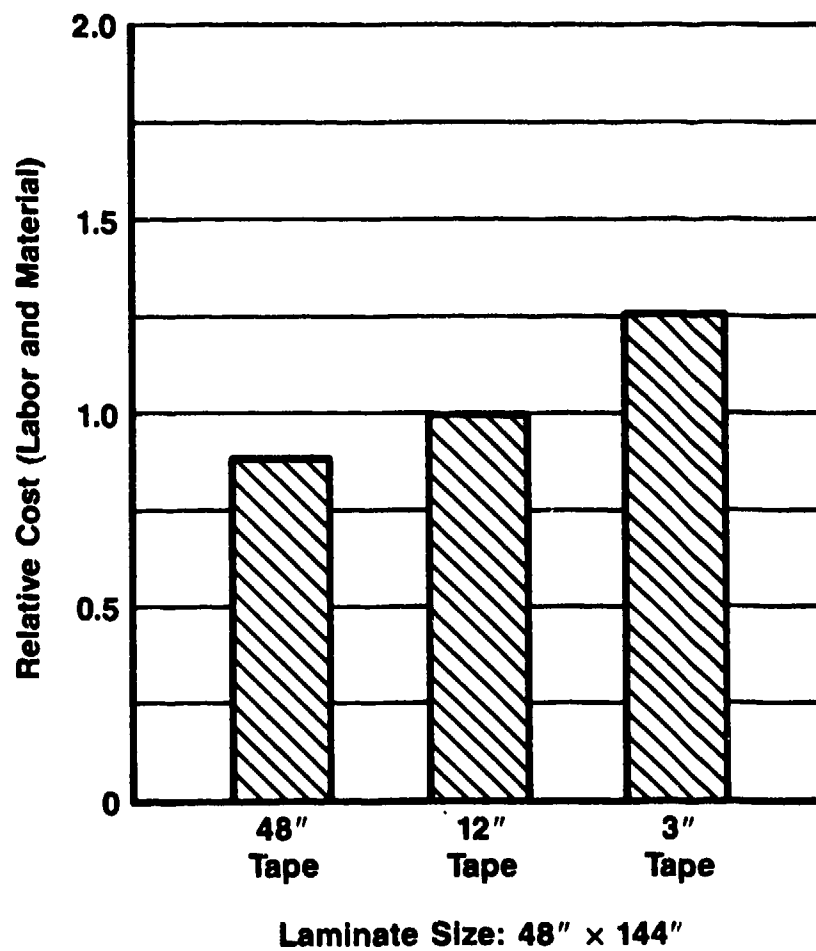
**COMPOSITE SINE-WAVE SPAR OR RIB
WITH TWO FLANGES;
THERMOPLASTIC VS. THERMOSETTING MATRIX**



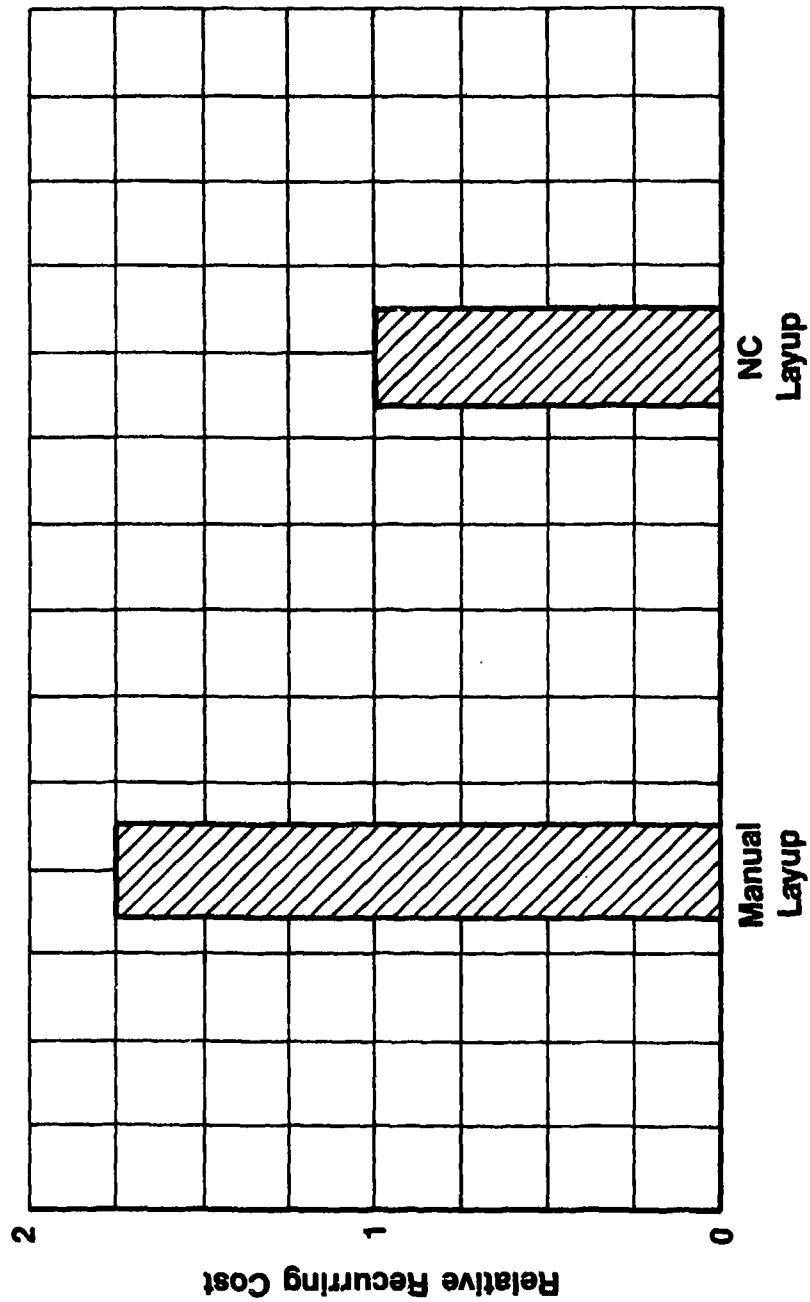
EDGE MACHINING OF COMPOSITE PANEL THERMOPLASTIC VS. THERMOSETTING MATRIX



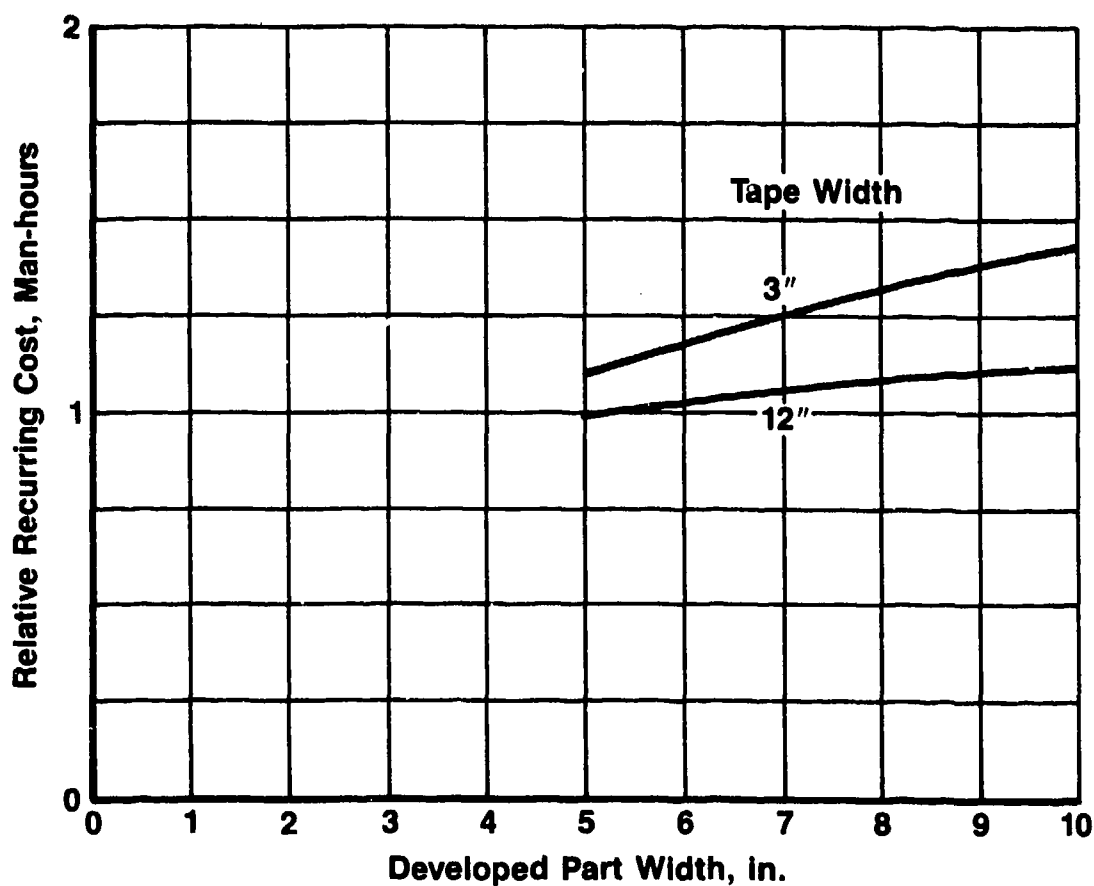
INFLUENCE OF MATERIAL FORM ON LAYUP COST



COMPARISON OF MANUAL VS. NC-LAYUP; COMPOSITE SINGLE CURVATURE PANEL



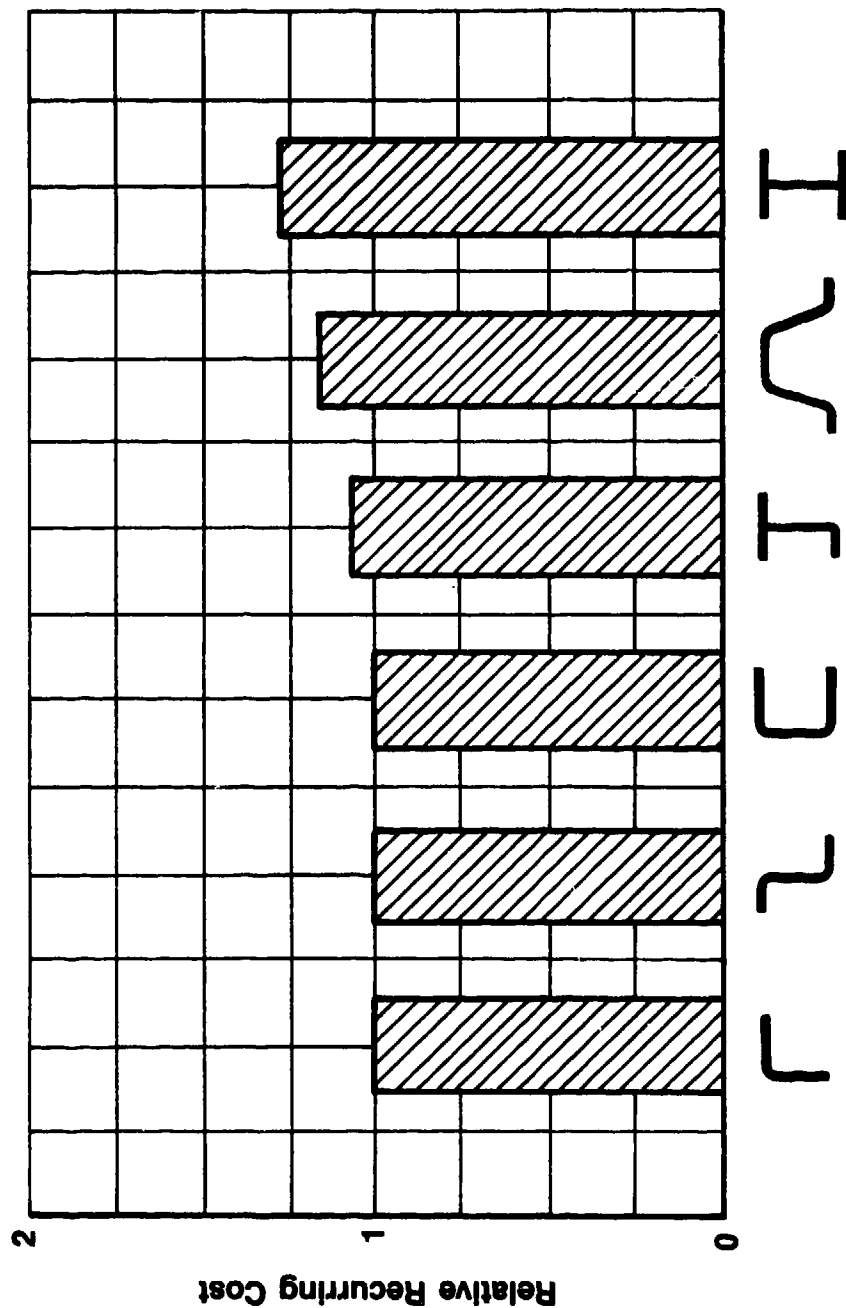
INFLUENCE OF TAPE WIDTH ON RECURRING COST OF LINEAL SHAPES



Notes:

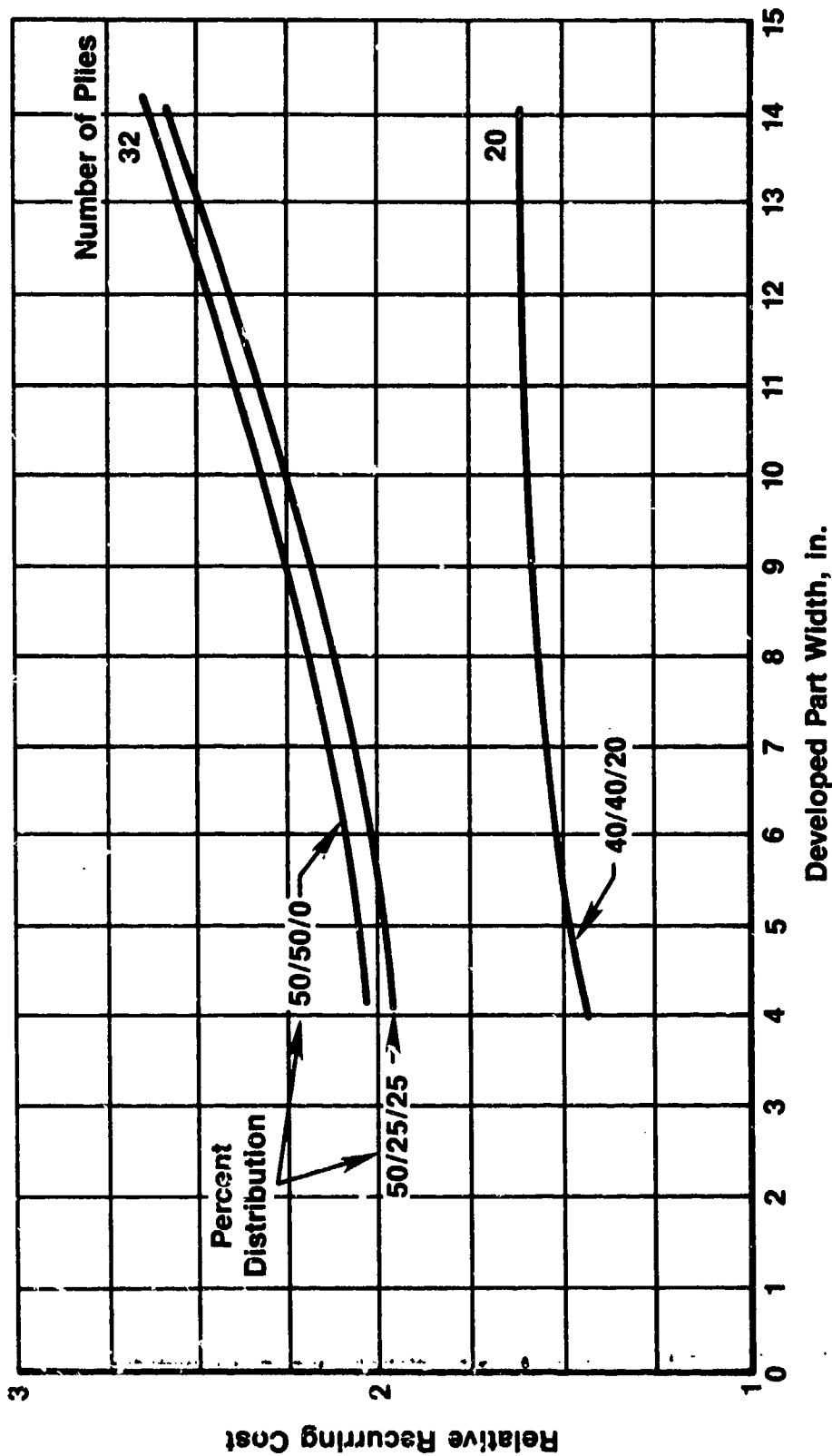
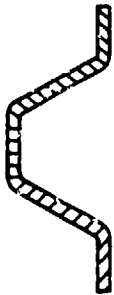
- Part Length = 48"
- No Strip Plies

INFLUENCE OF CROSS-SECTION OF COMPOSITE STRAIGHT LINEAL STRUCTURAL MEMBERS; RECURRING COST



LINEAL HAT SECTION; RECURRING COST

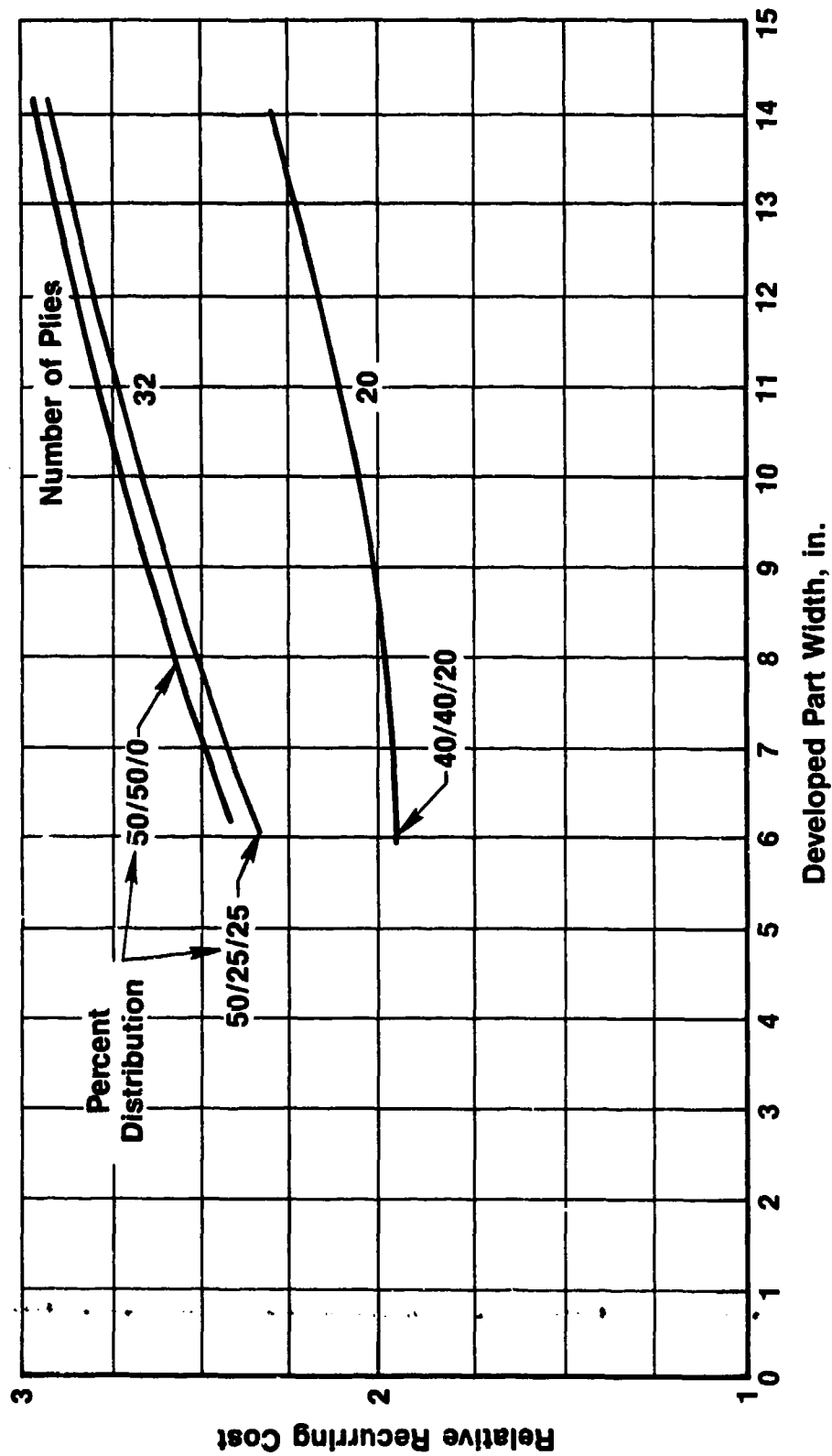
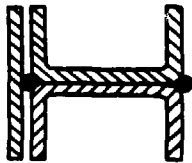
influenced by {
• Number of Plies
• Ply Orientation
• Developed Width



*Ply Orientation Code: 0°/±45°/90°

LINEAL "I" SECTION; RECURRING COST

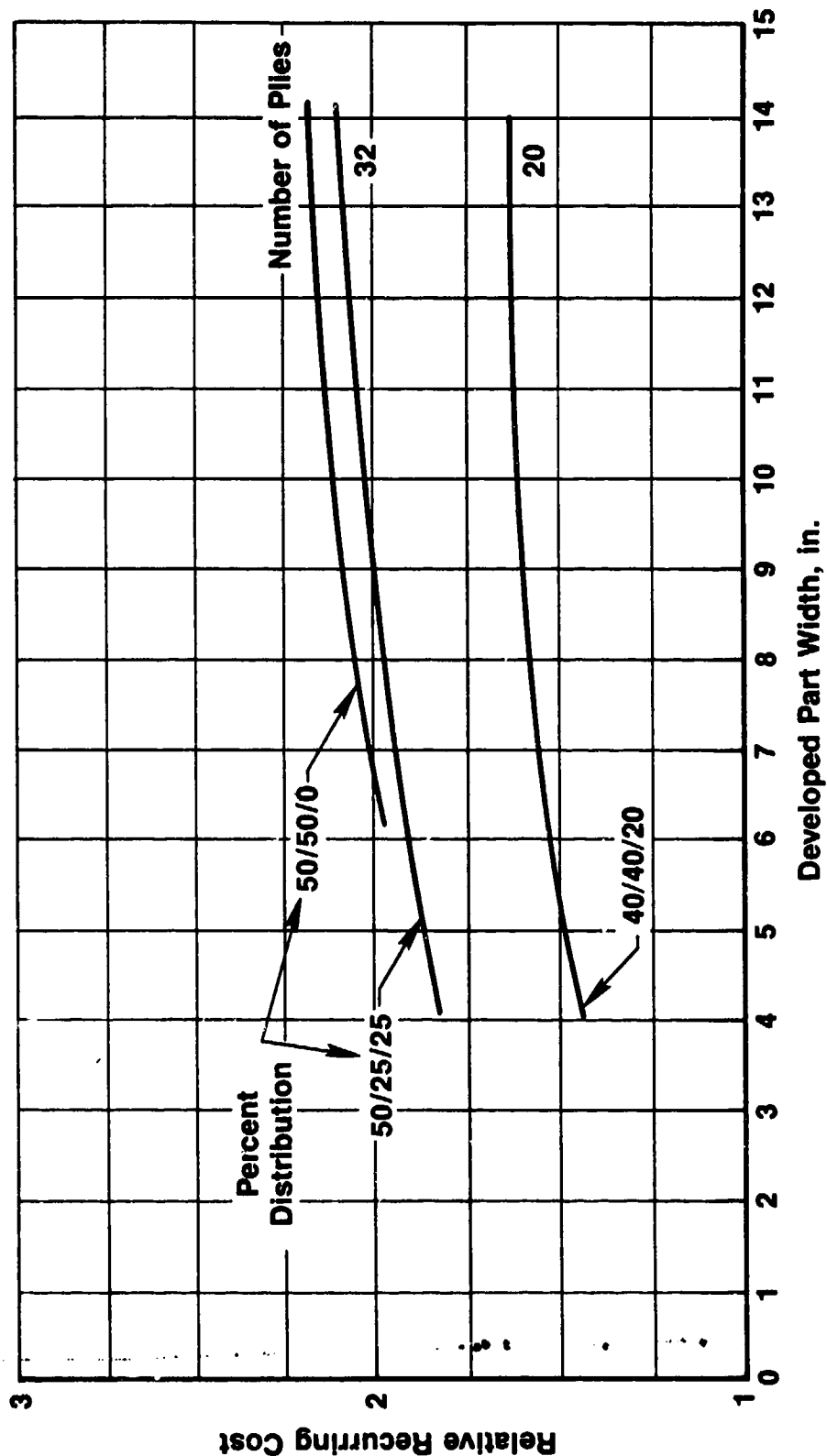
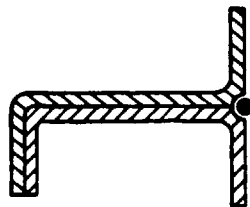
Influenced by { • Number of Plies
• Ply Orientation
• Developed Width



*Ply Orientation Code: 0°/±45°/90°

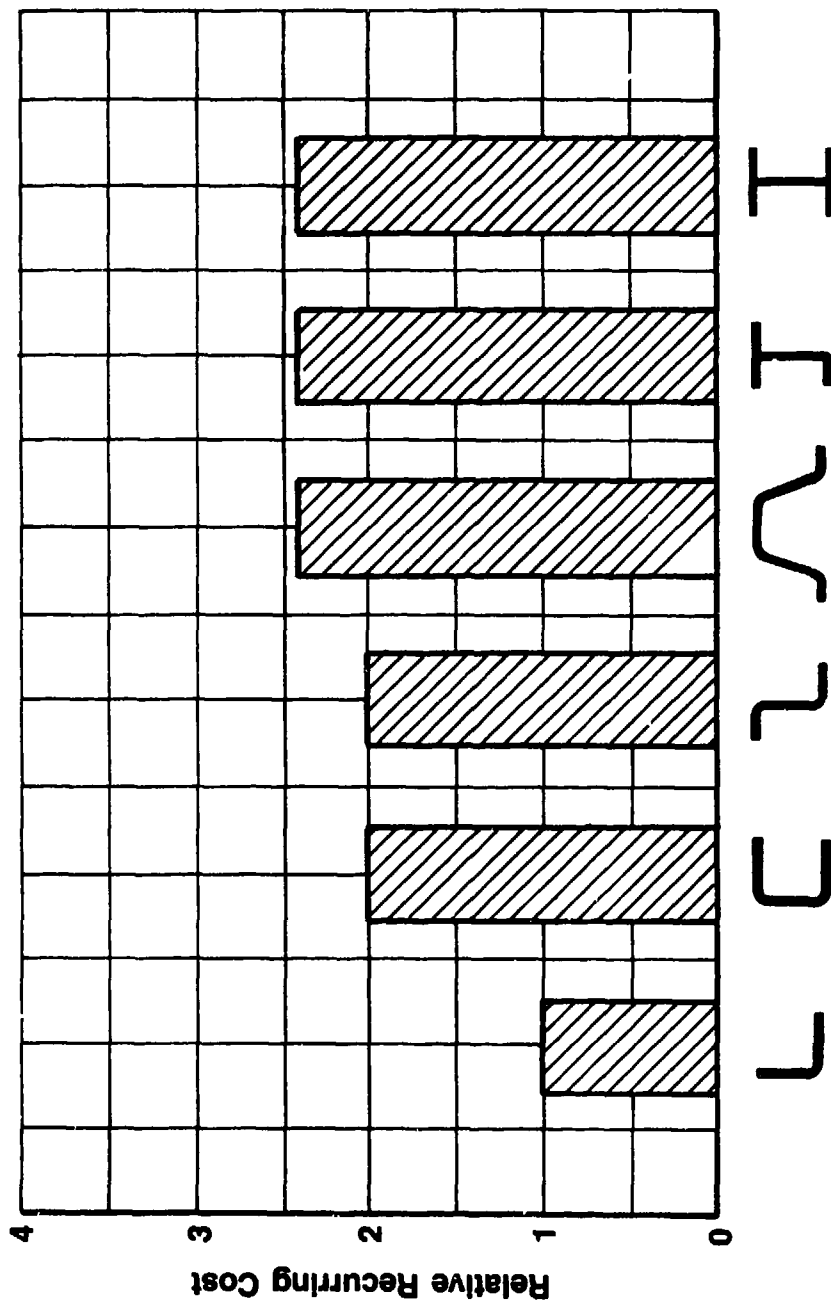
LINEAL "J" SECTION; RECURRING COST

Influenced by { • Number of Plies
• Ply Orientation
• Developed Width

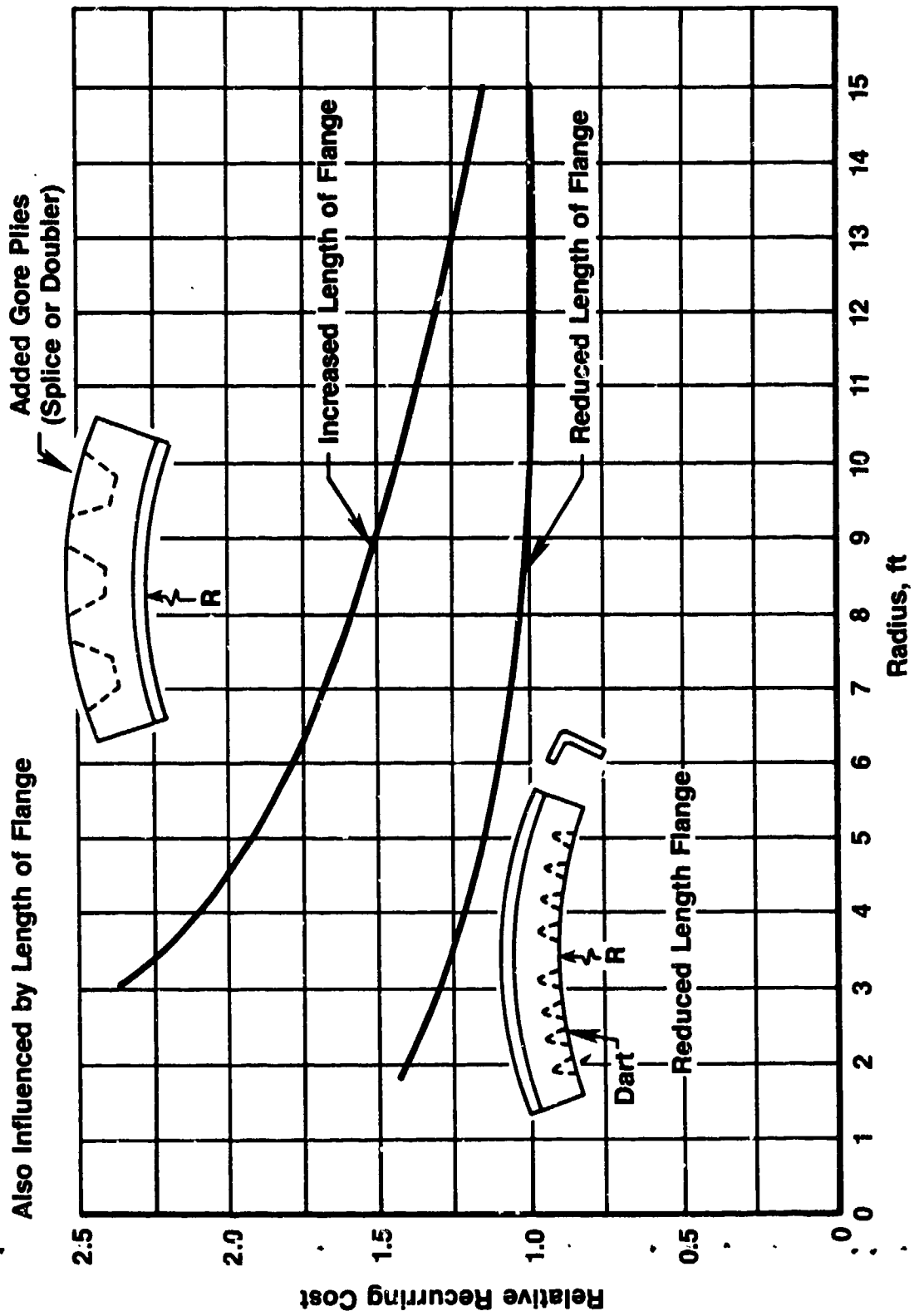


*Ply Orientation Code: 0°/±45°/90°

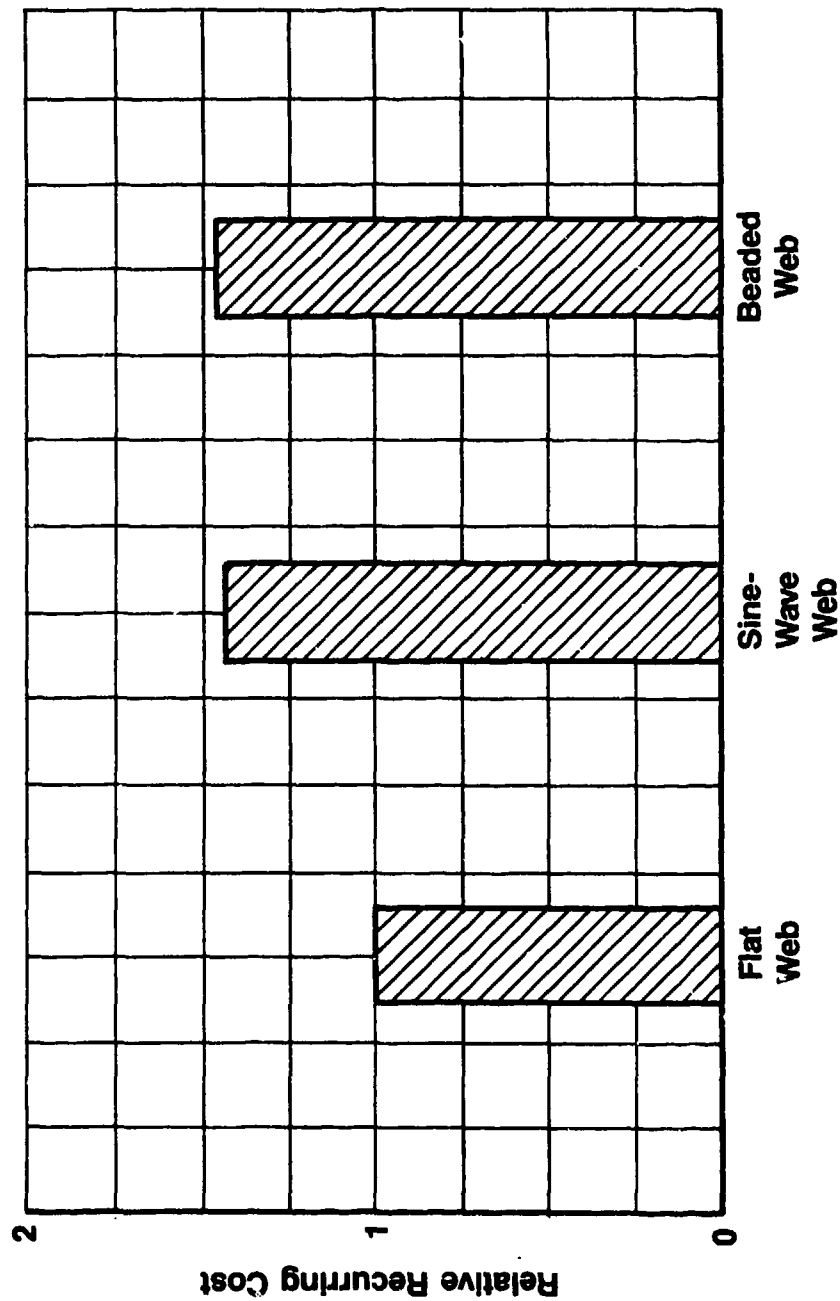
INFLUENCE OF CROSS-SECTION OF COMPOSITE CURVED LINEAL STRUCTURAL MEMBERS RECURRING COST



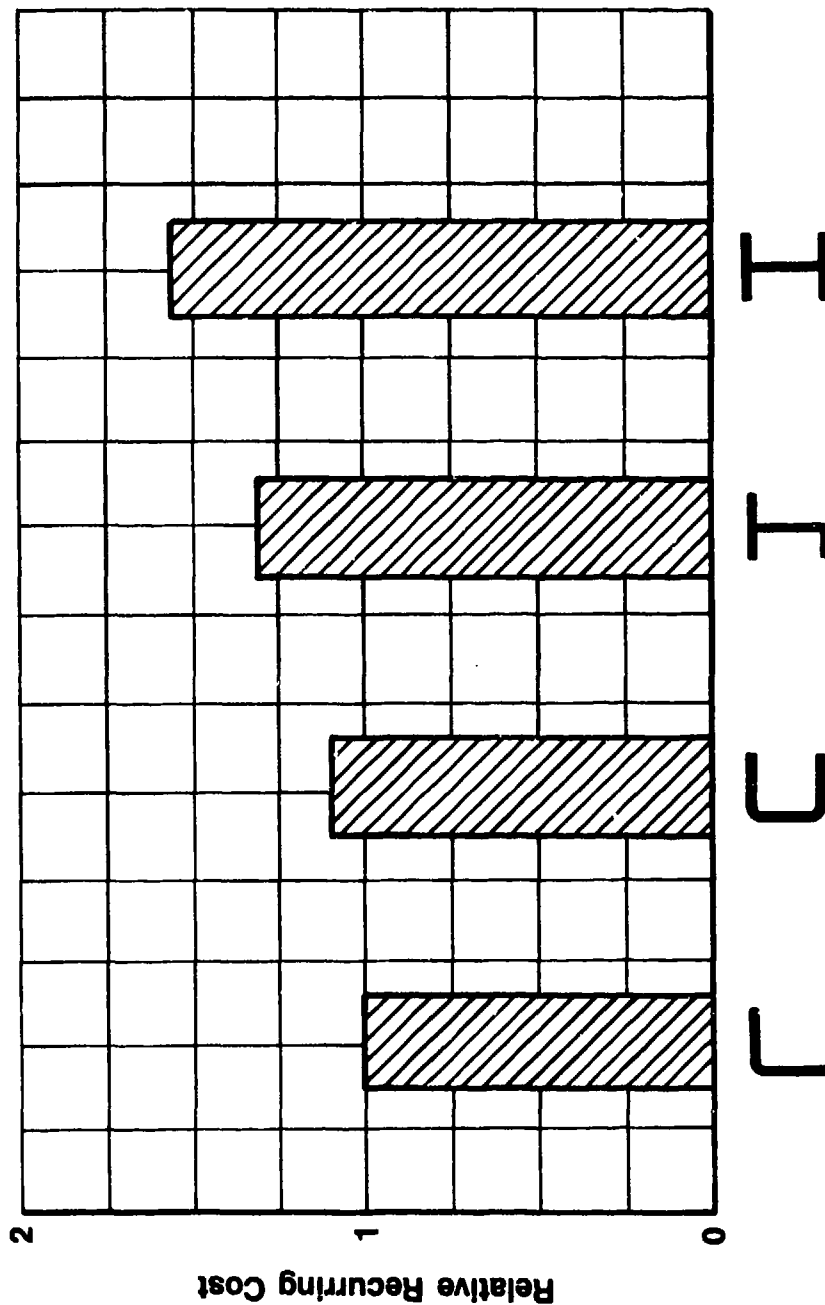
INFLUENCE OF RADIUS OF CURVATURE ON RECURRING COST OF LINEAL SHAPES



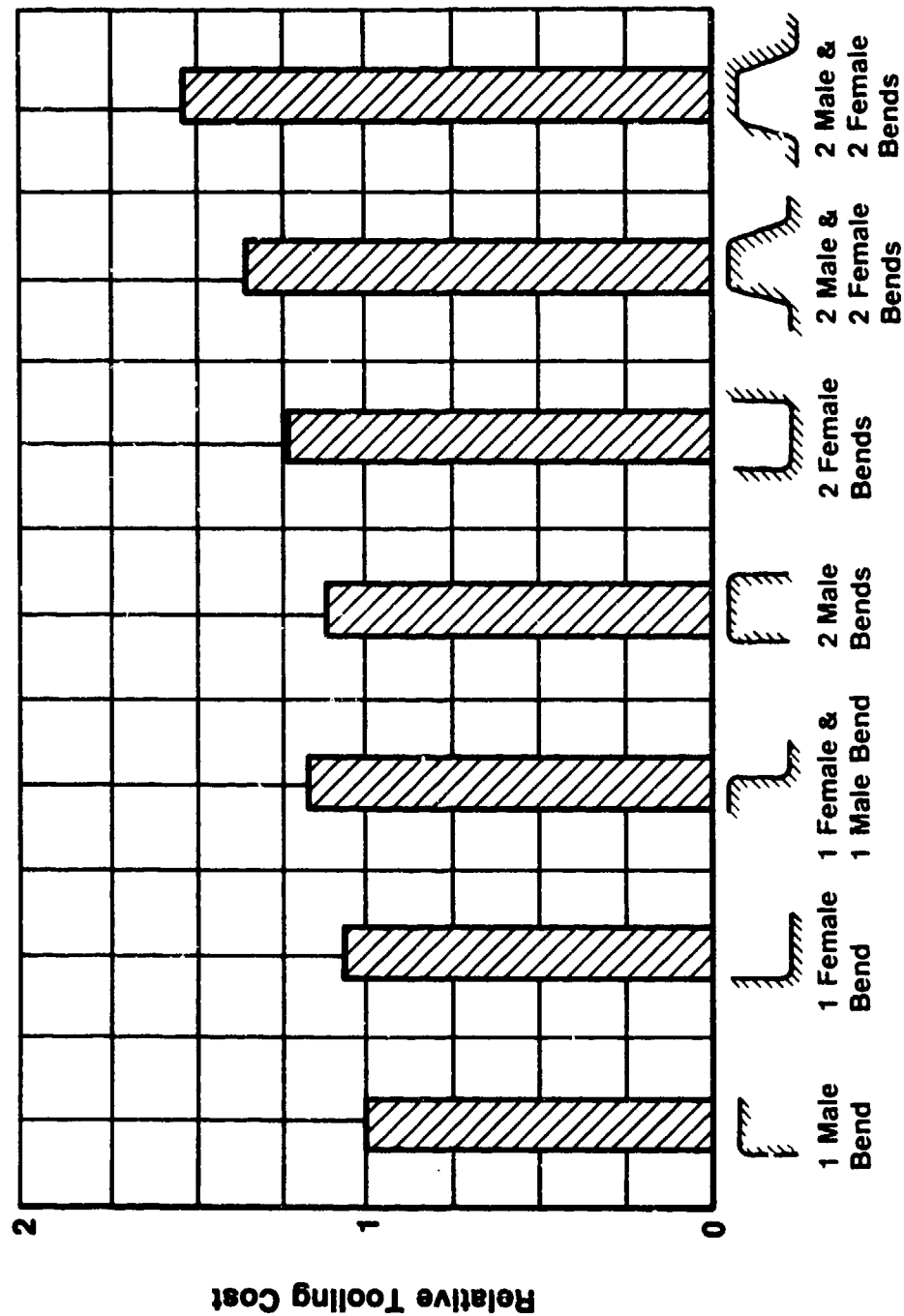
INFLUENCE OF WEB TYPES IN "I" BEAMS; RECURRING COST



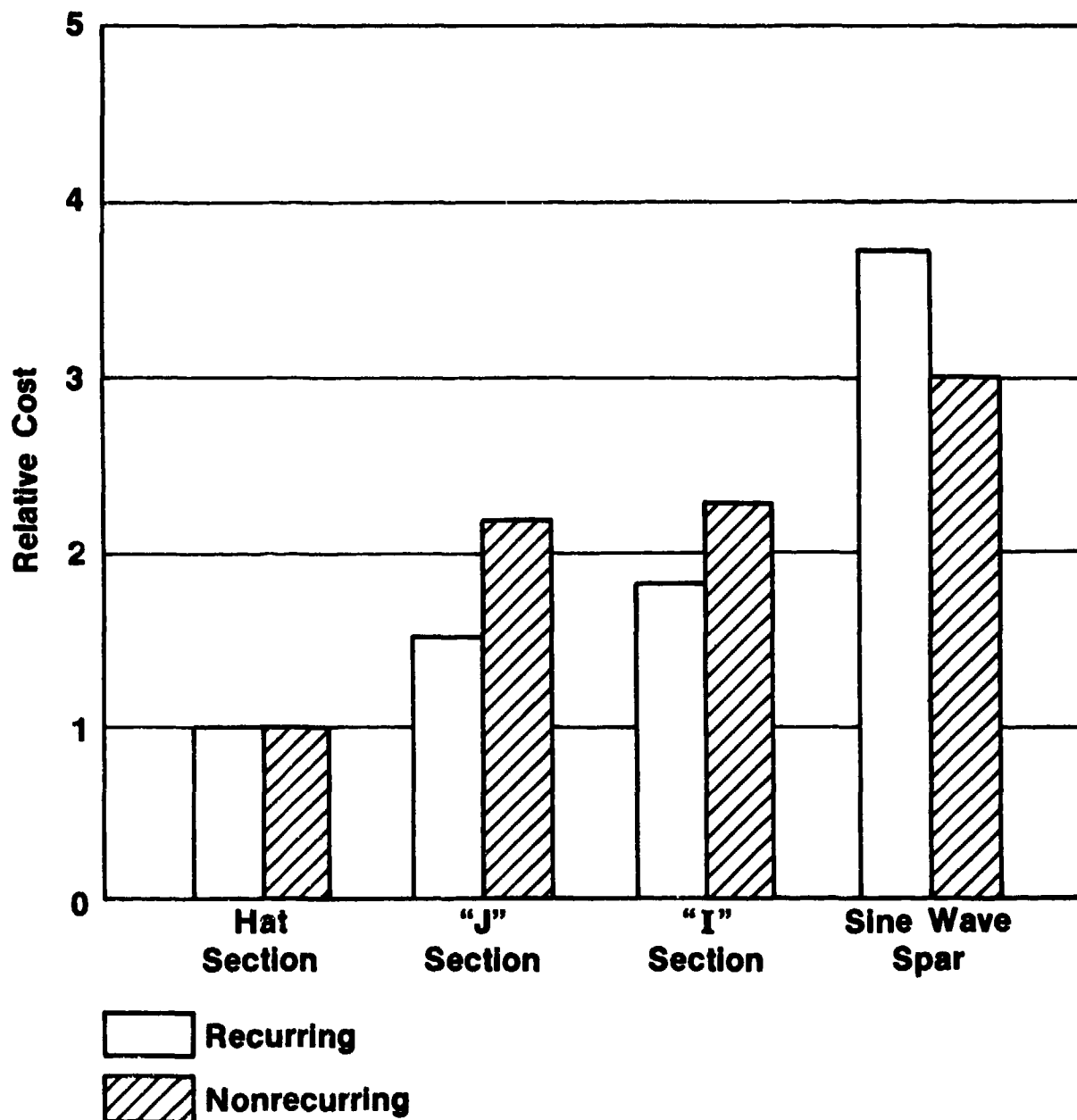
INFLUENCE OF SECTION OF COMPOSITE MEMBERS WITH SINE-WAVE WEBS; RECURRING COST



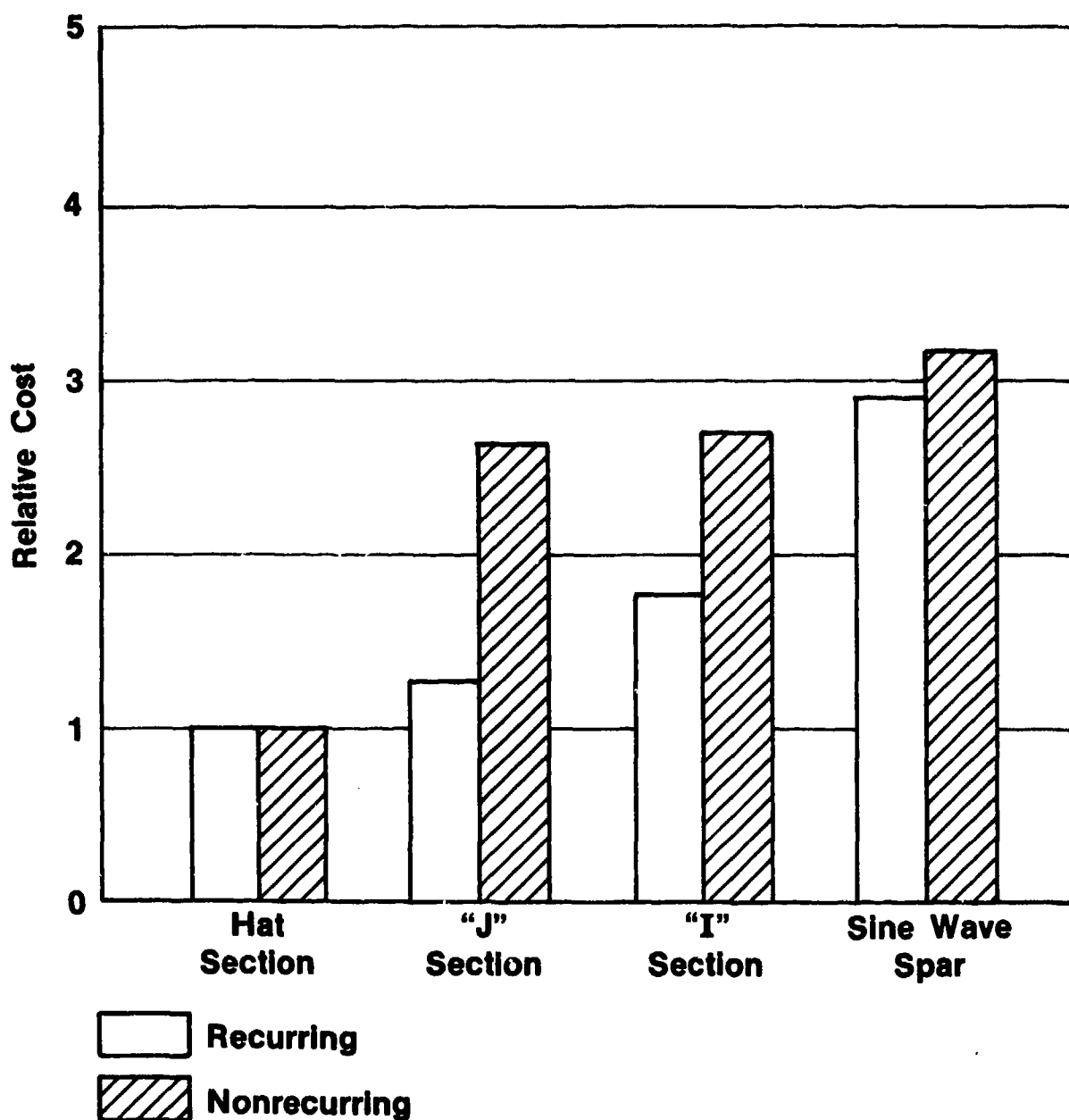
INFLUENCE OF { NUMBER OF BENDS } ON TOOLING COST OF
• SHAPE COMPOSITE
• TOOL TYPE LINEAL SHAPES



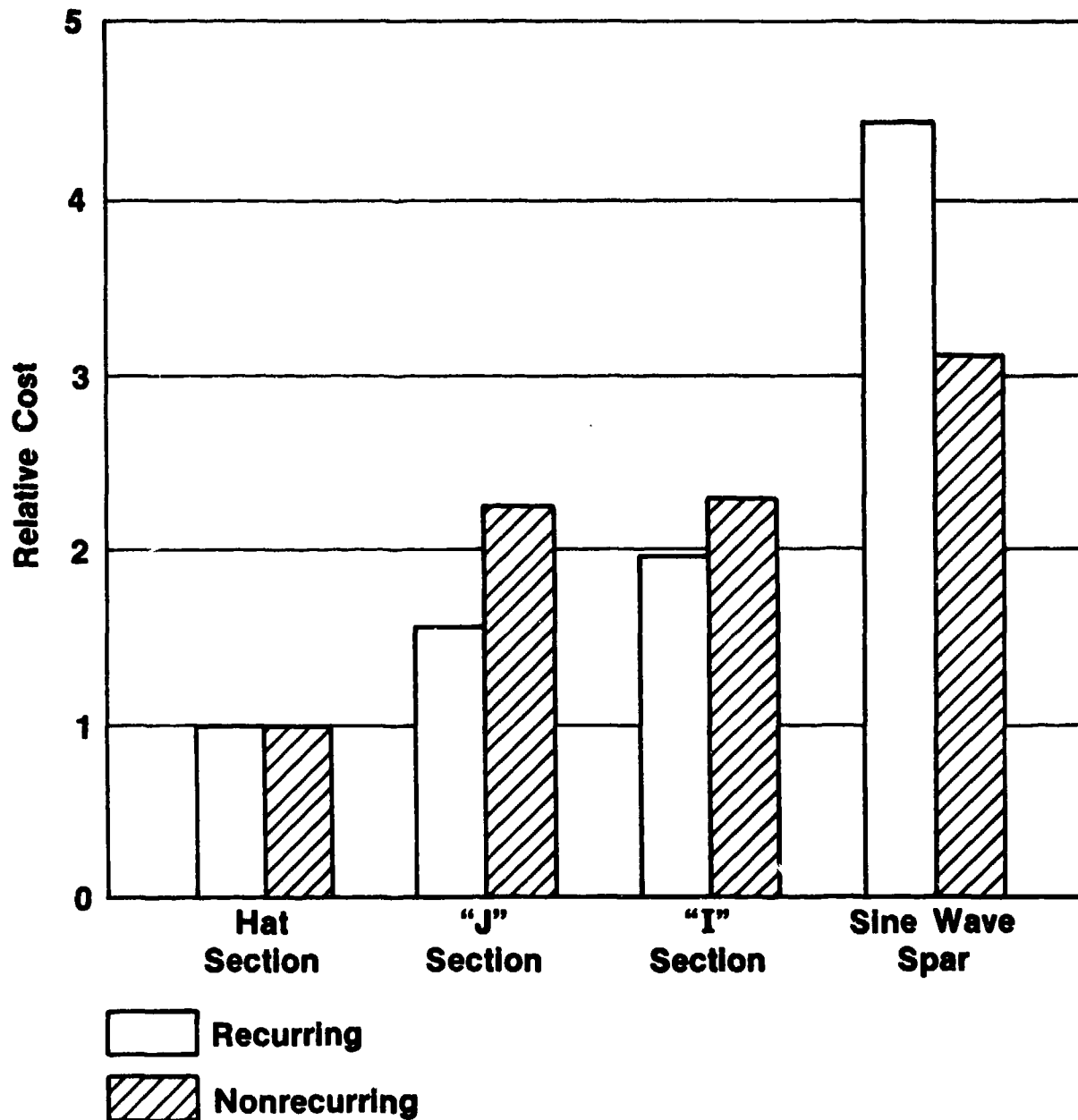
**TEST, INSPECTION AND EVALUATION (TI&E)
OF COMPOSITES
EFFECT OF SHAPE ON
RECURRING AND NONRECURRING TI&E COST**



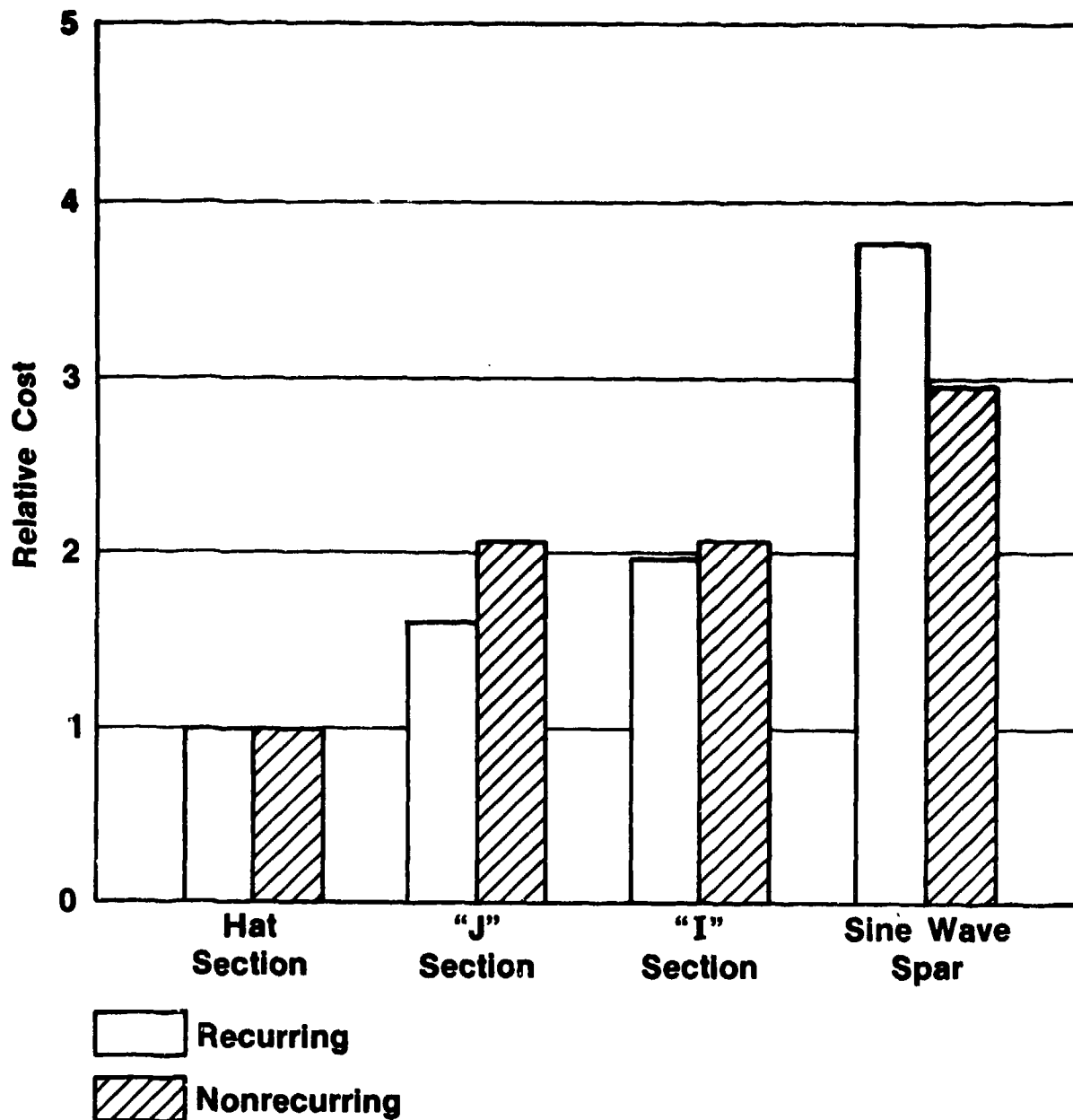
**TEST, INSPECTION AND EVALUATION (TI&E)
OF COMPOSITES
EFFECT OF SHAPE ON
RECURRING AND NONRECURRING TI&E COST
2 FOOT SECTION**



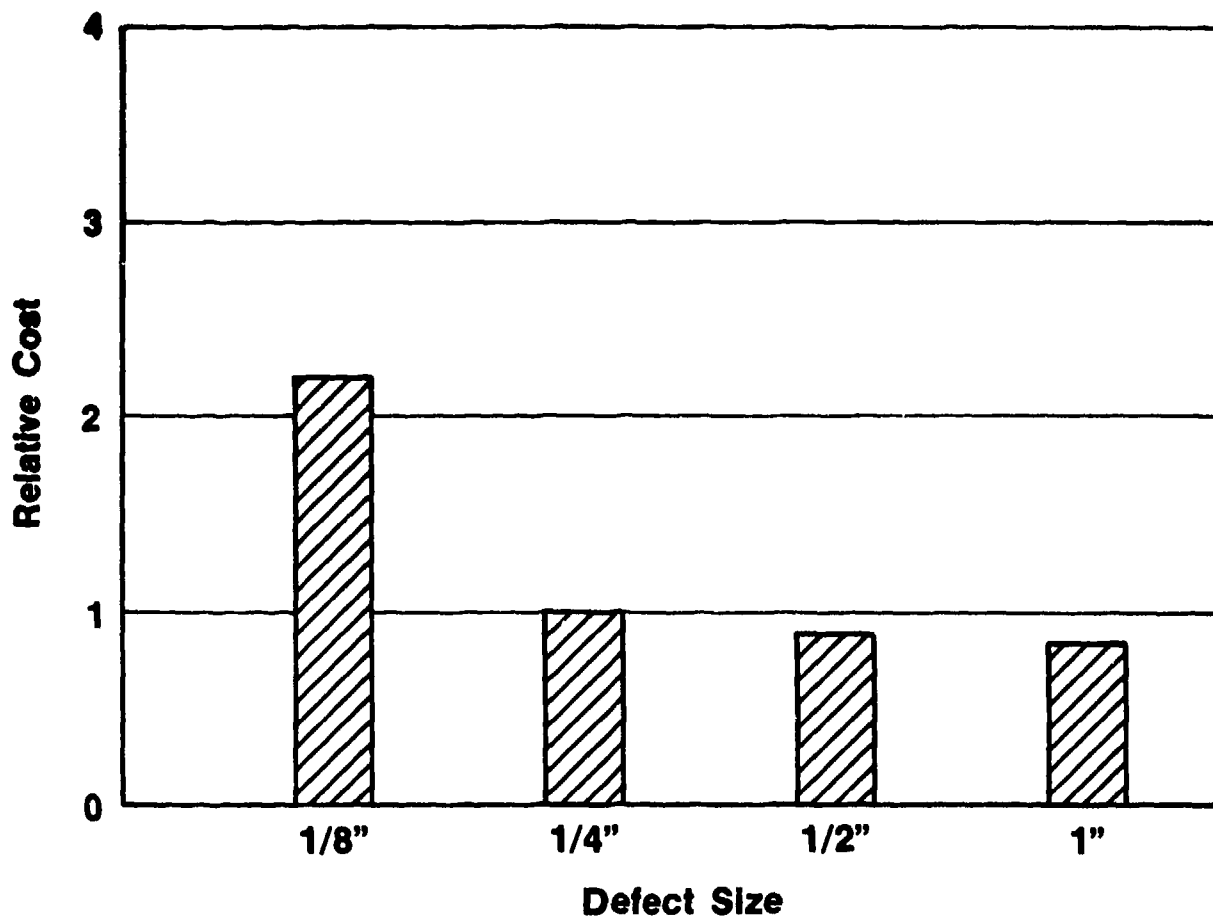
**TEST, INSPECTION AND EVALUATION (TI&E)
OF COMPOSITES
EFFECT OF SHAPE ON
RECURRING AND NONRECURRING TI&E COST
8 FOOT SECTION**



**TEST, INSPECTION AND EVALUATION (TI&E)
OF COMPOSITES
EFFECT OF SHAPE ON
RECURRING AND NONRECURRING TI&E COST
12 FOOT SECTION**

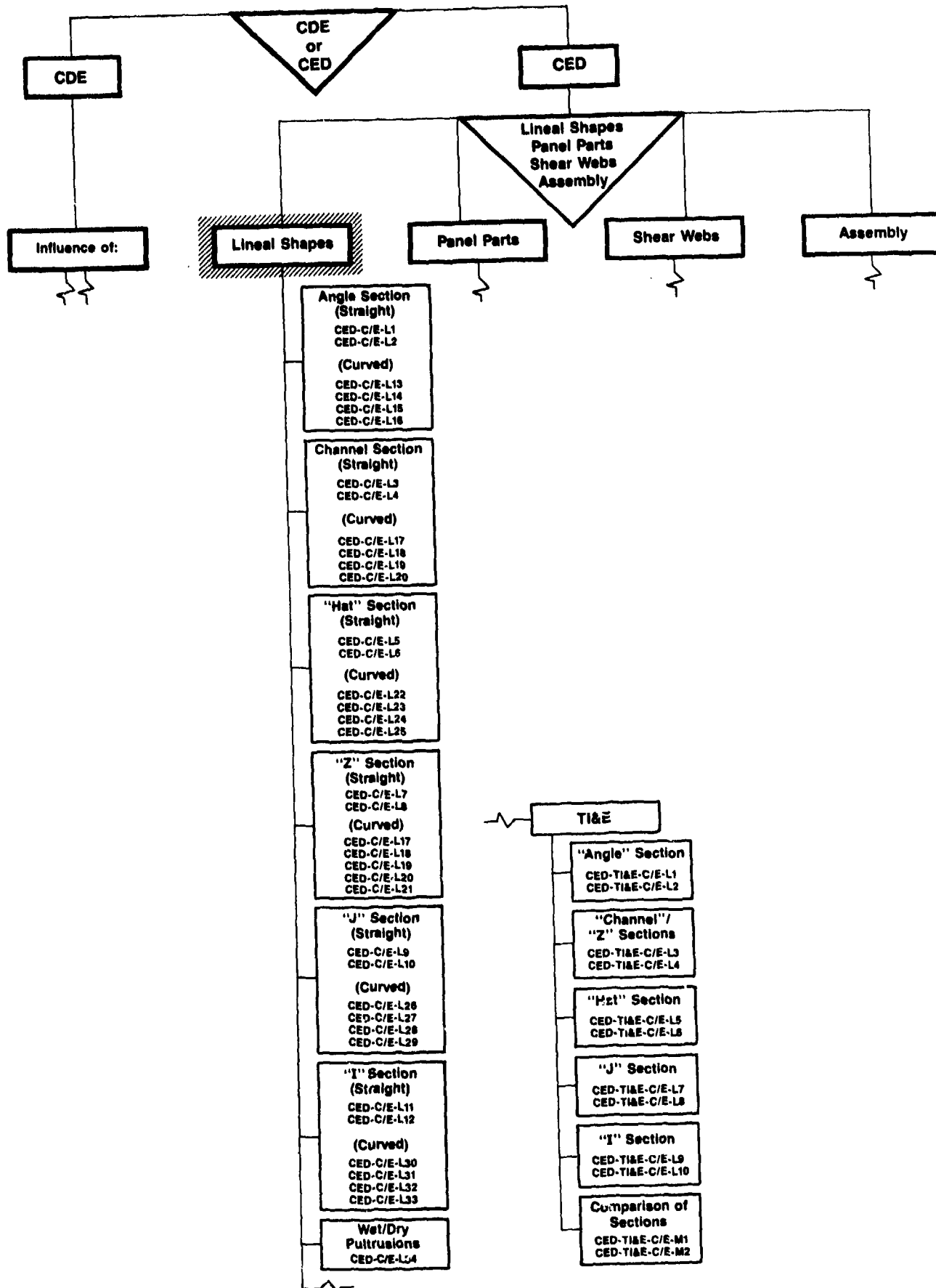


**TEST, INSPECTION AND EVALUATION (TI&E)
OF COMPOSITES
EFFECT OF MAXIMUM ALLOWABLE
DEFECT SIZE ON TI&E COST**



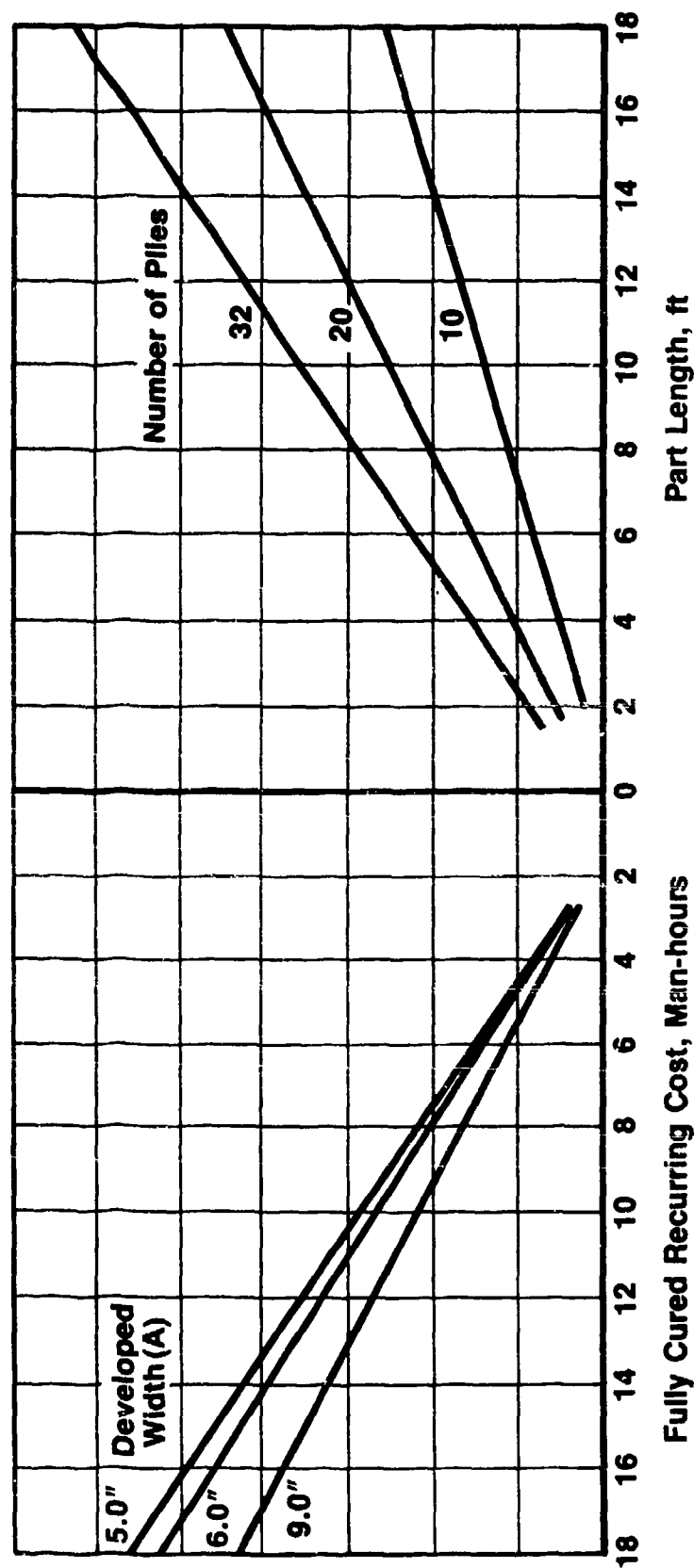
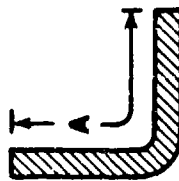
FORMAT SELECTION AID

Advanced Composite Fabrication



COMPOSITE ANGLE SECTION; RECURRING COST/PART

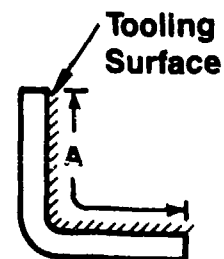
- Influenced by {
- Part Length
 - Number of Piles
 - Developed Flat Pattern Width
 - Cure Stage



Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

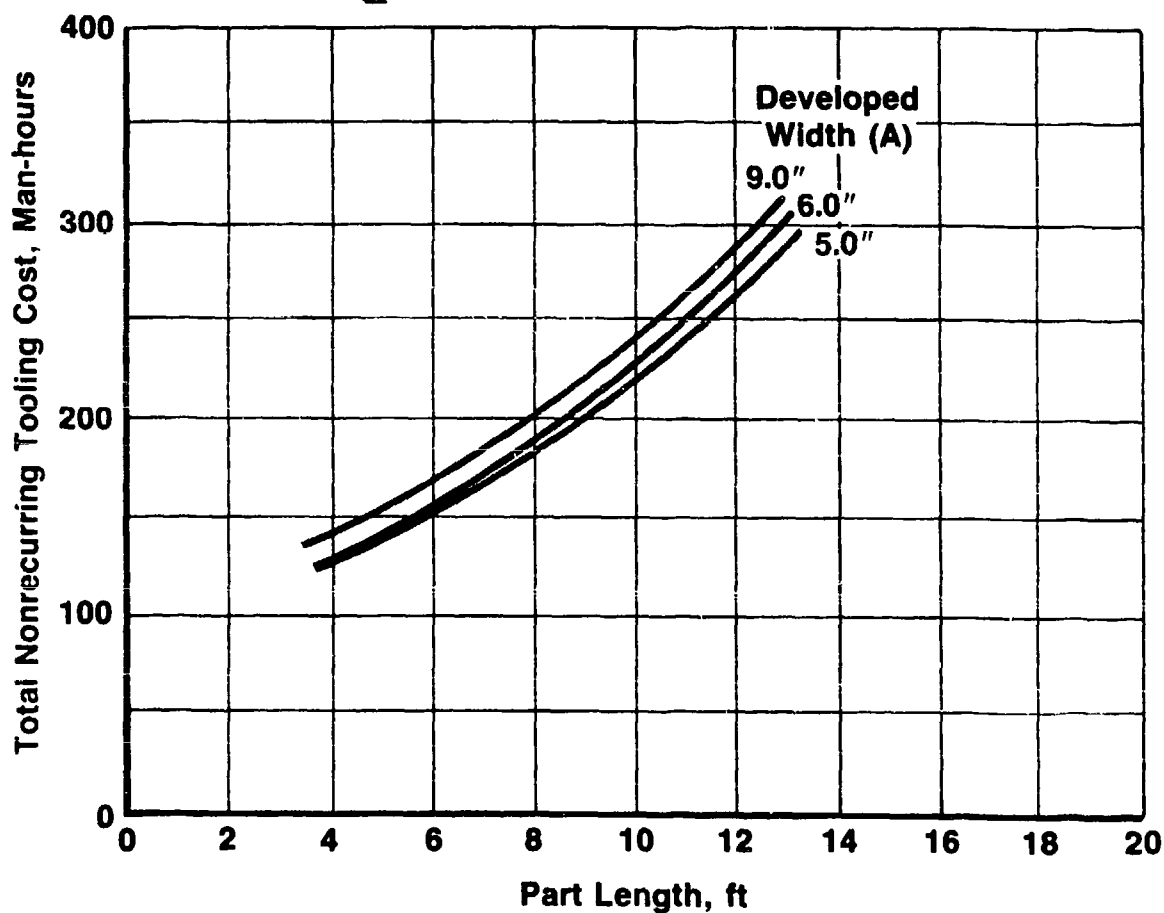
See ground rules for limitations and considerations.

COMPOSITE ANGLE SECTION; TOTAL NONRECURRING TOOLING COST/PART



Influenced by {

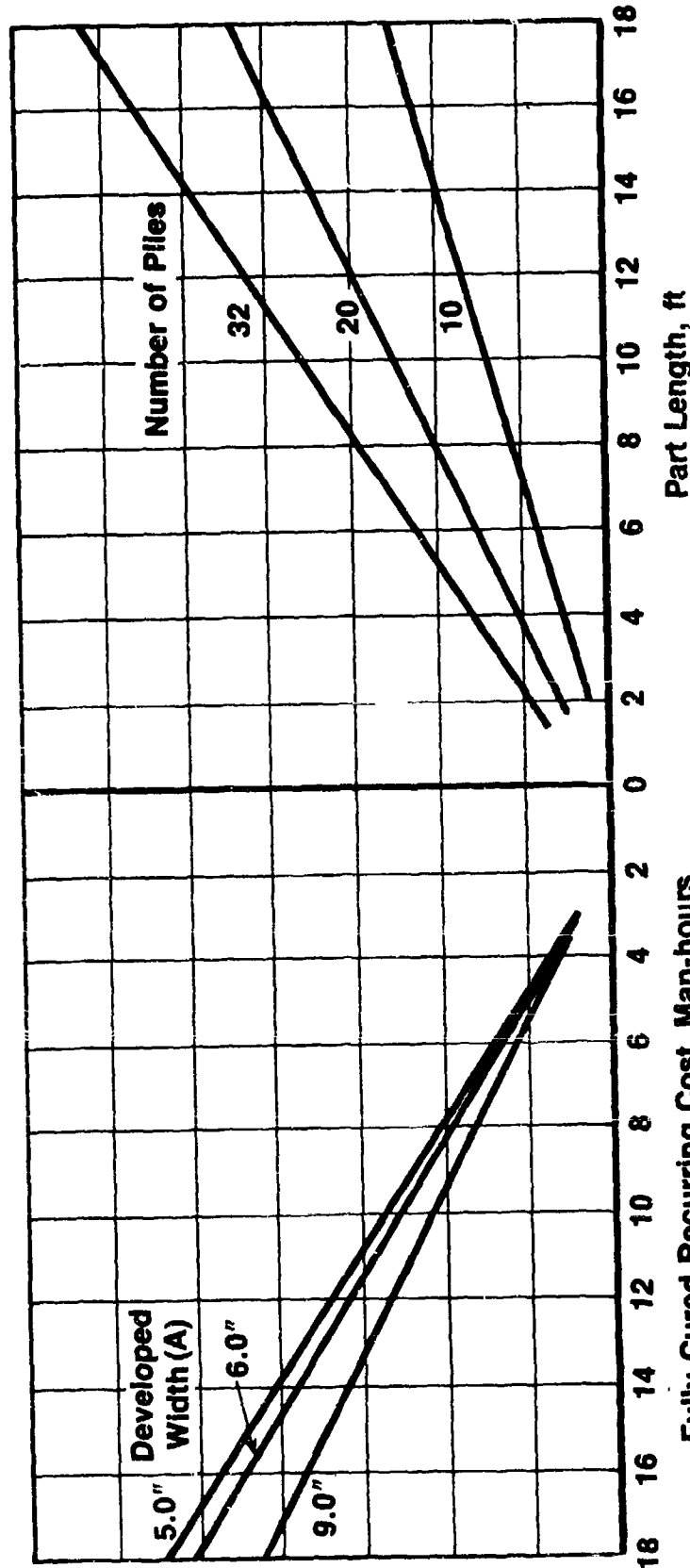
- Part Length
- Developed Width



See ground rules for limitations and considerations.

COMPOSITE CHANNEL SECTION; RECURRING COST/PART

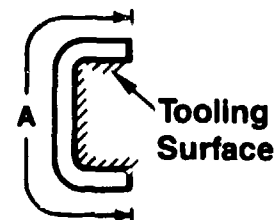
- Influenced by {
- Part Length
 - Number of Piles
 - Developed Flat Pattern Width
 - Cure Stage



Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

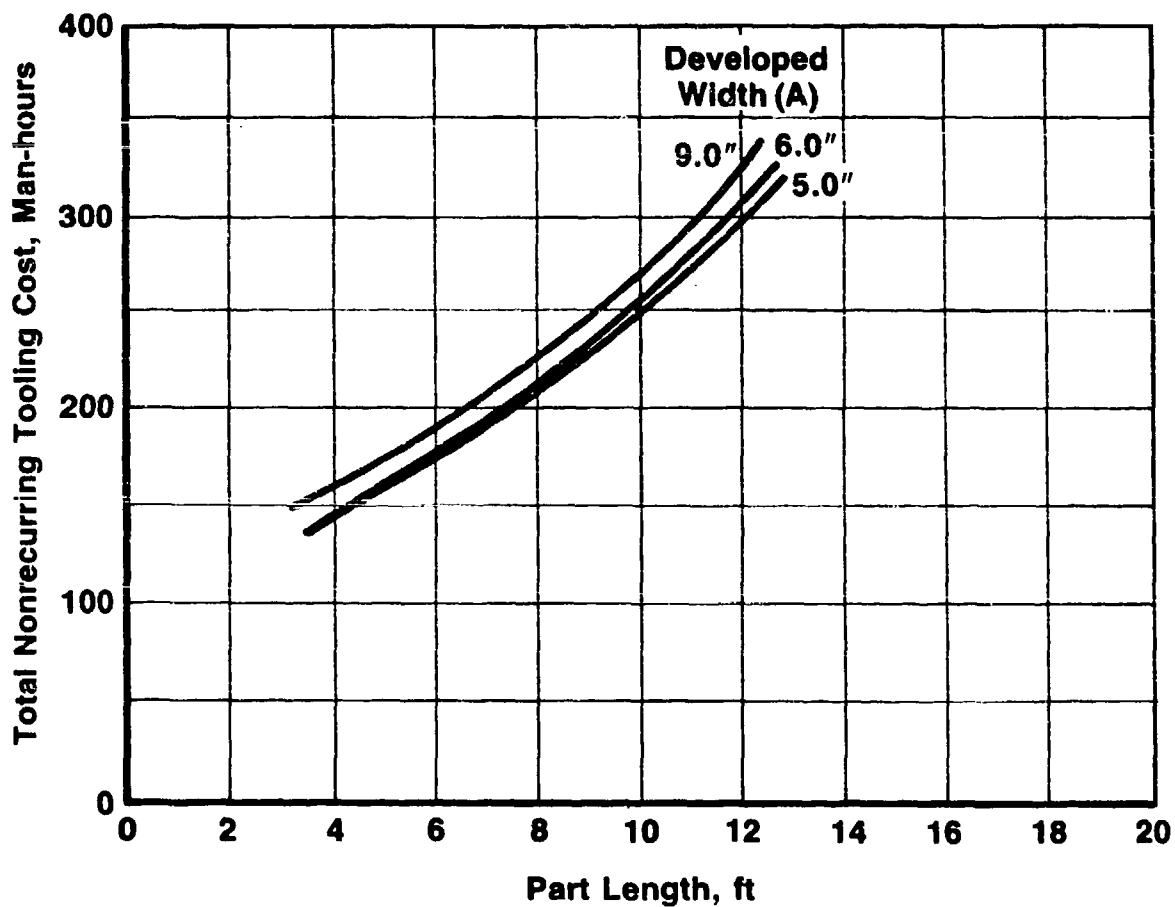
See ground rules for limitations and considerations.

COMPOSITE CHANNEL SECTION; TOTAL NONRECURRING TOOLING COST/PART



Influenced by {

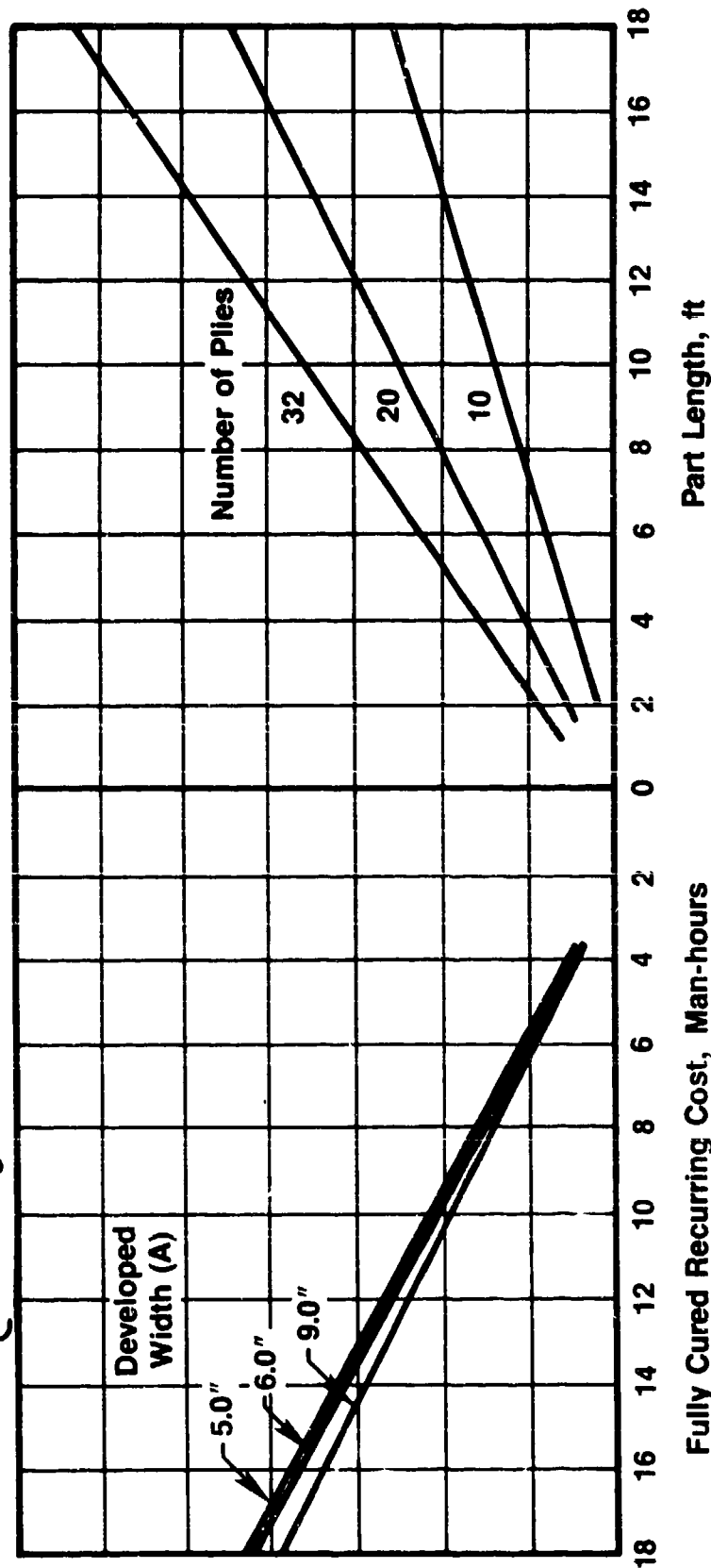
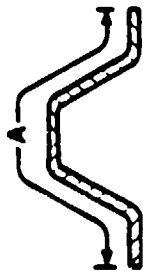
- Part Length
- Developed Width



See ground rules for limitations and considerations.

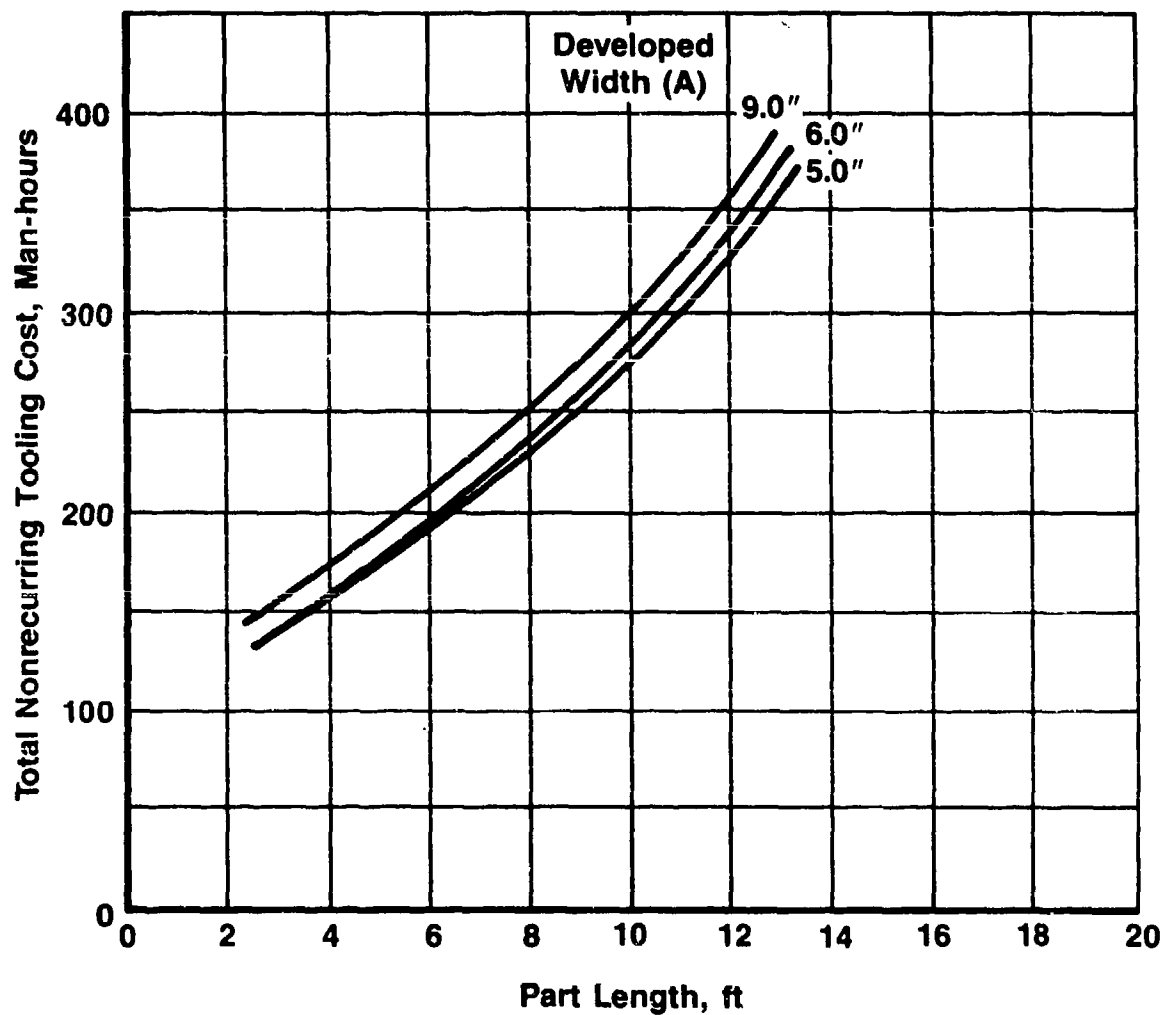
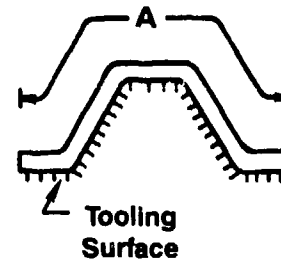
COMPOSITE HAT SECTION; RECURRING COST/PART

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



COMPOSITE HAT SECTION; TOTAL NONRECURRING COST/PART

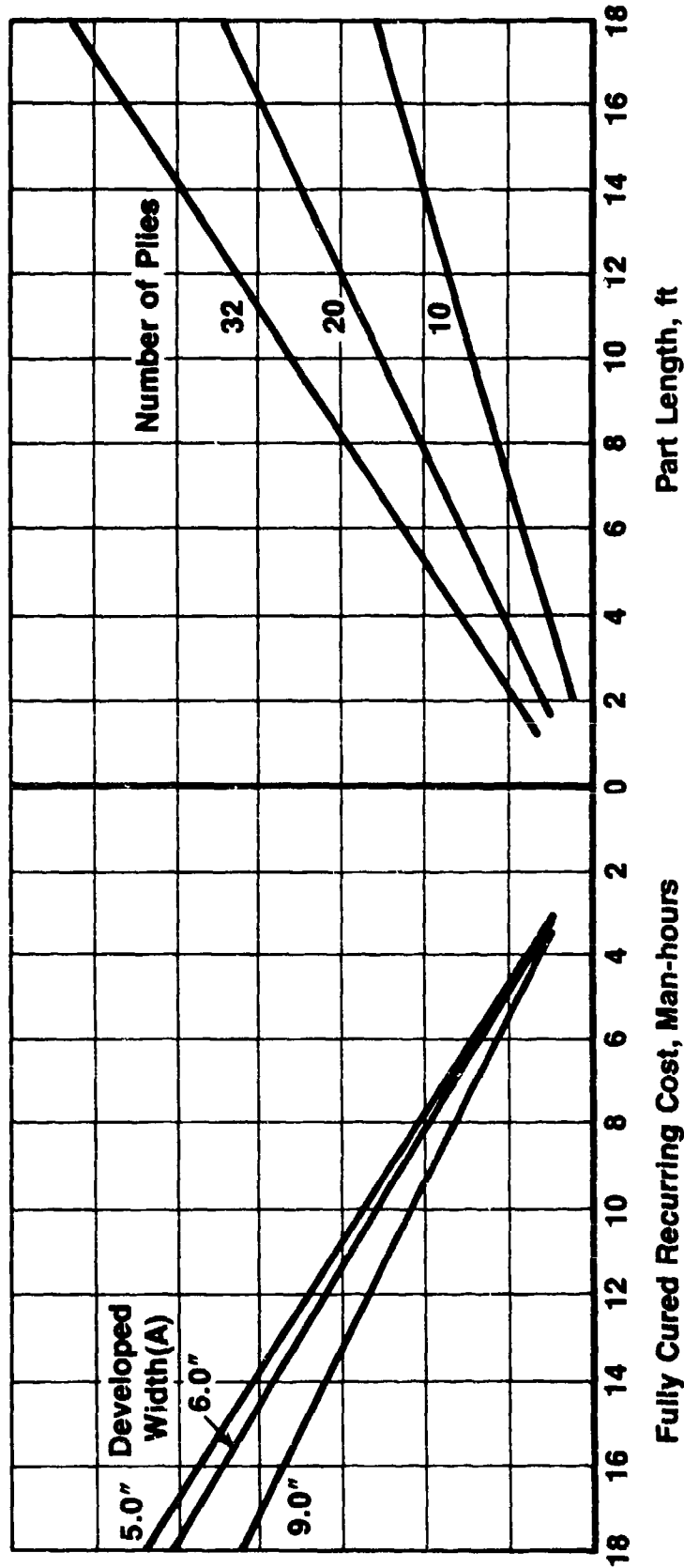
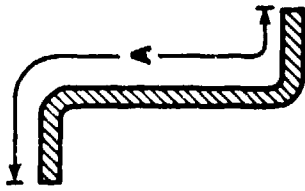
Influenced by { • Part Length
• Developed Width



See ground rules for limitations and considerations.

COMPOSITE Z-SECTION; RECURRING COST/PART

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage

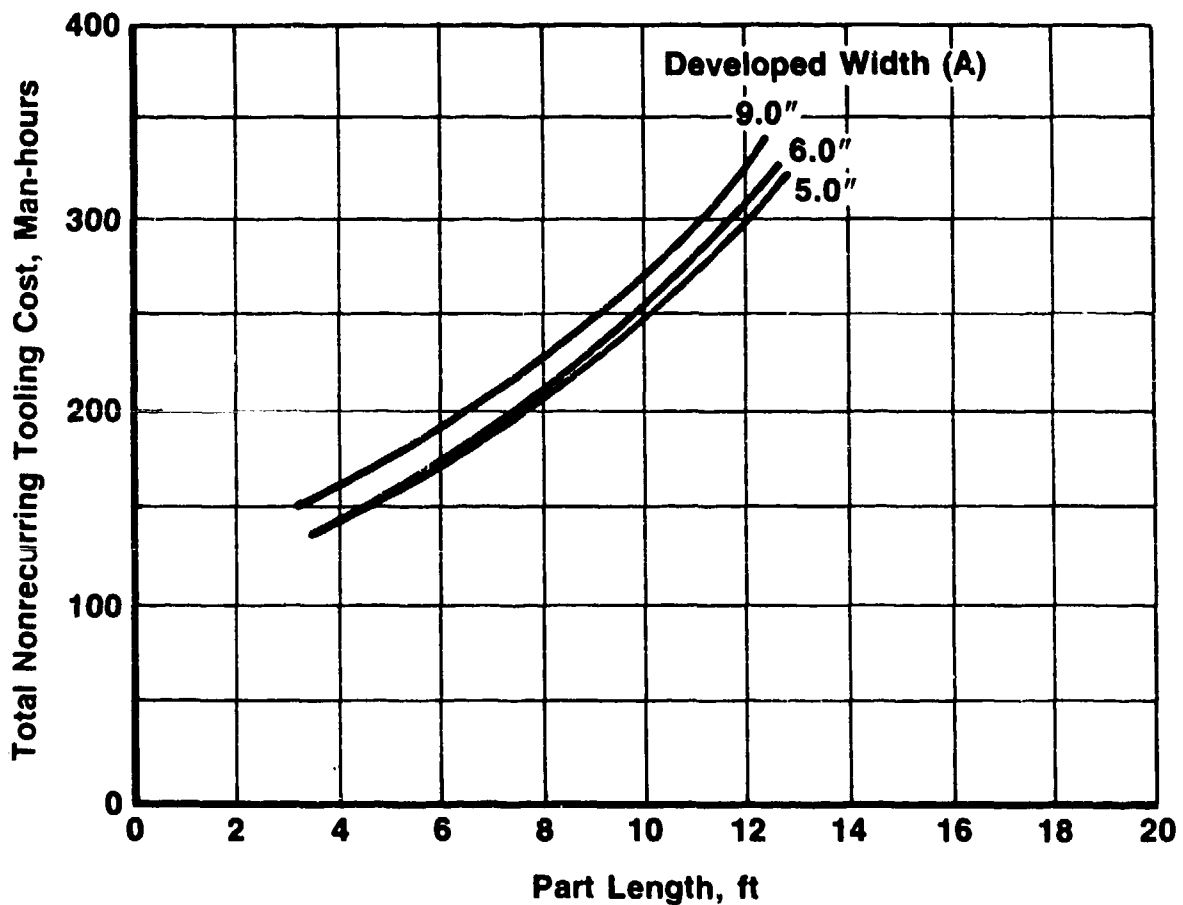
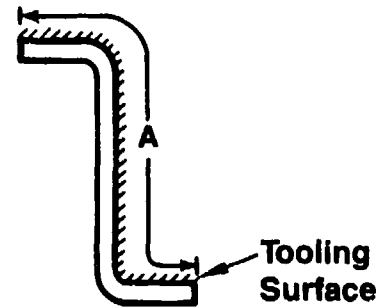


Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

-See ground rules for limitations and considerations.

COMPOSITE Z-SECTION; TOTAL NONRECURRING TOOLING COST/PART

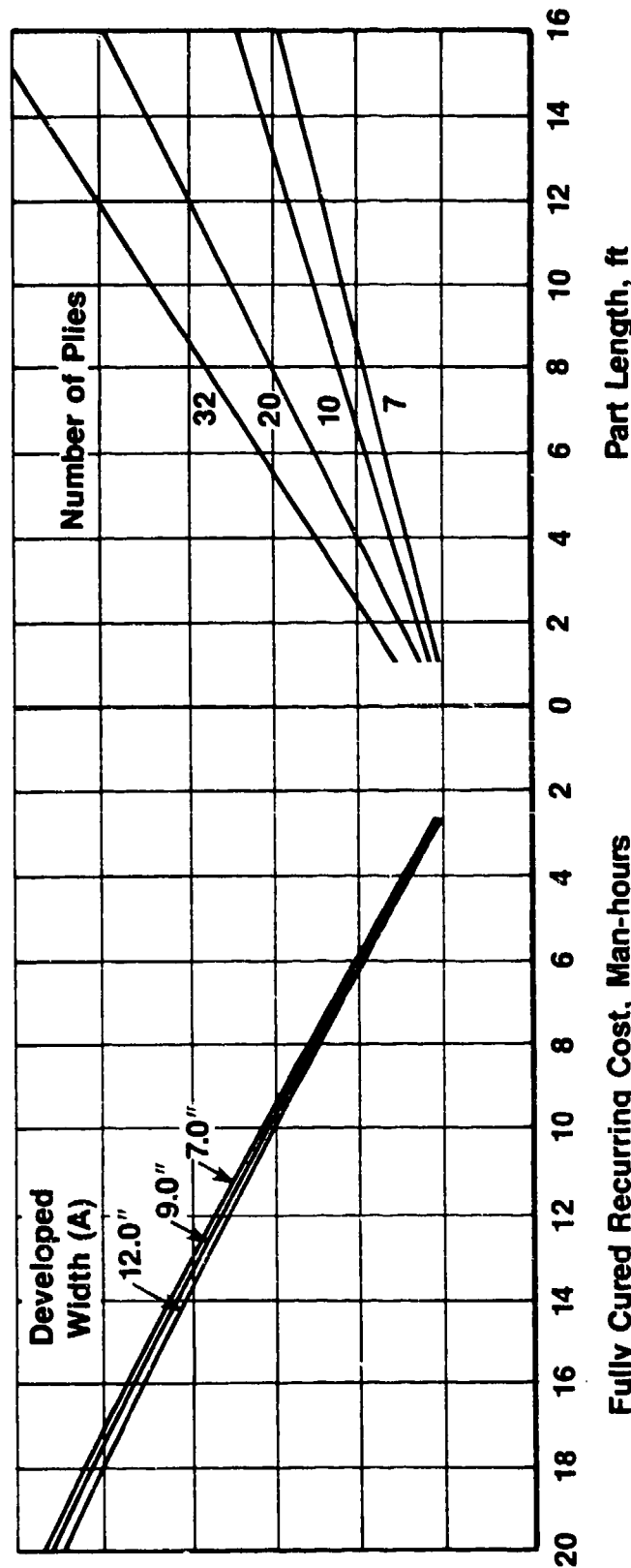
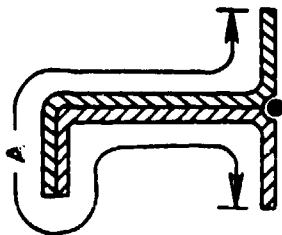
Influenced by {
• Part Length
• Developed Width



See ground rules for limitations and considerations.

COMPOSITE "J" SECTION; RECURRING COST/PART

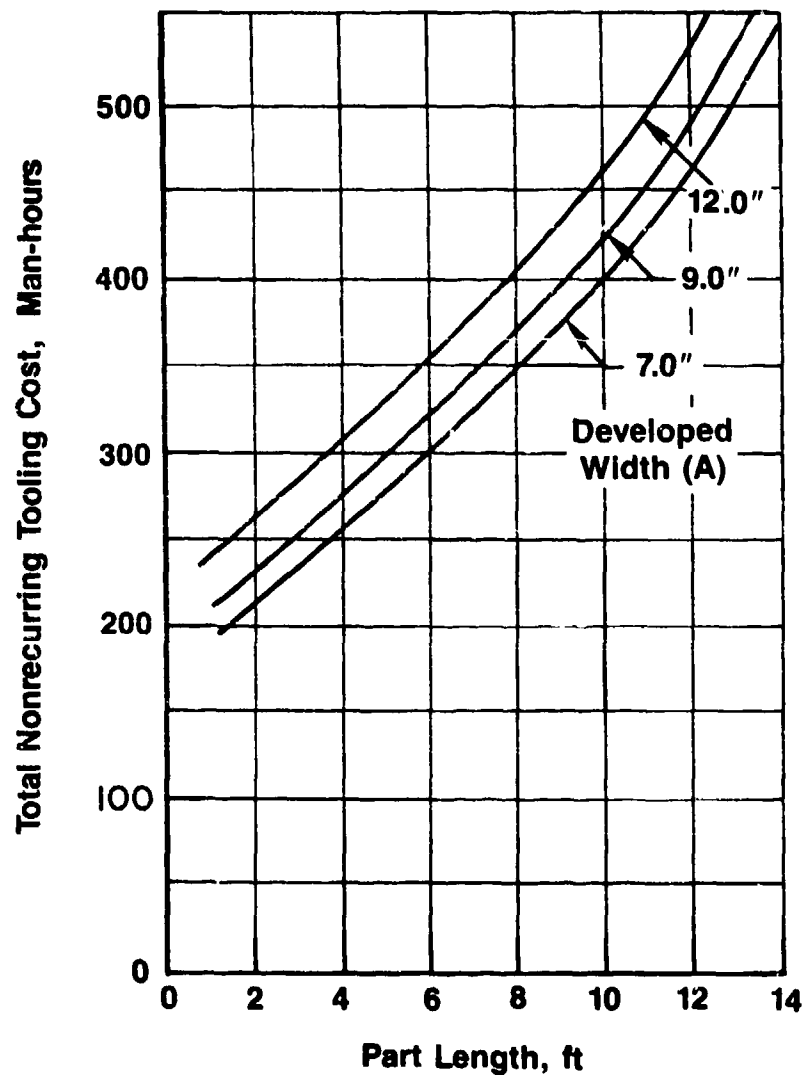
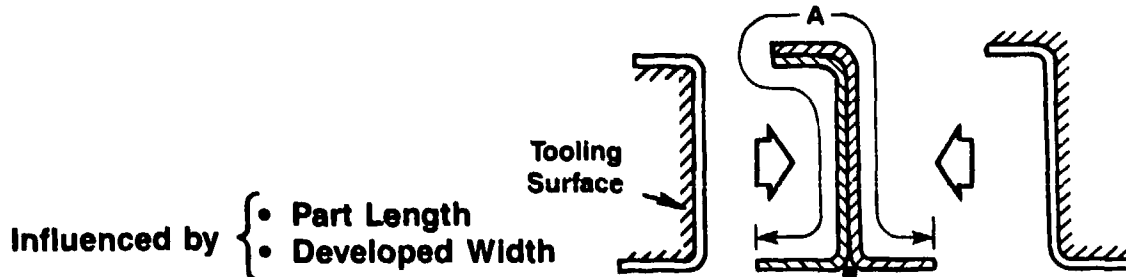
- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

See ground rules for limitations and considerations.

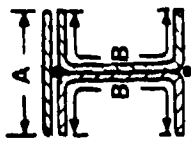
COMPOSITE "U" SECTION; TOTAL NONRECURRING TOOLING COST



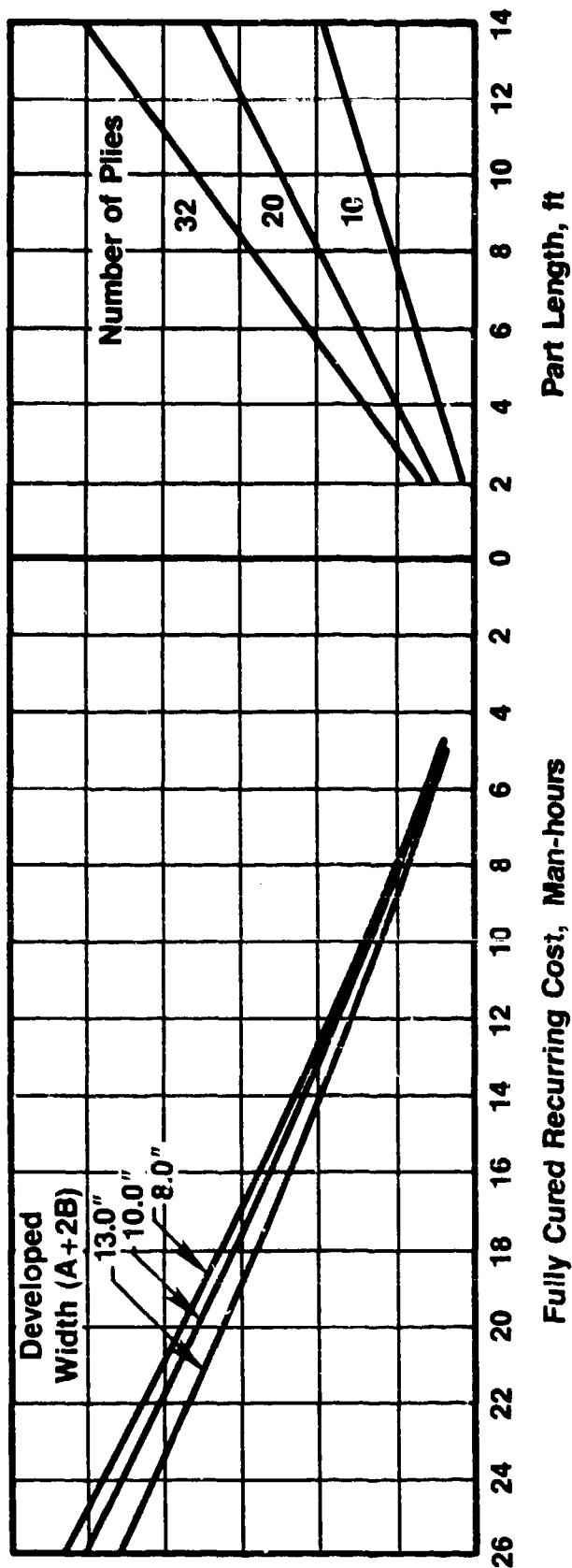
See ground rules for limitations and considerations.

COMPOSITE "I" SECTION; RECURRING COST/PART

- Influenced by
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



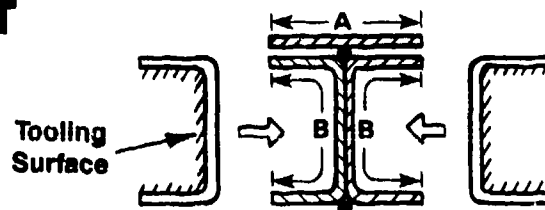
Developed
Width = $A + 2B$



(For "B" Stage Recurring Cost, Multiply by 0.84)

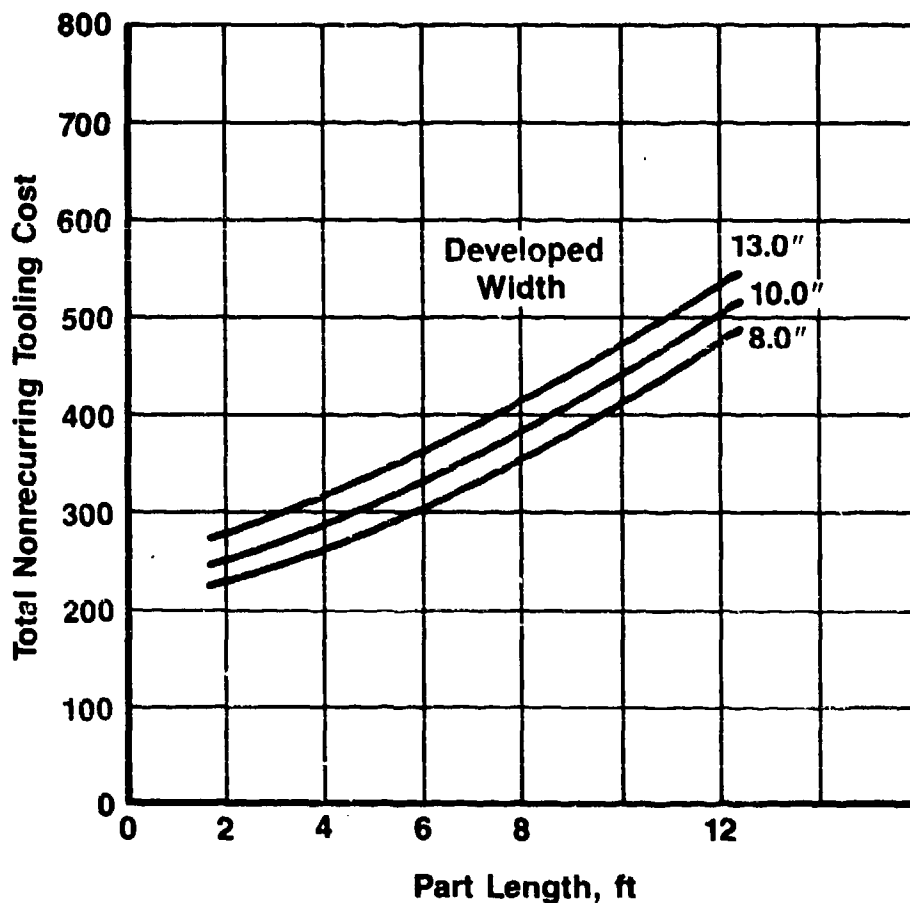
See ground rules for limitations and considerations.

COMPOSITE "I" SECTION; TOTAL NONRECURRING TOOLING COST/PART



Influenced by {
• Part Length
• Developed Width

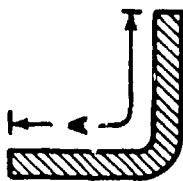
Developed
Width = $A + 2B$



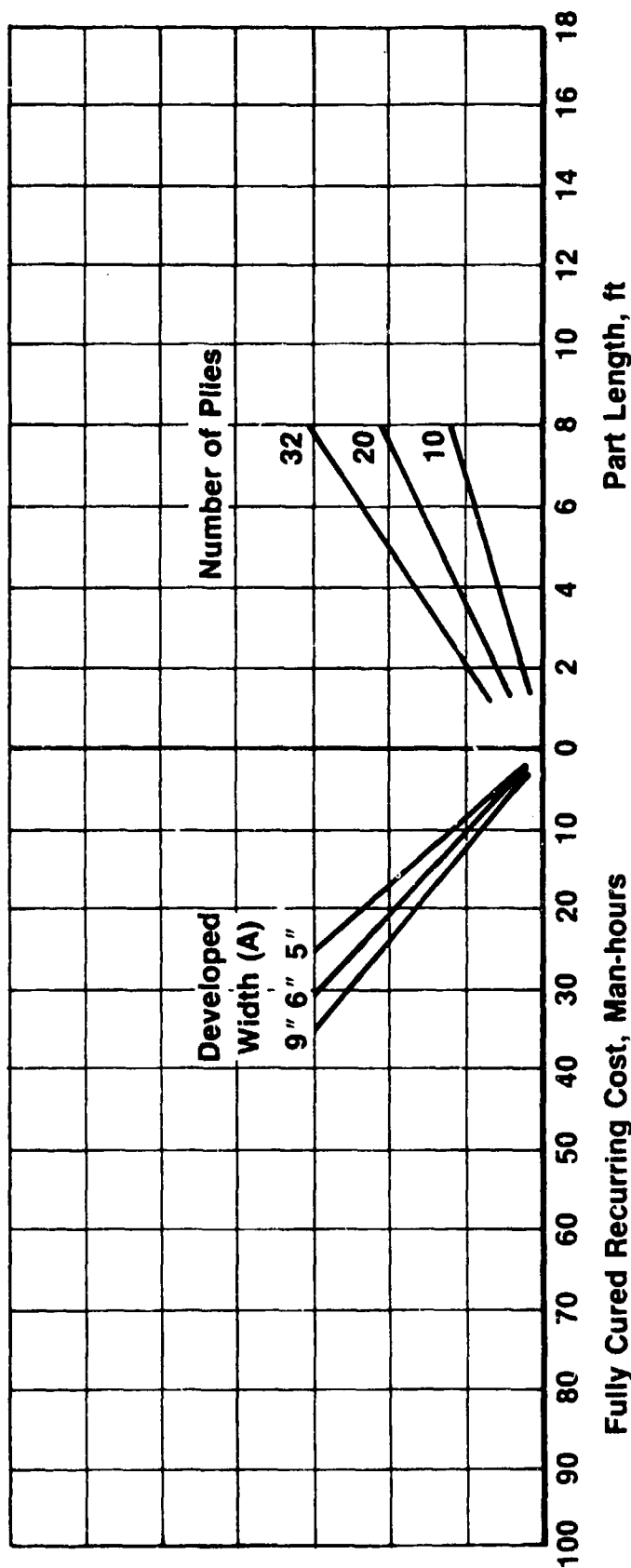
See ground rules for limitations and considerations.

CURVED COMPOSITE ANGLE SECTION; RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



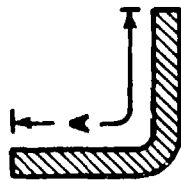
Radius: 24 inches



Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

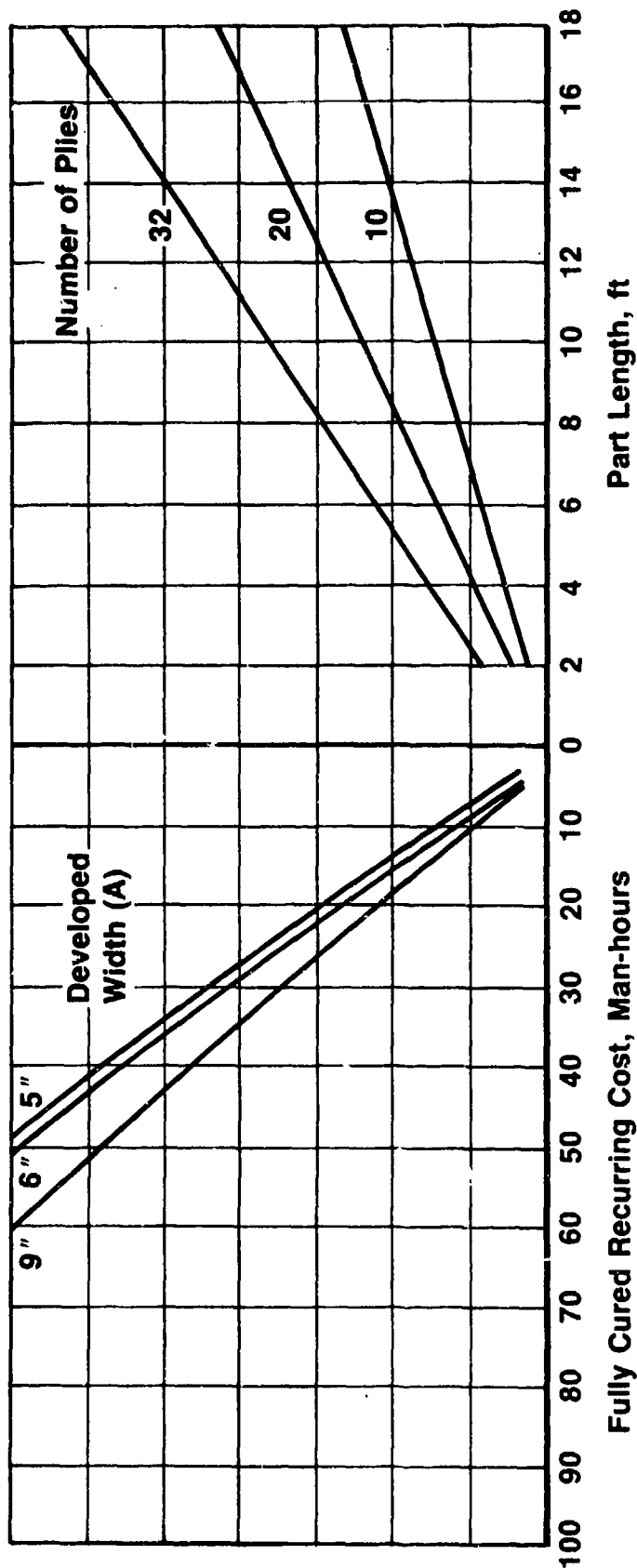
See ground rules for limitations and considerations.

CURVED COMPOSITE ANGLE SECTION; RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)



- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage

Radius: 60 inches



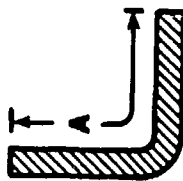
Fully Cured Recurring Cost, Man-hours

(For "B" Stage Recurring Cost, Multiply by 0.84)

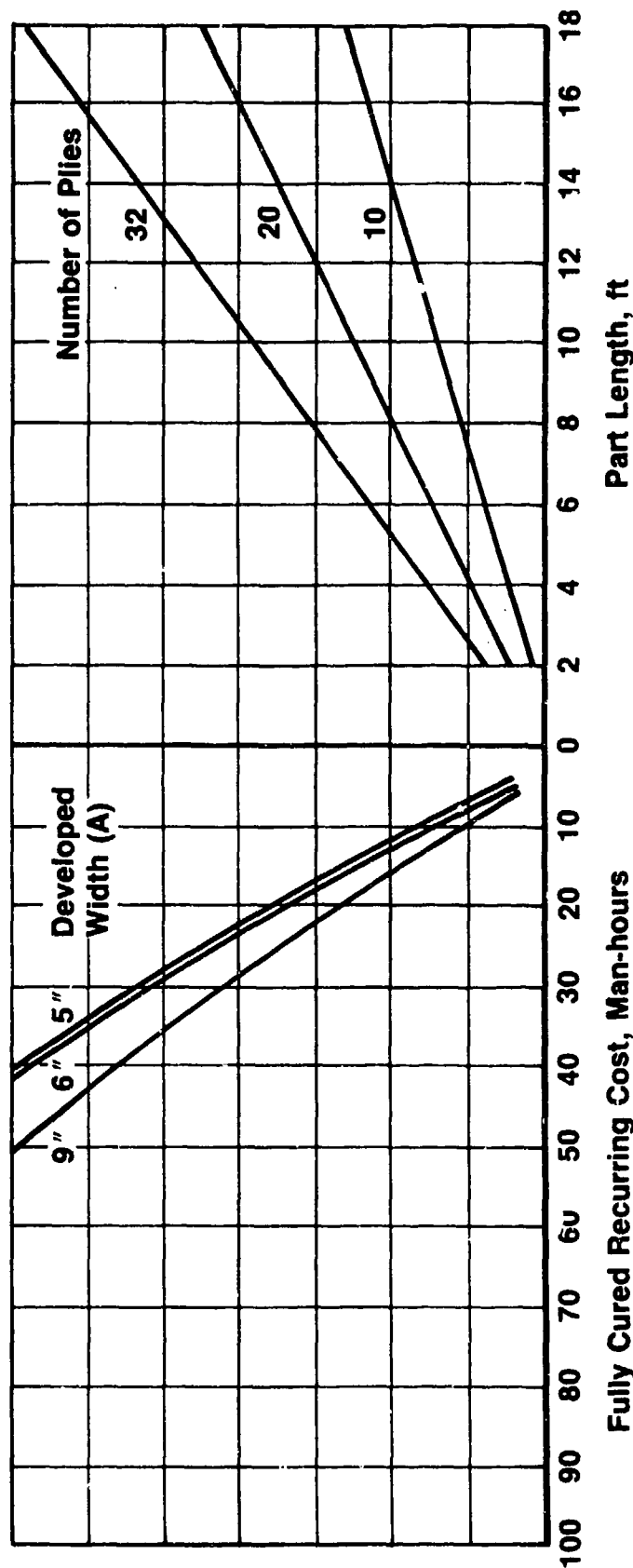
See ground rules for limitations and considerations.

CURVED COMPOSITE ANGLE SECTION; RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



Radius: 96 inches



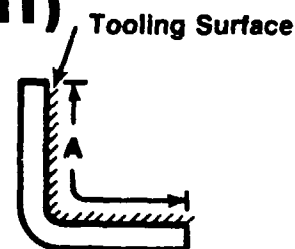
Fully Cured Recurring Cost, Man-hours

(For "B" Stage Recurring Cost, Multiply by 0.84)

See ground rules for limitations and considerations.

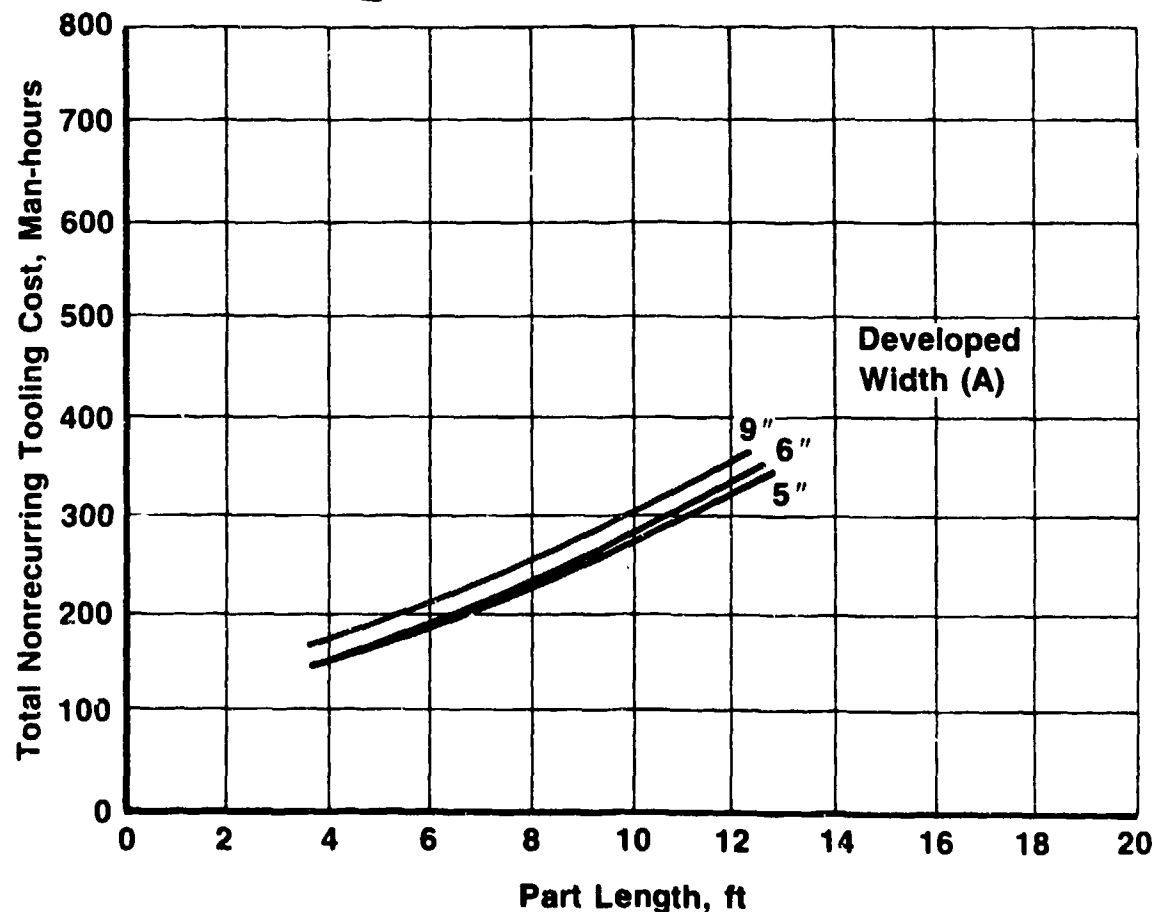
CURVED COMPOSITE ANGLE SECTION; TOTAL NONRECURRING TOOLING COST/PART (CONSTANT & VARIABLE HEIGHT)

Radius 24 to 96 Inches



Influenced by {

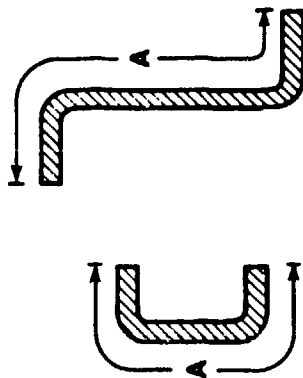
- Part Length
- Developed Width



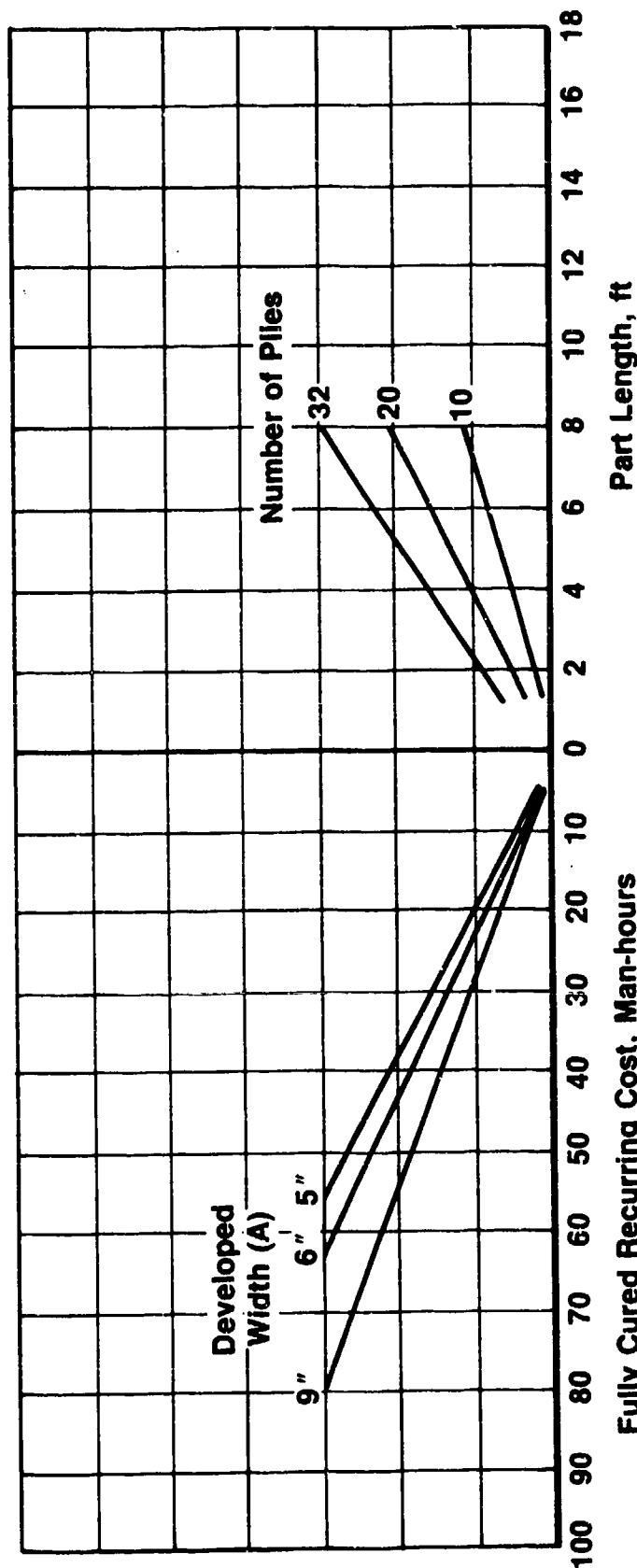
See ground rules for limitations and considerations.

CURVED COMPOSITE CHANNEL & "Z" SECTION; RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



Radius: 24 inches

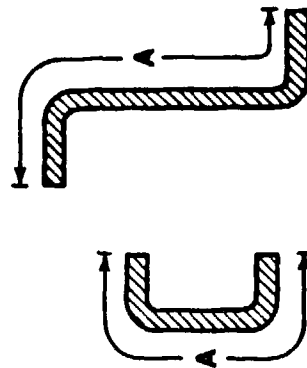


Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

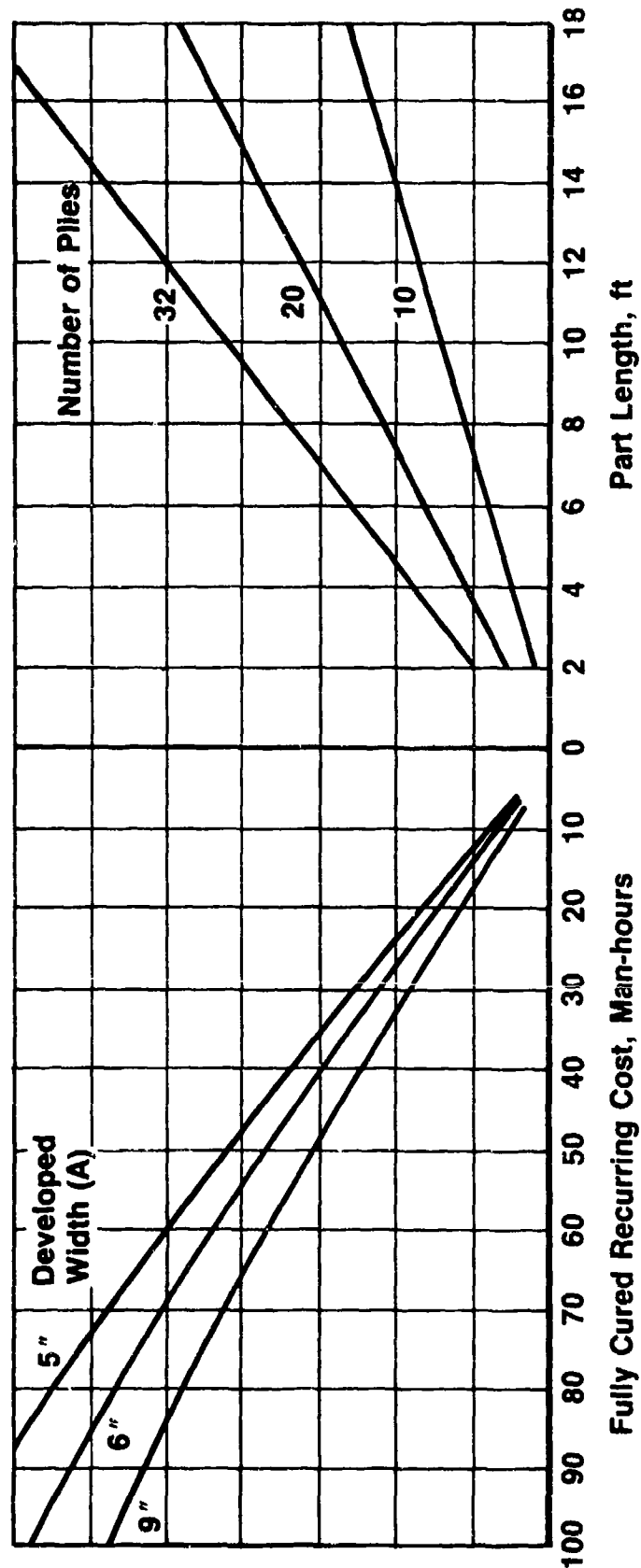
See ground rules for limitations and considerations.

CURVED COMPOSITE CHANNEL & "Z" SECTION; RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



Radius: 60 inches

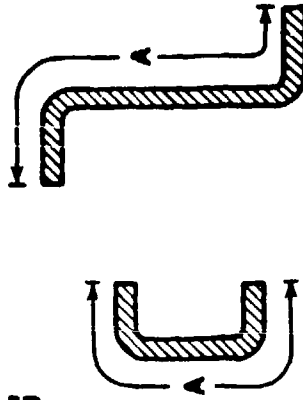


Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

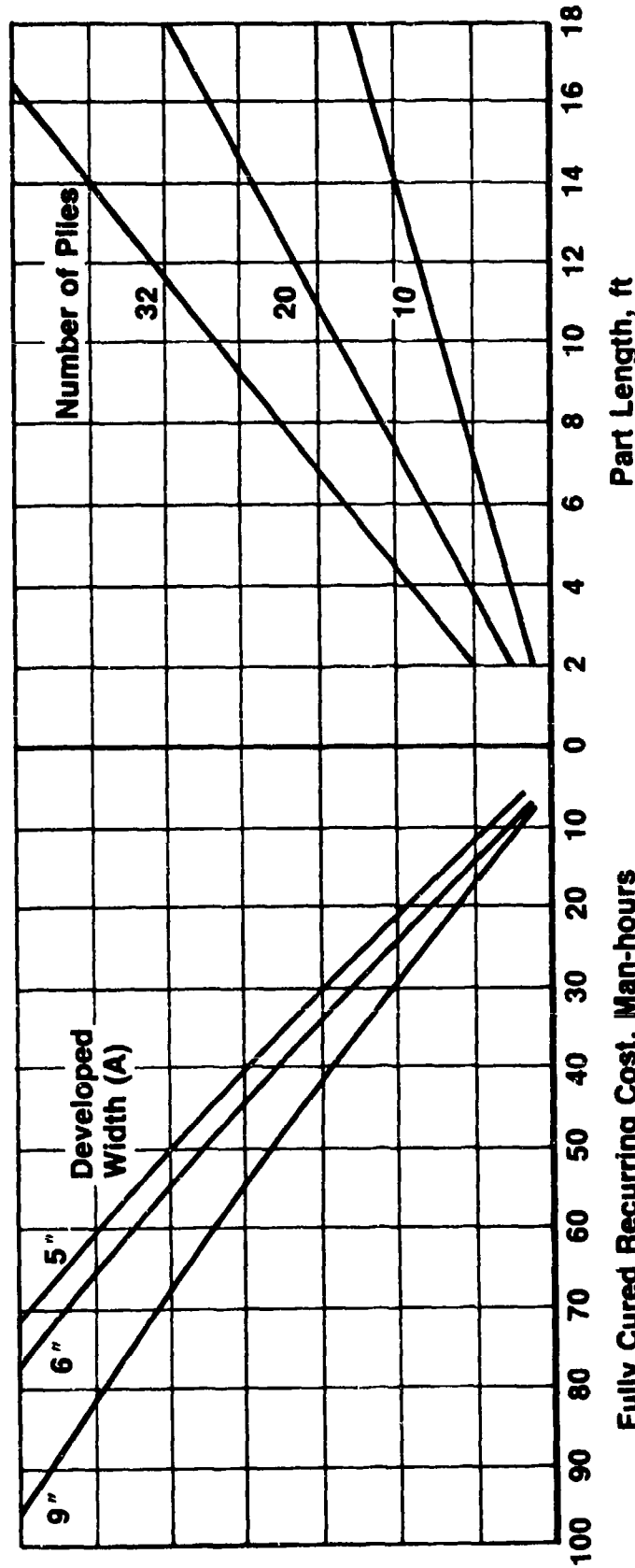
See ground rules for limitations and considerations.

CURVED COMPOSITE CHANNEL & "Z" SECTION; RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



Radius: 96 inches



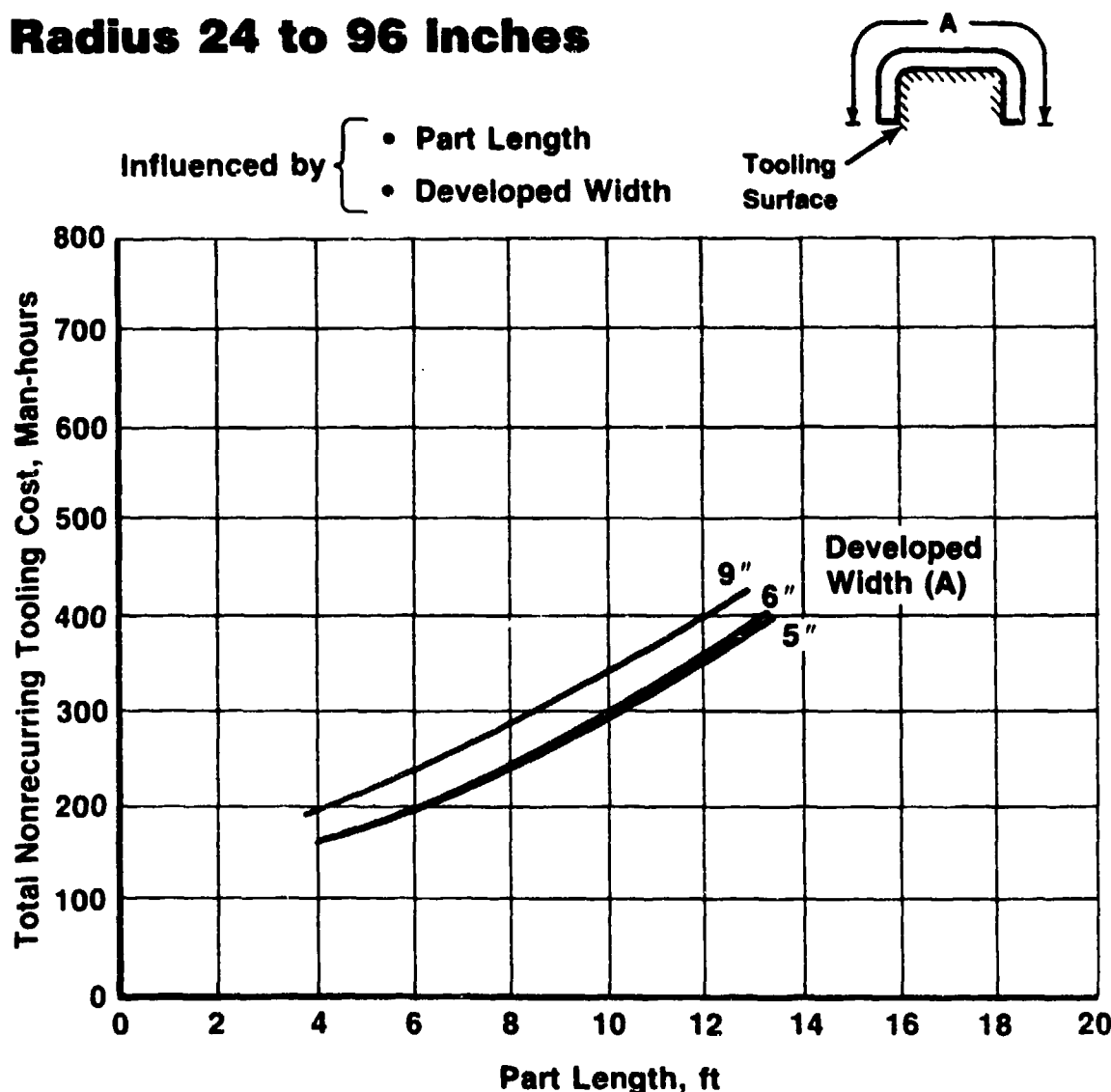
Fully Cured Recurring Cost, Man-hours

(For "B" Stage Recurring Cost, Multiply by 0.84)

See ground rules for limitations and considerations.

CURVED COMPOSITE CHANNEL SECTION; TOTAL NONRECURRING TOOLING COST/PART (CONSTANT & VARIABLE HEIGHT)

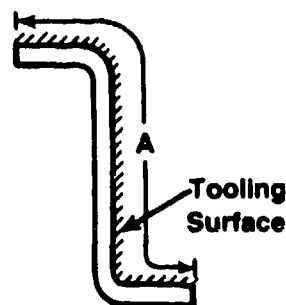
Radius 24 to 96 Inches



See ground rules for limitations and considerations.

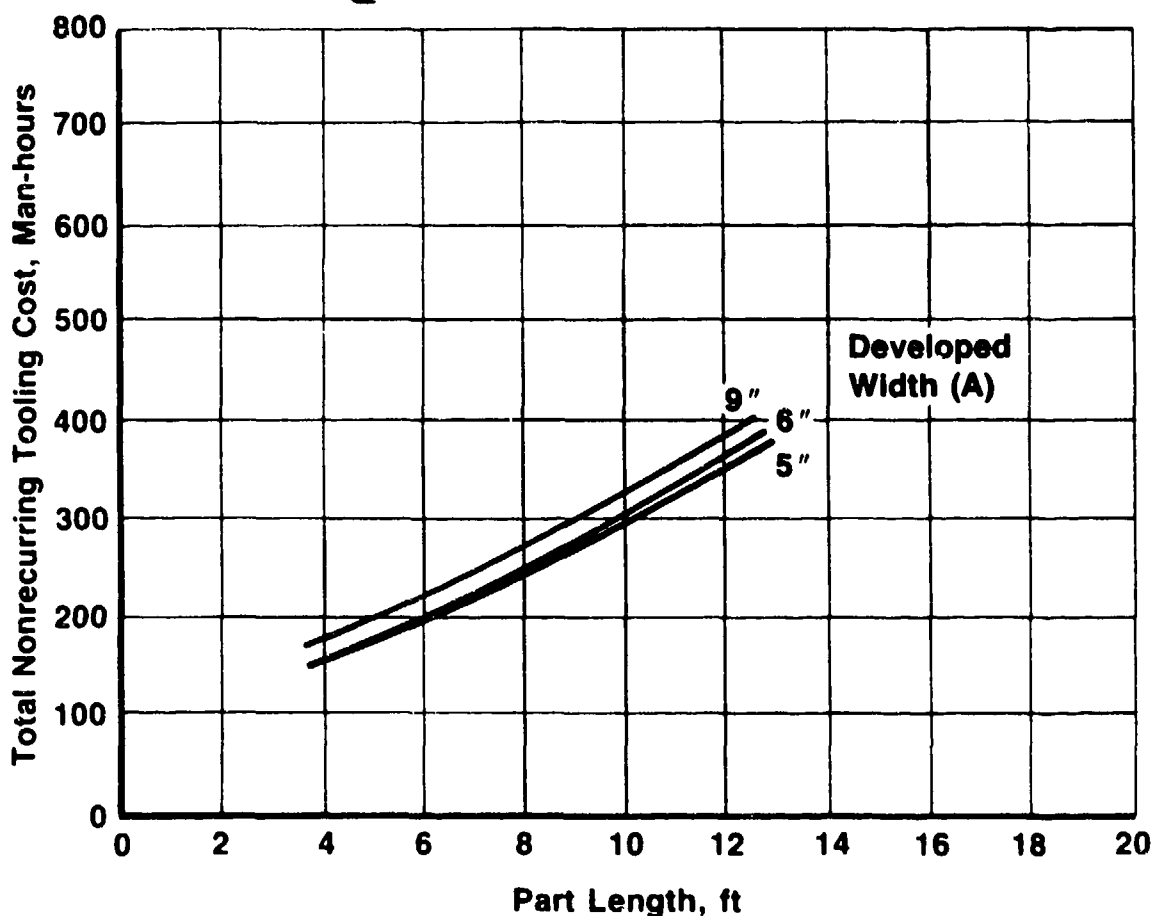
CURVED COMPOSITE "Z" SECTION; TOTAL NONRECURRING TOOLING COST/PART (CONSTANT & VARIABLE HEIGHT)

Radius 24 to 96 inches



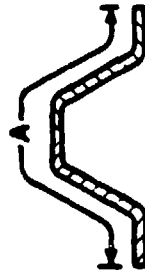
Influenced by {

- Part Length
- Developed Width



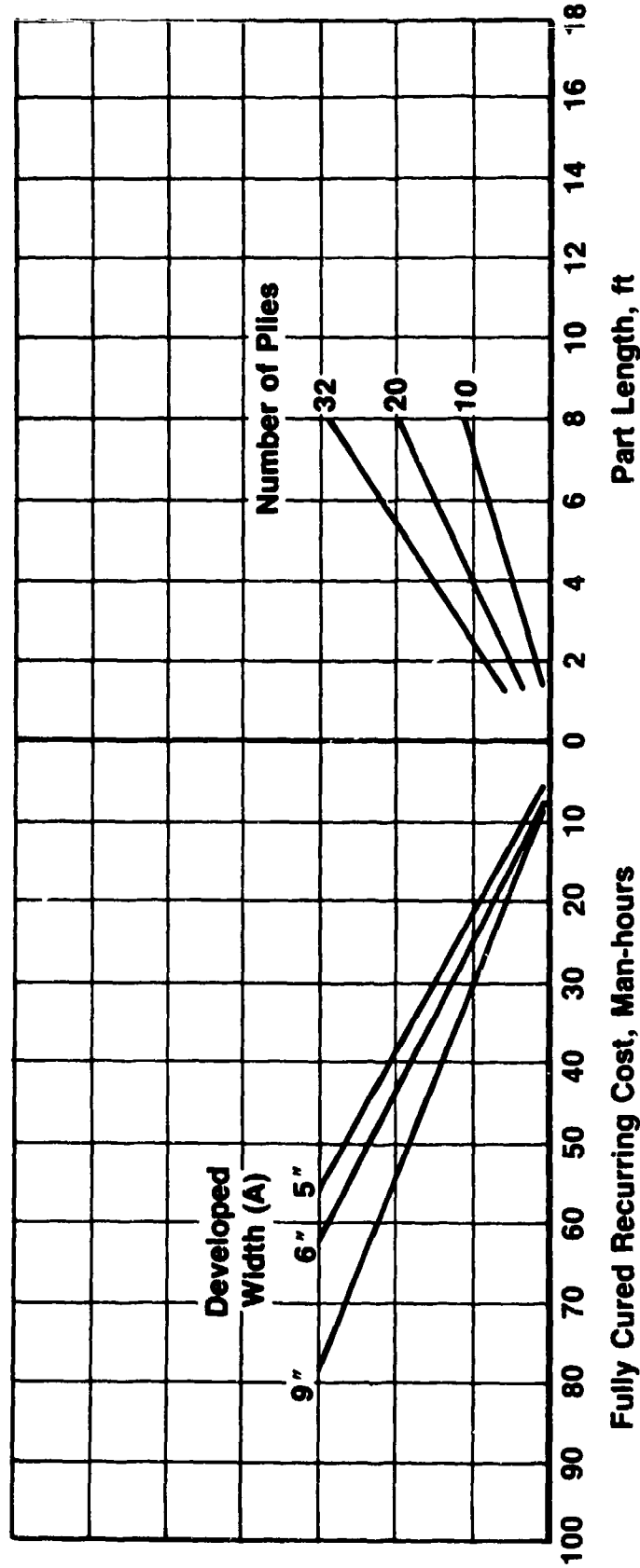
See ground rules for limitations and considerations.

CURVED COMPOSITE HAT SECTION RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)



- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage

Radius: 24 inches



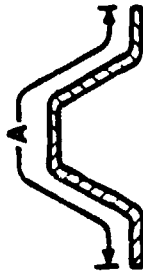
Fully Cured Recurring Cost, Man-hours

(For "B" Stage Recurring Cost, Multiply by 0.84)

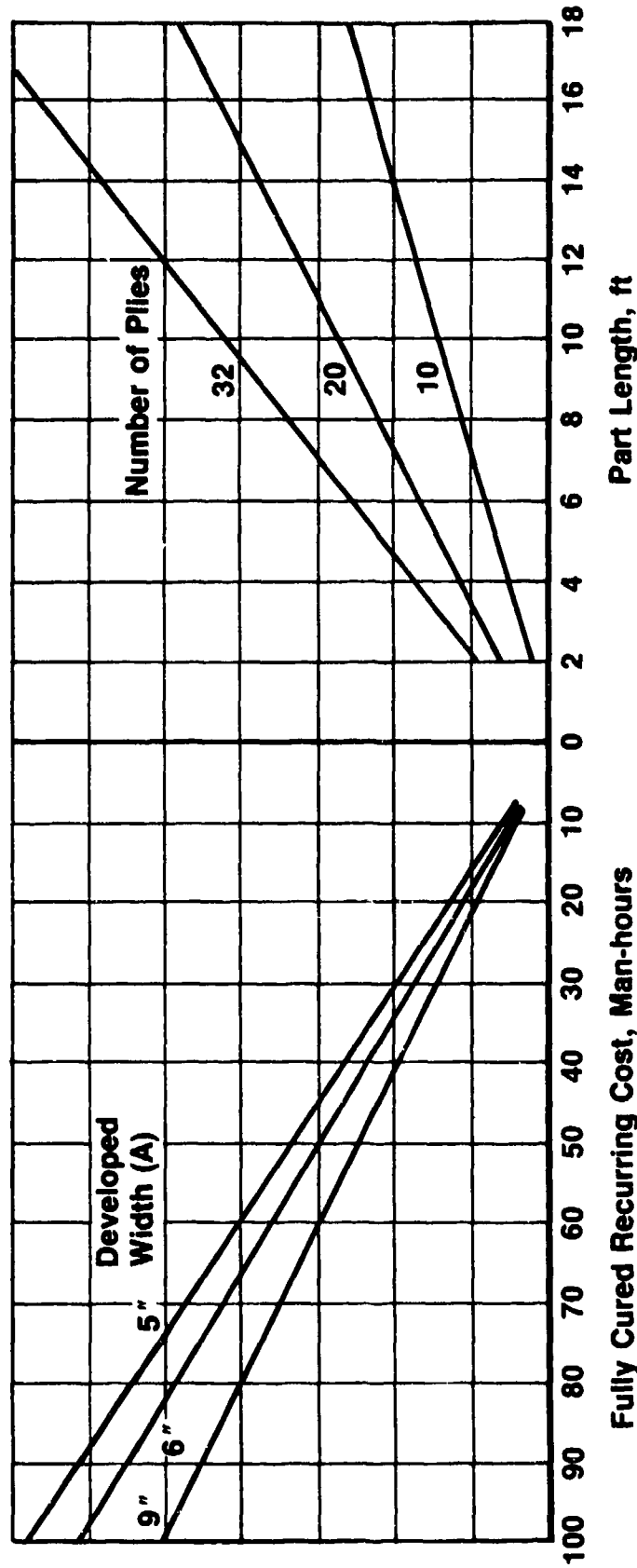
See ground rules for limitations and considerations.

CURVED COMPOSITE HAT SECTION RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



Radius: 60 inches

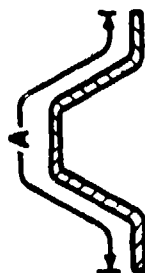


Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

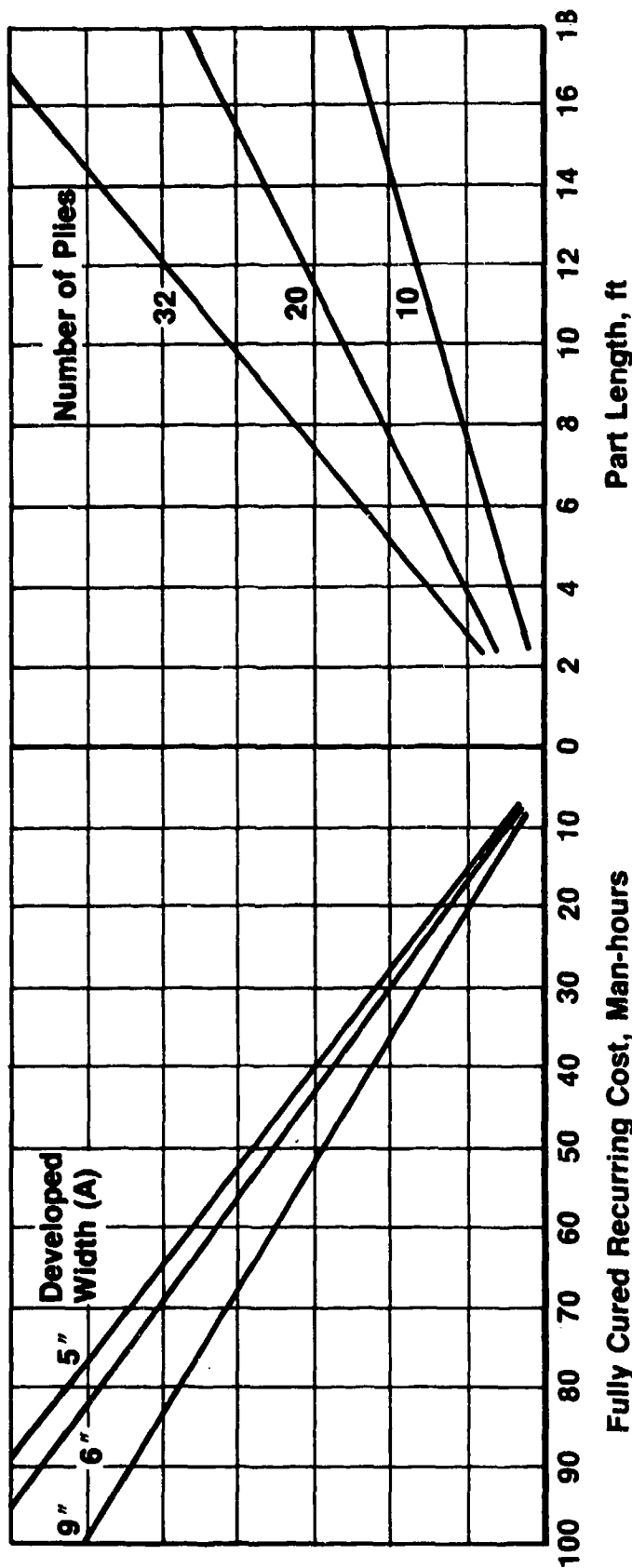
See ground rules for limitations and considerations.

CURVED COMPOSITE HAT SECTION RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



Radius: 96 inches



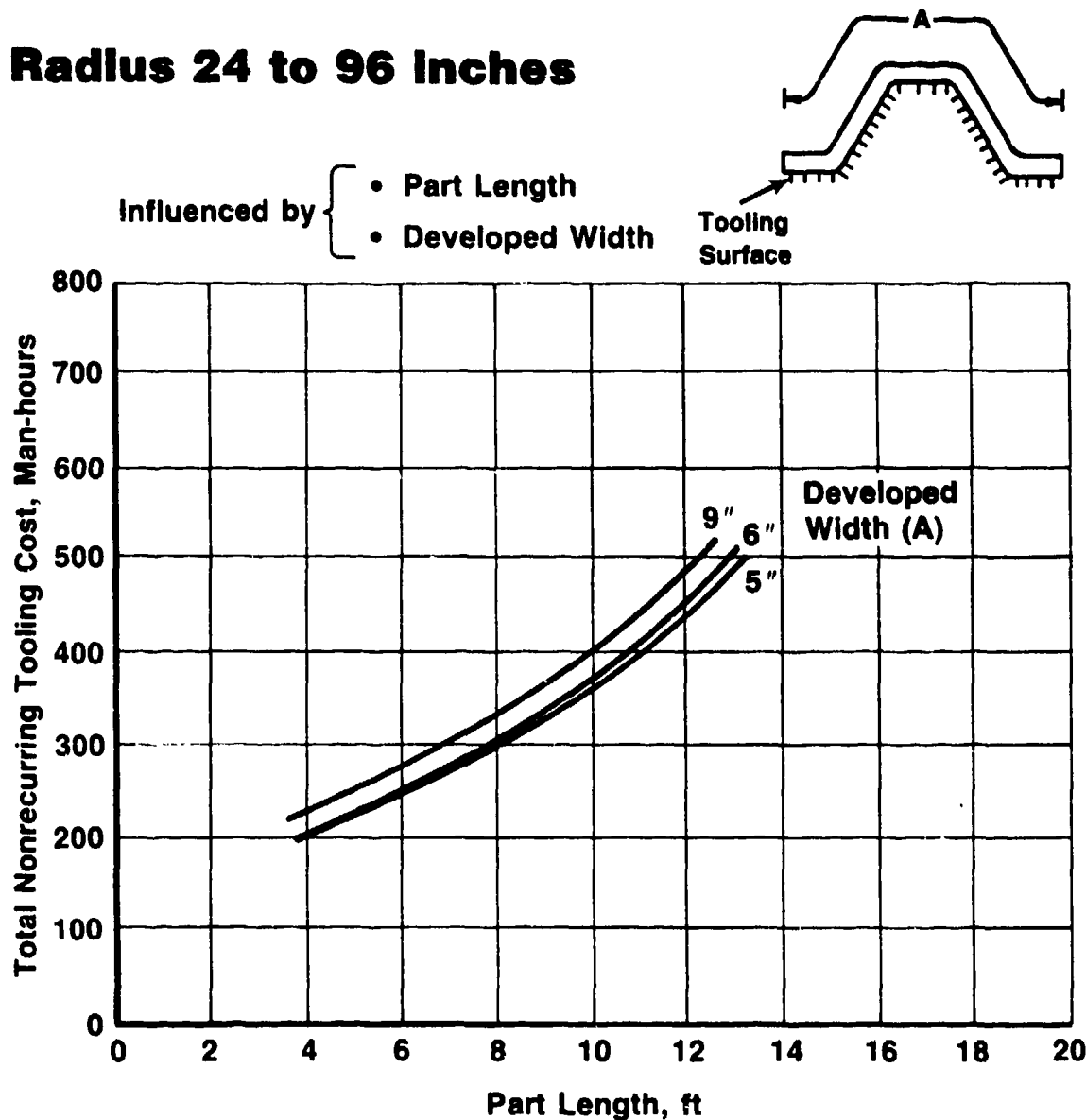
Fully Cured Recurring Cost, Man-hours

(For "B" Stage Recurring Cost, Multiply by 0.84)

See ground rules for limitations and considerations.

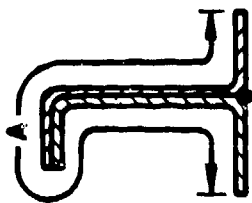
CURVED COMPOSITE HAT SECTION; TOTAL NONRECURRING TOOLING COST/PART (CONSTANT & VARIABLE HEIGHT)

Radius 24 to 96 Inches



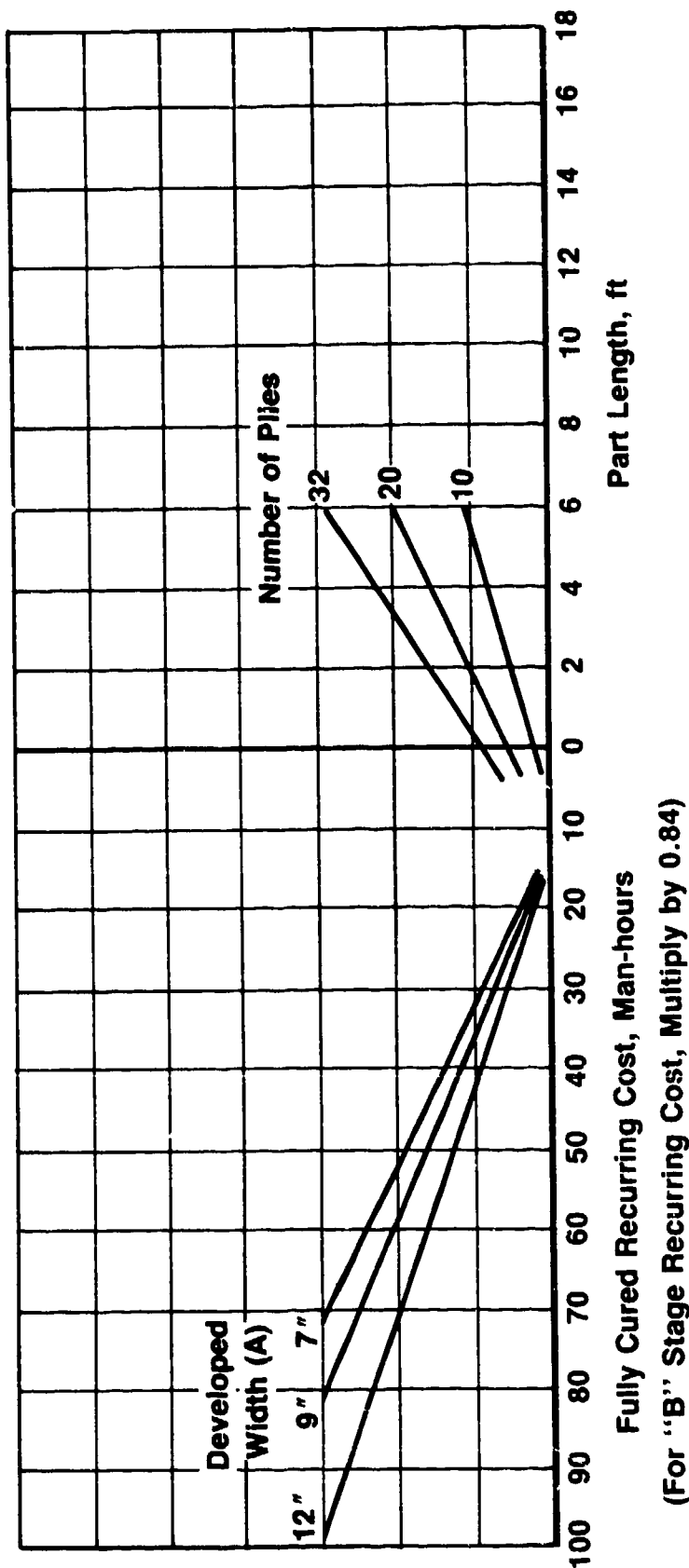
See ground rules for limitations and considerations.

CURVED COMPOSITE "J" SECTION RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)



- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage

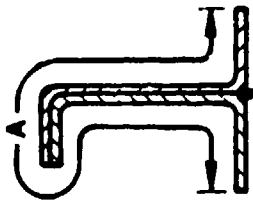
Radius: 24 inches



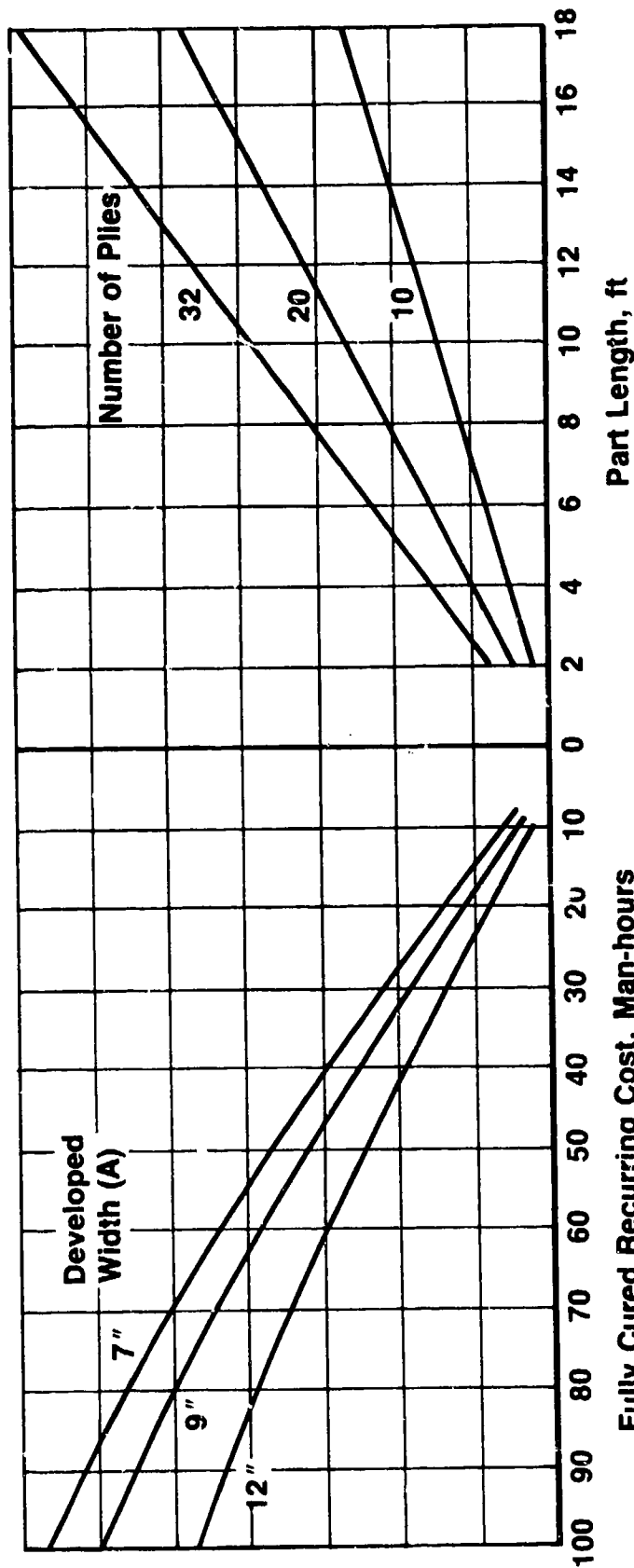
See ground rules for limitations and considerations.

CURVED COMPOSITE "J" SECTION RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



Radius: 60 inches



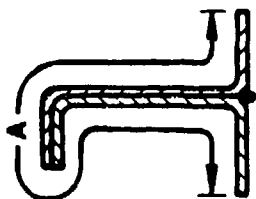
Fully Cured Recurring Cost, Man-hours

(For "B" Stage Recurring Cost, Multiply by 0.84)

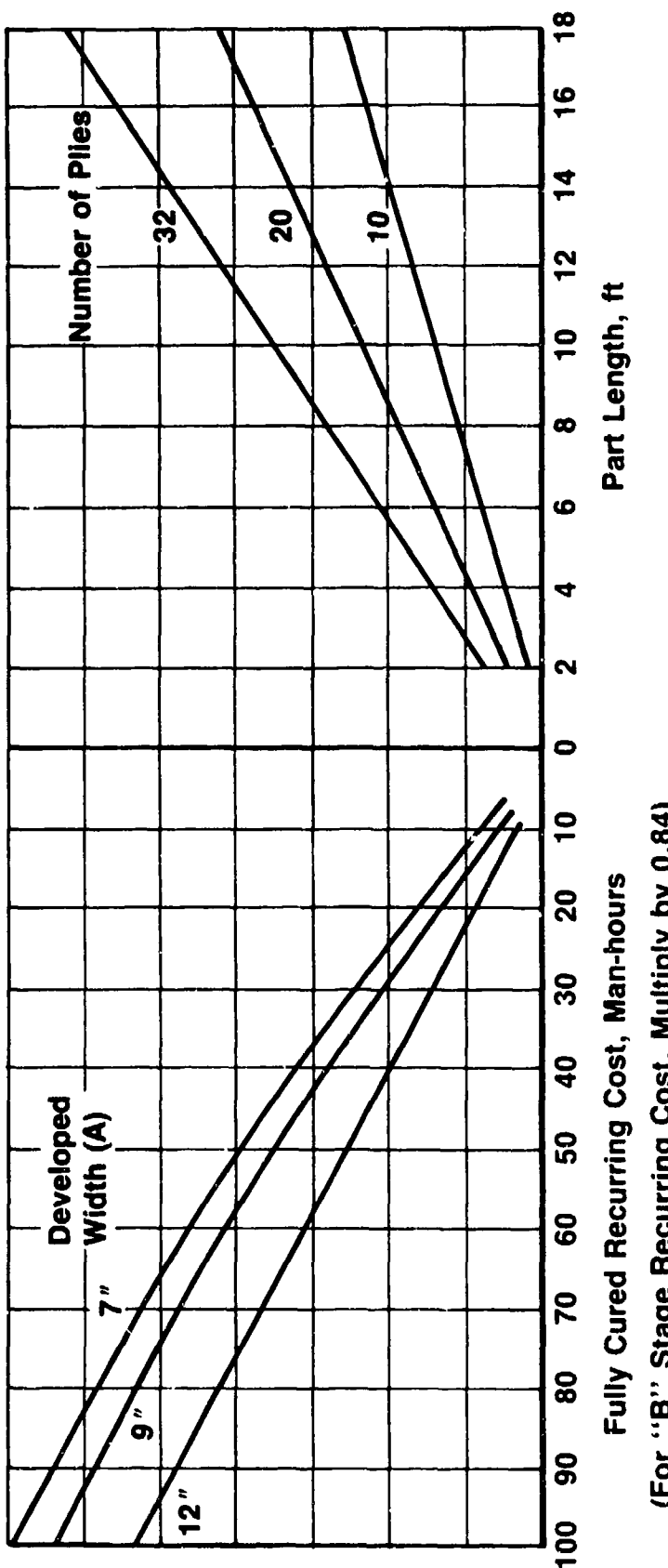
See ground rules for limitations and considerations.

CURVED COMPOSITE "J" SECTION RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



Radius: 96 inches

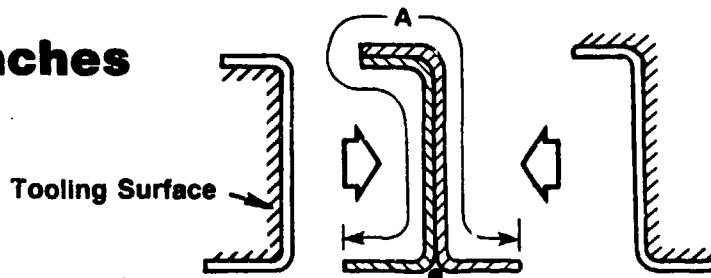


Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

See ground rules for limitations and considerations.

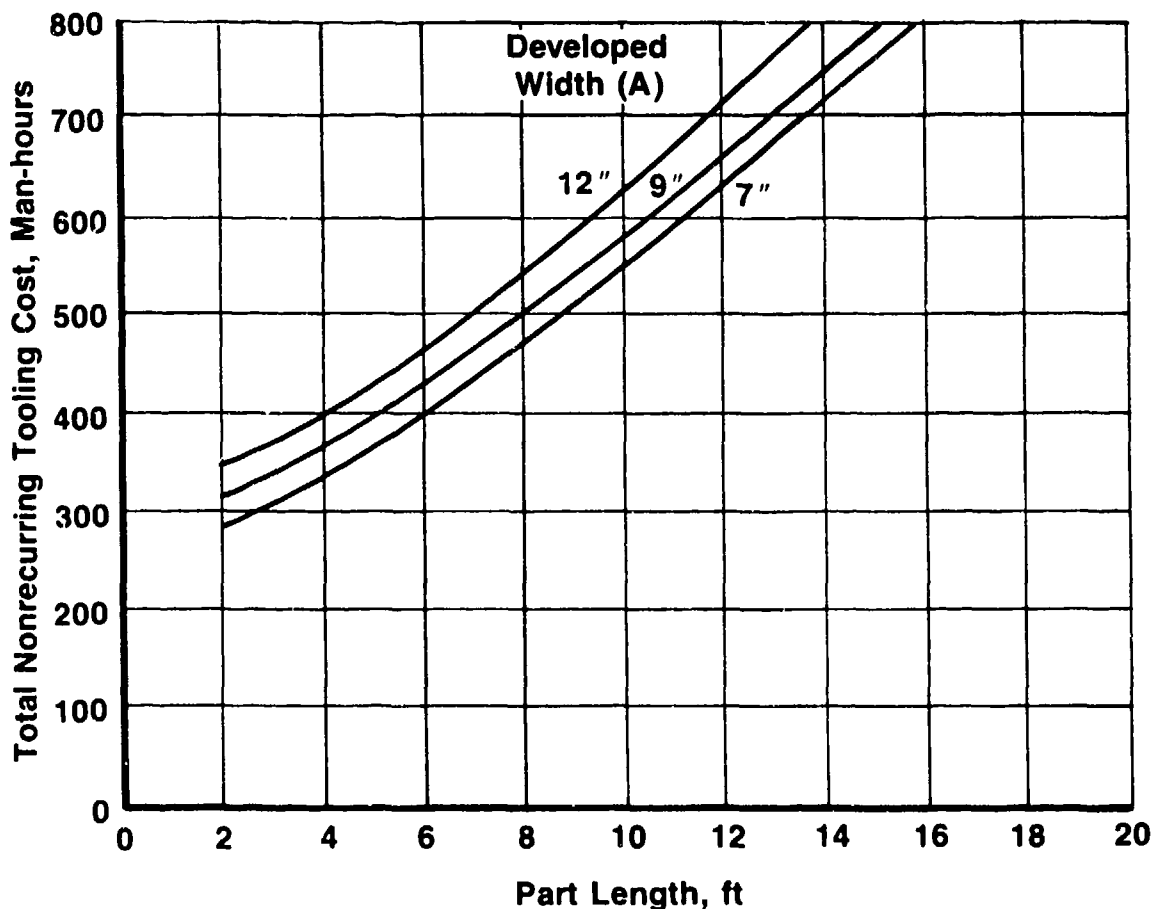
COMPOSITE "U" SECTION; TOTAL NONRECURRING TOOLING COST (CONSTANT & VARIABLE HEIGHT)

Radius 24 to 96 Inches



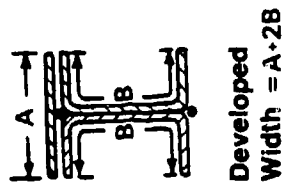
Influenced by {

- Part Length
- Developed Width



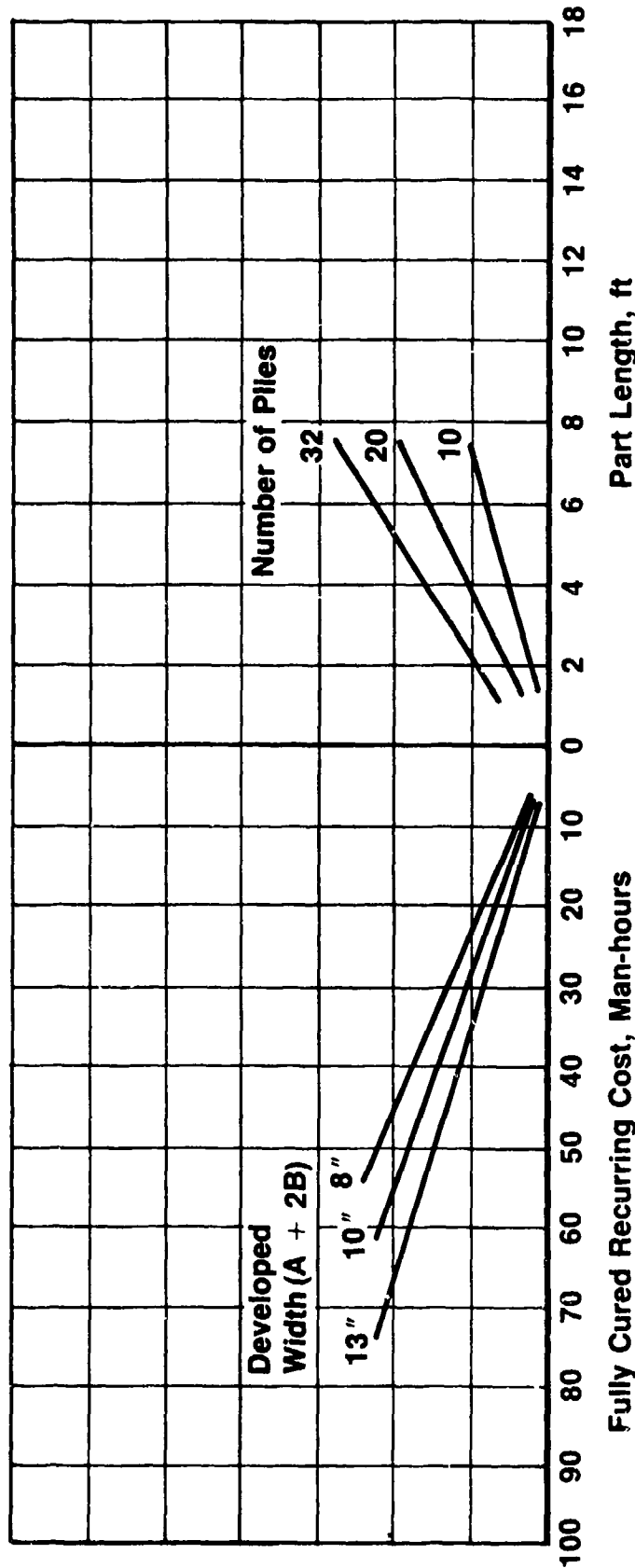
See ground rules for limitations and considerations.

CURVED COMPOSITE "I" SECTION; RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)



- Influenced by {
- Part Length
 - Number of Piles
 - Developed Flat Pattern Width
 - Cure Stage

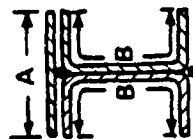
Radius: 24 inches



See ground rules for limitations and considerations.

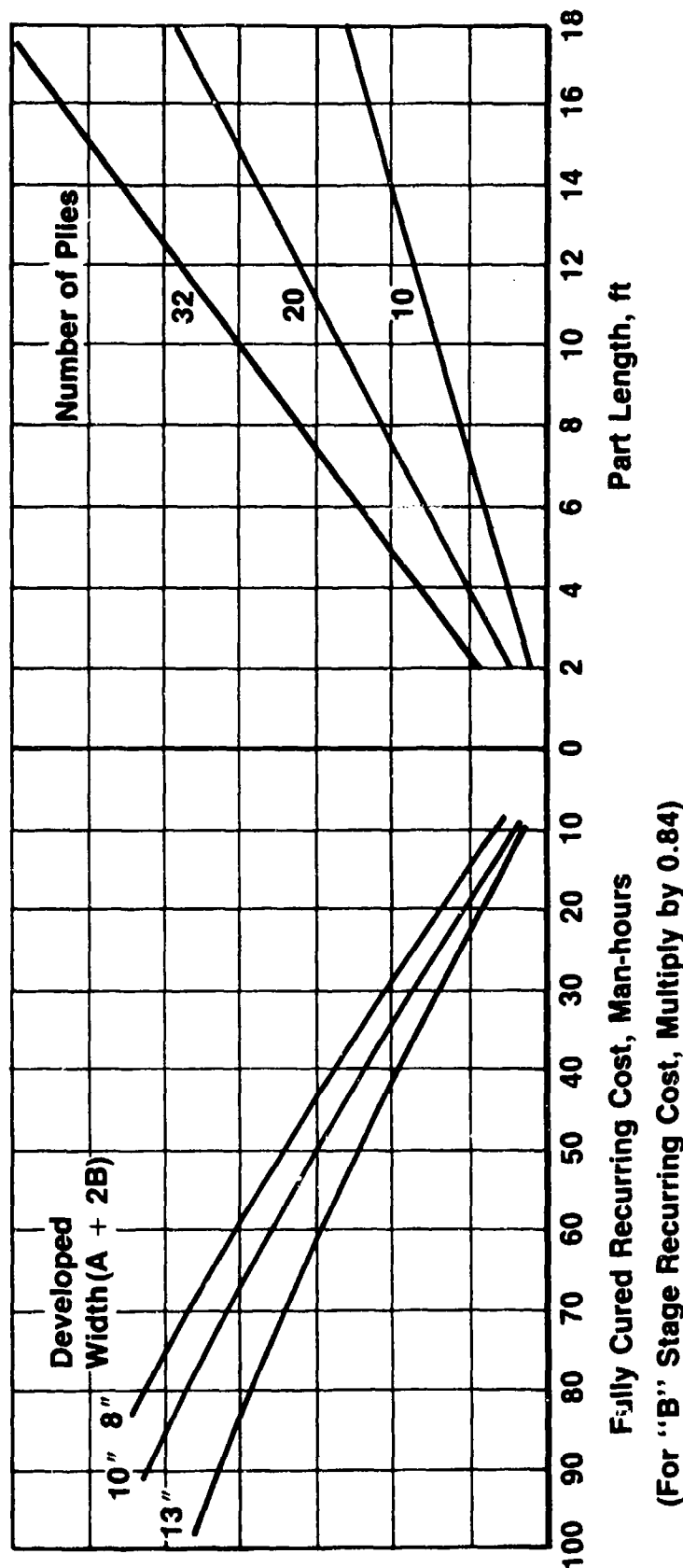
CURVED COMPOSITE "I" SECTION; RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



Developed
Width = $A + 2B$

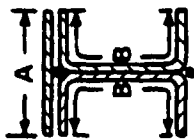
Radius: 60 inches



See ground rules for limitations and considerations.

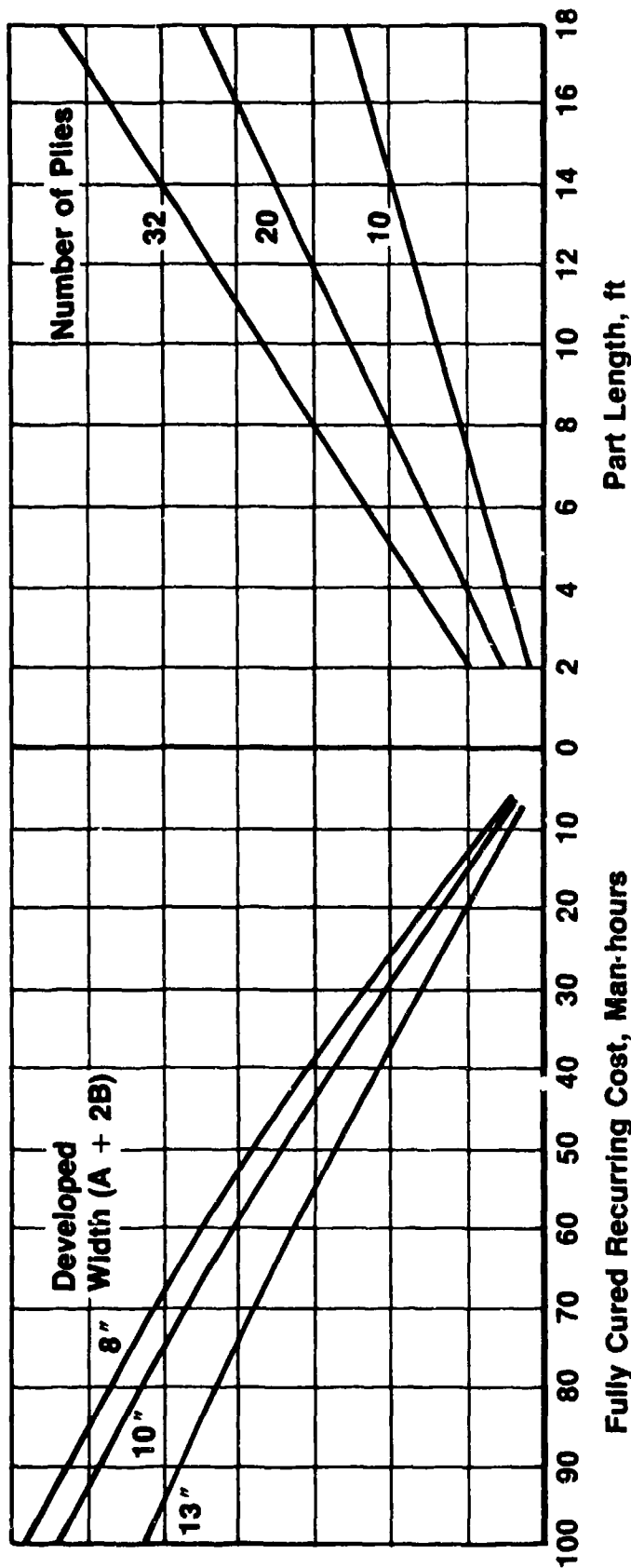
CURVED COMPOSITE "I" SECTION; RECURRING COST/PART (CONSTANT & VARIABLE HEIGHT)

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



Developed
Width = $A \cdot 2B$

Radius: 96 inches



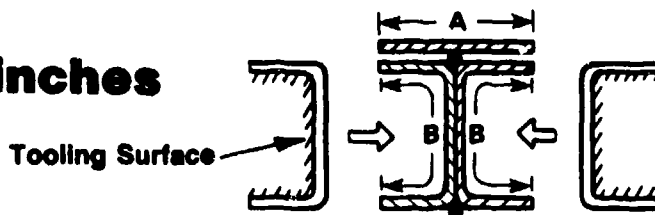
Fully Cured Recurring Cost, Man-hours

(For "B" Stage Recurring Cost, Multiply by 0.84)

See ground rules for limitations and considerations.

COMPOSITE "I" SECTION; TOTAL NONRECURRING TOOLING COST (CONSTANT & VARIABLE HEIGHT)

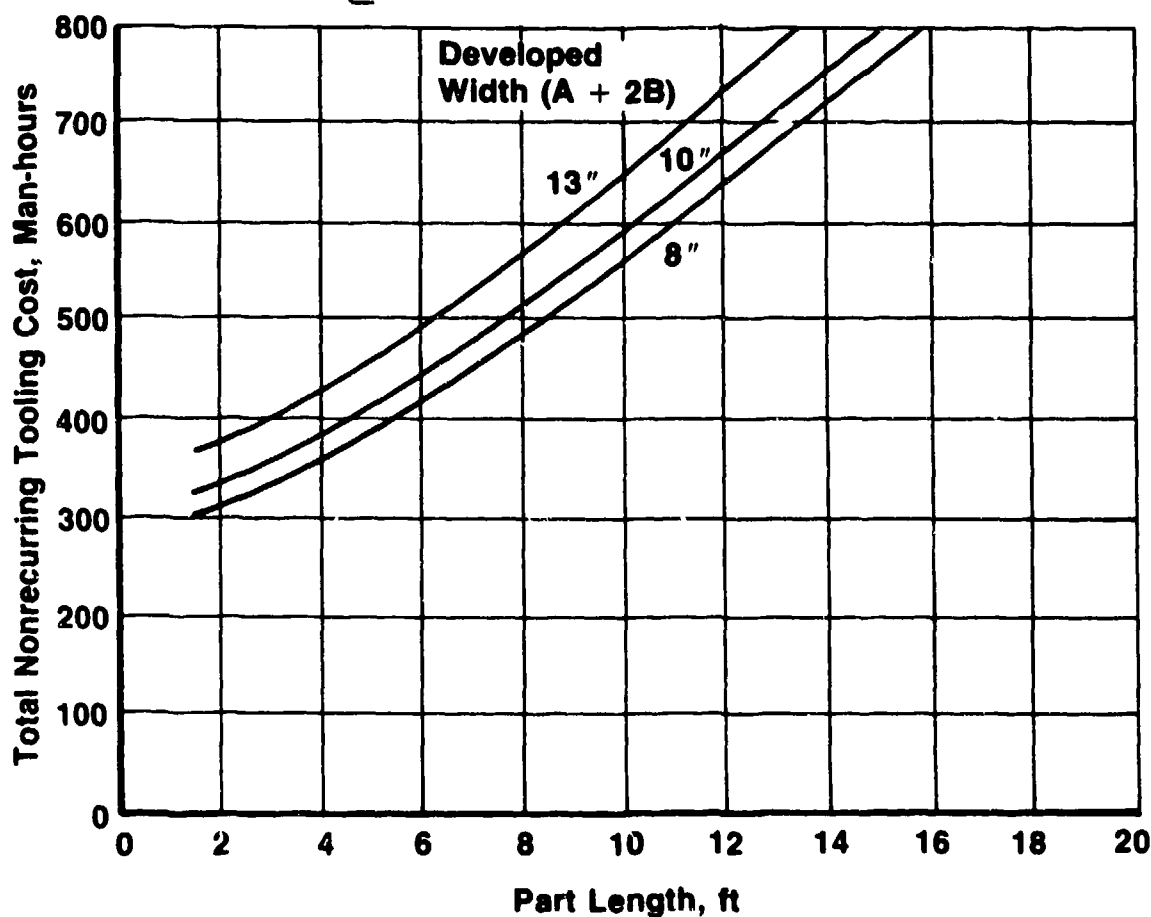
Radius 24 to 96 Inches



Influenced by {

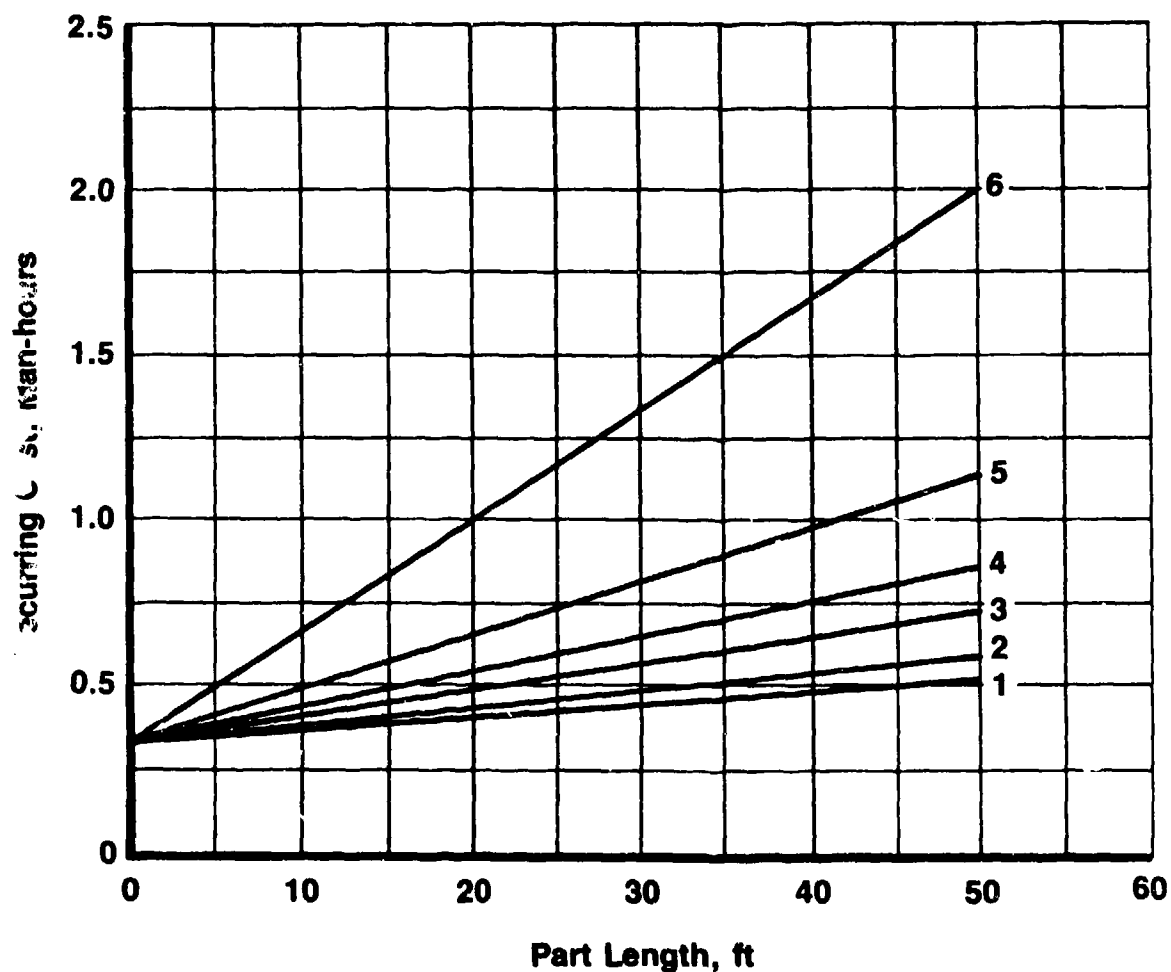
- Part Length
- Developed Width

Developed
Width = $A + 2B$



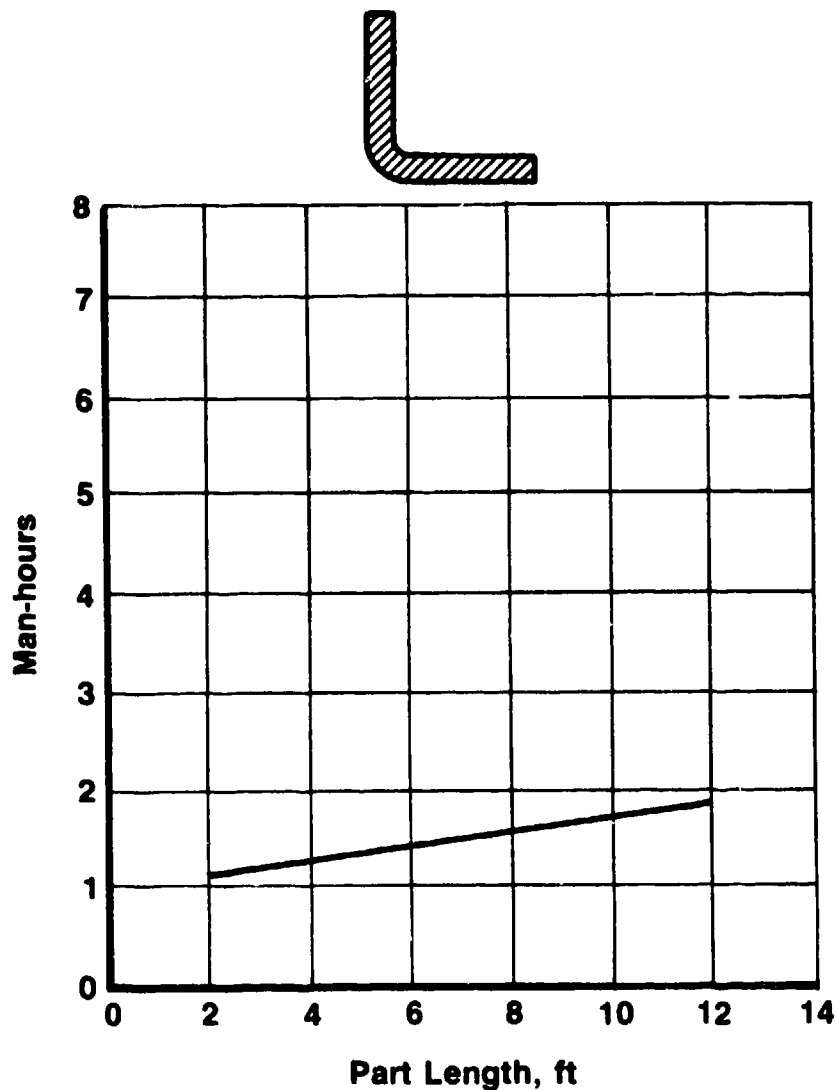
See ground rules for limitations and considerations.

COMPOSITE STIFFENING SECTIONS WET/DRY PULTRUSIONS; RECURRING COST/PART



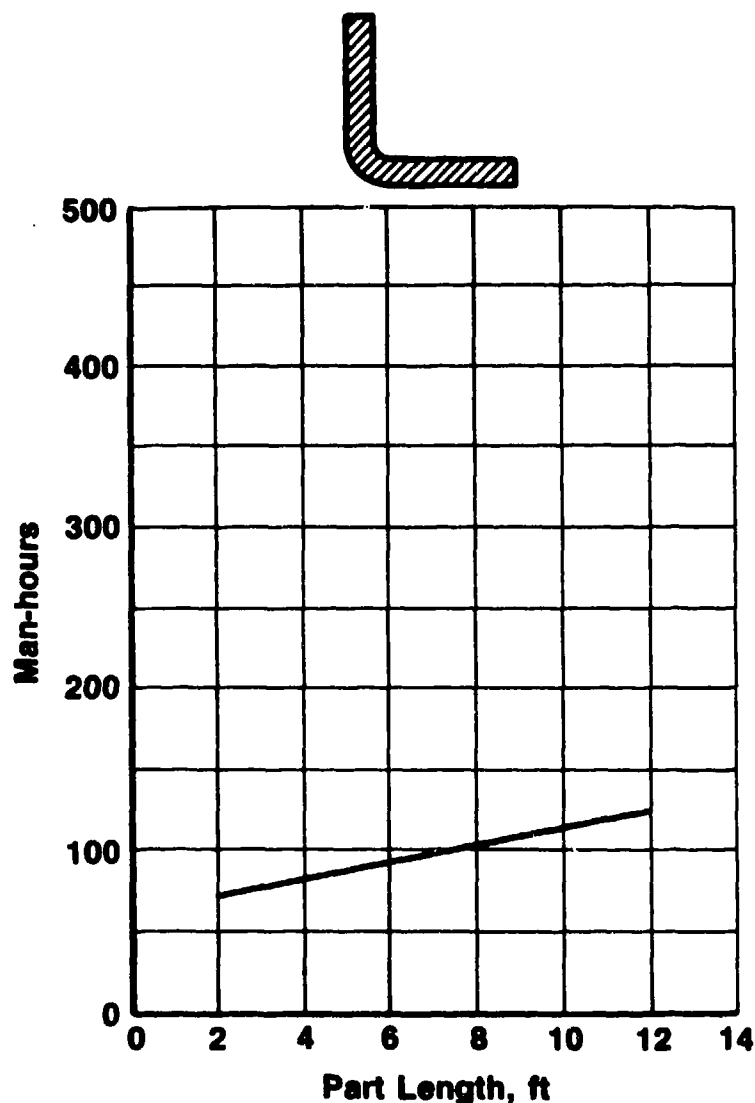
Curve	1	2	3	4	5	6
Pull Rate, in./min	48	36	24	18	12	6

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE ANGLE SECTION RECURRING COST/PART



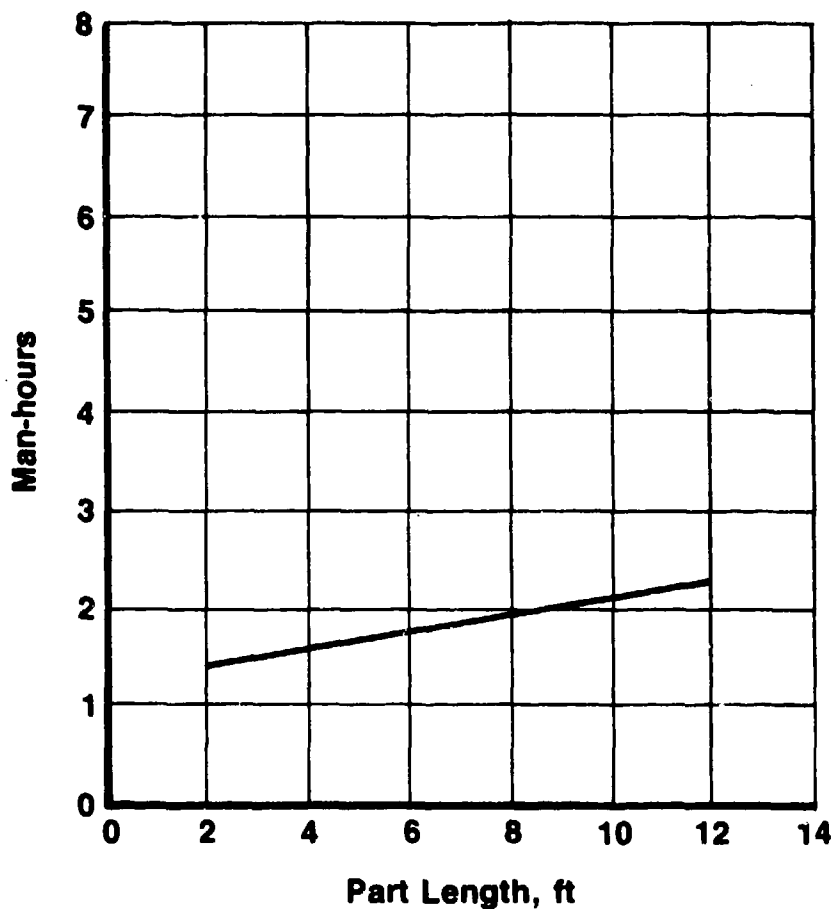
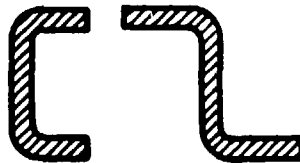
- Applies to laminates up to 32 plies.
- Applies to curved/straight, constant & variable height sections, and also a 2-8 foot radius of curvature.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE ANGLE SECTION NONRECURRING COST/PART



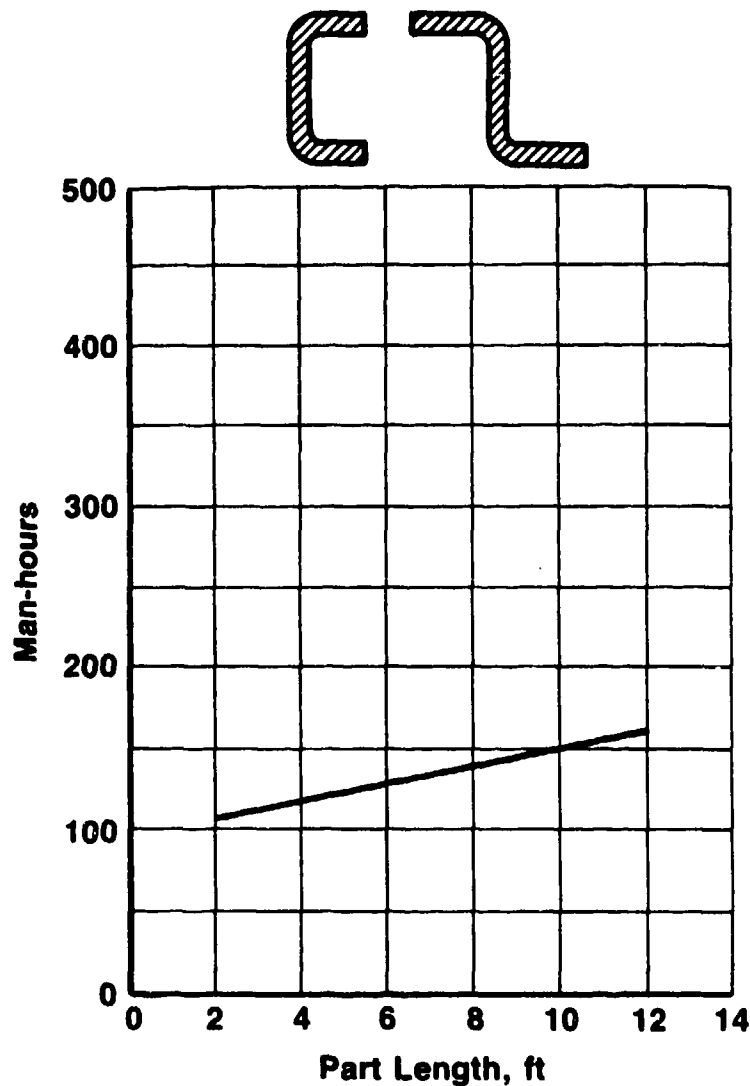
- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- Applies to curved/straight, constant & variable height sections, and also a 2-8 foot radius of curvature.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE CHANNEL AND "Z" SECTIONS RECURRING COST/PART



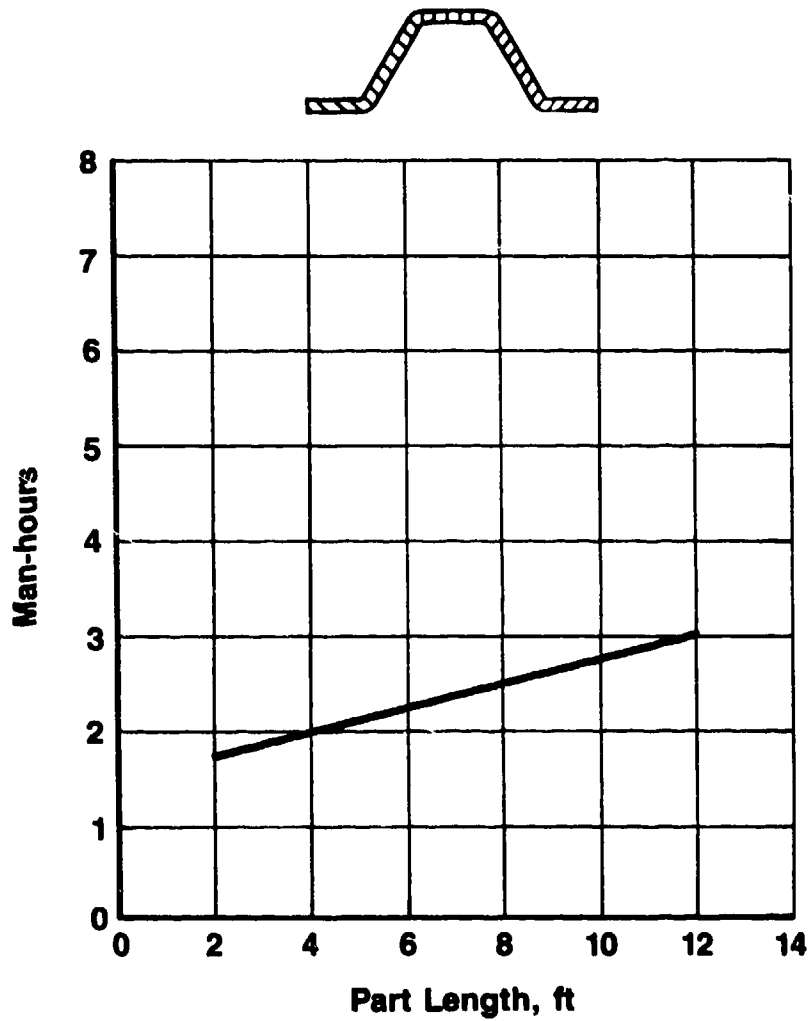
- Applies to laminates up to 32 plies.
- Applies to curved/straight, constant & variable height sections, and also a 2-8 foot radius of curvature.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE CHANNEL AND "Z" SECTION NONRECURRING COST/PART



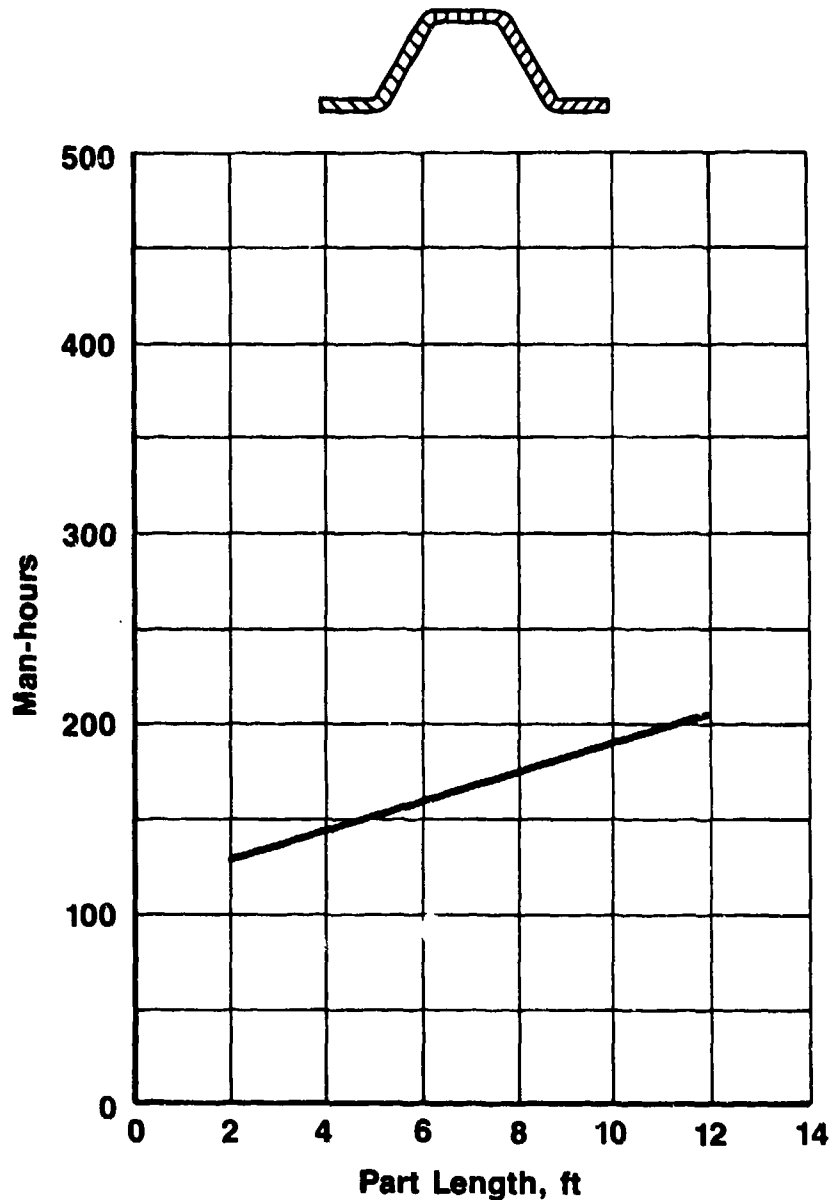
- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- Applies to curved/straight, constant & variable height sections, and also a 2-8 foot radius of curvature.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE HAT SECTION RECURRING COST/PART



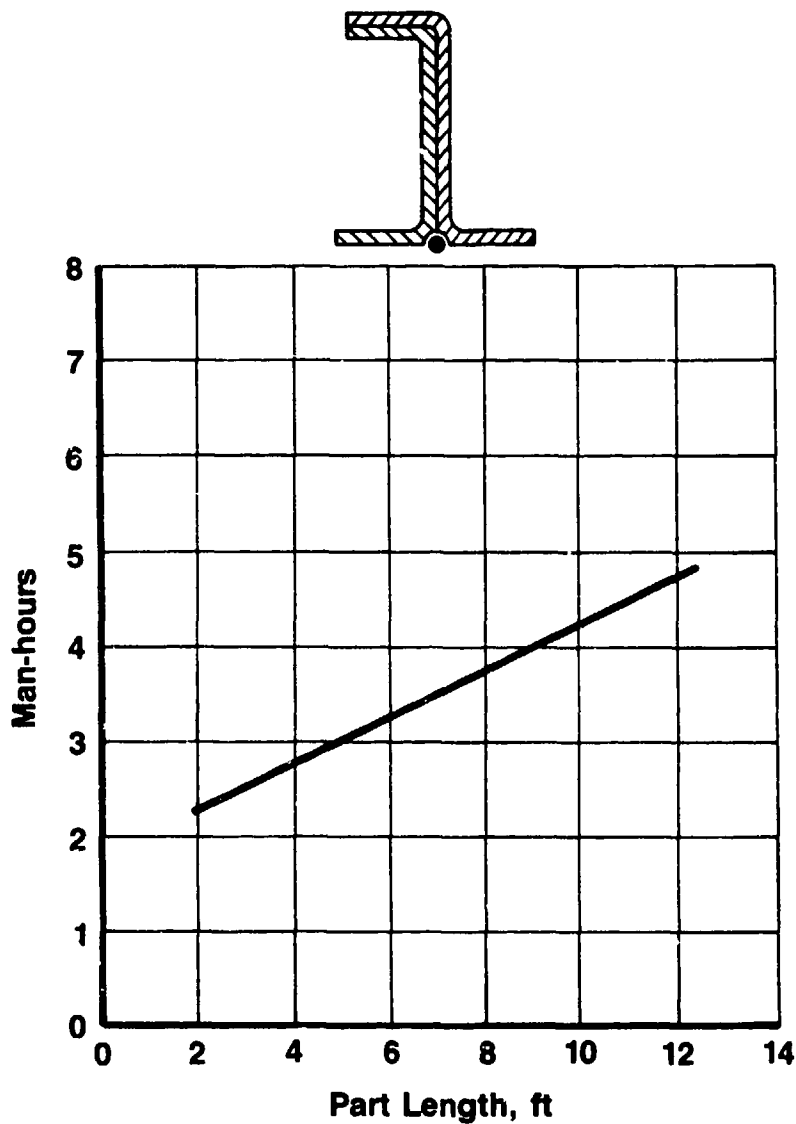
- Applies to laminates up to 32 plies.
- Applies to curved/straight, constant/variable height sections, and a 2-8 foot radius of curvature.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE HAT SECTION NONRECURRING COST/PART



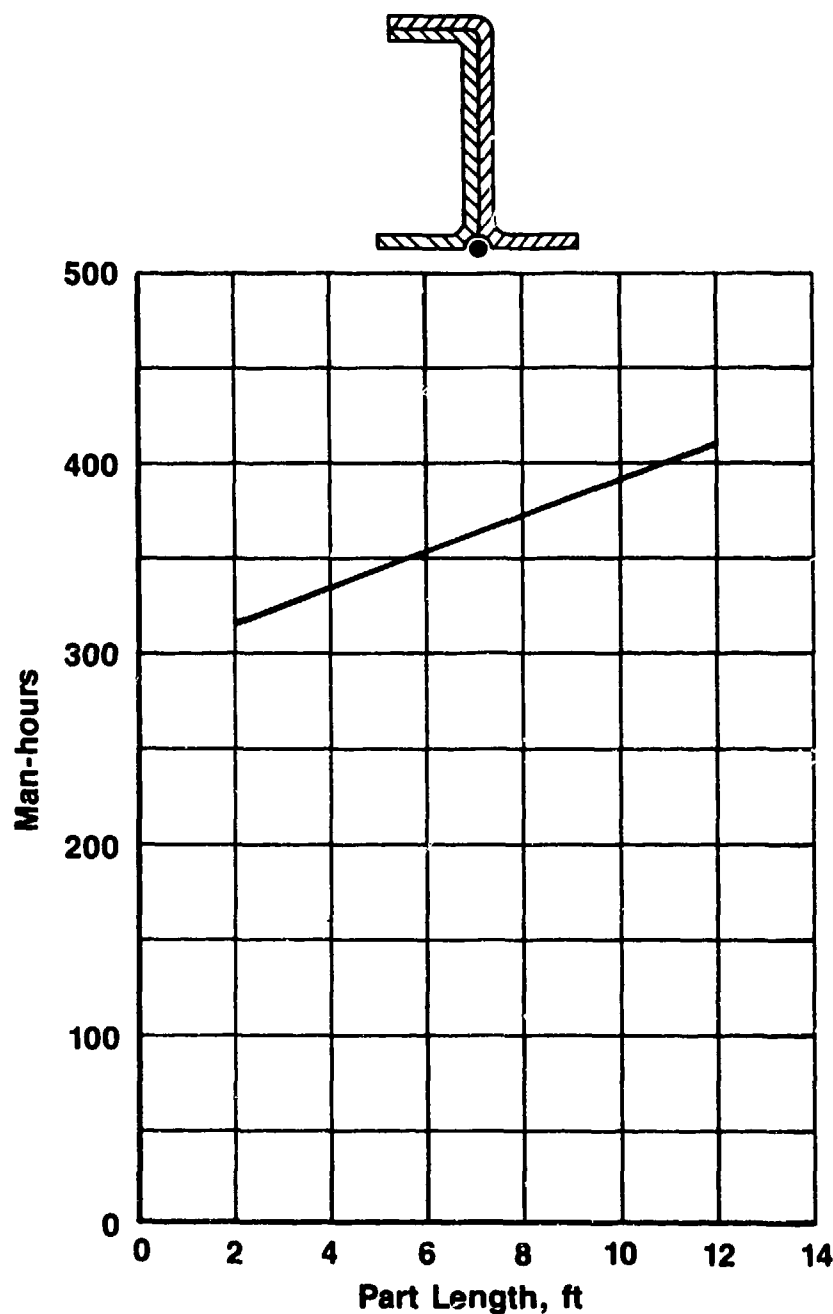
- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- Applies to curved/straight, constant/variable height sections, and a 2-8 foot radius of curvature.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE "U" SECTION RECURRING COST/PART



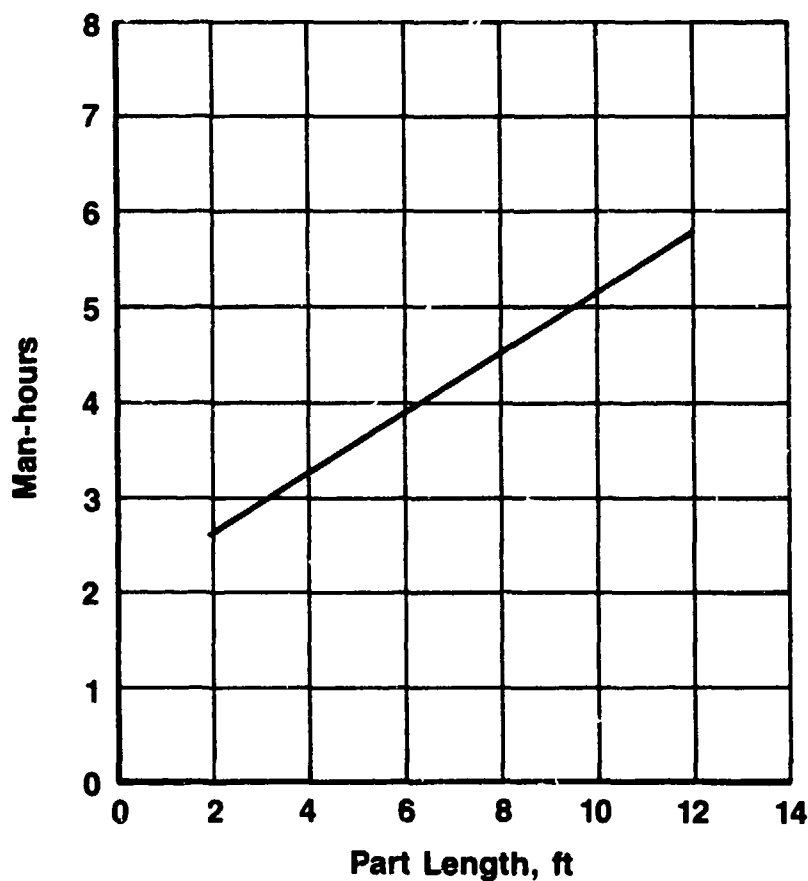
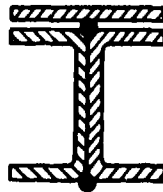
- Applies to laminates up to 32 plies.
- Applies to curved/straight, constant/variable height sections, and a 2-8 foot radius of curvature.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE "U" SECTION NONRECURRING COST/PART



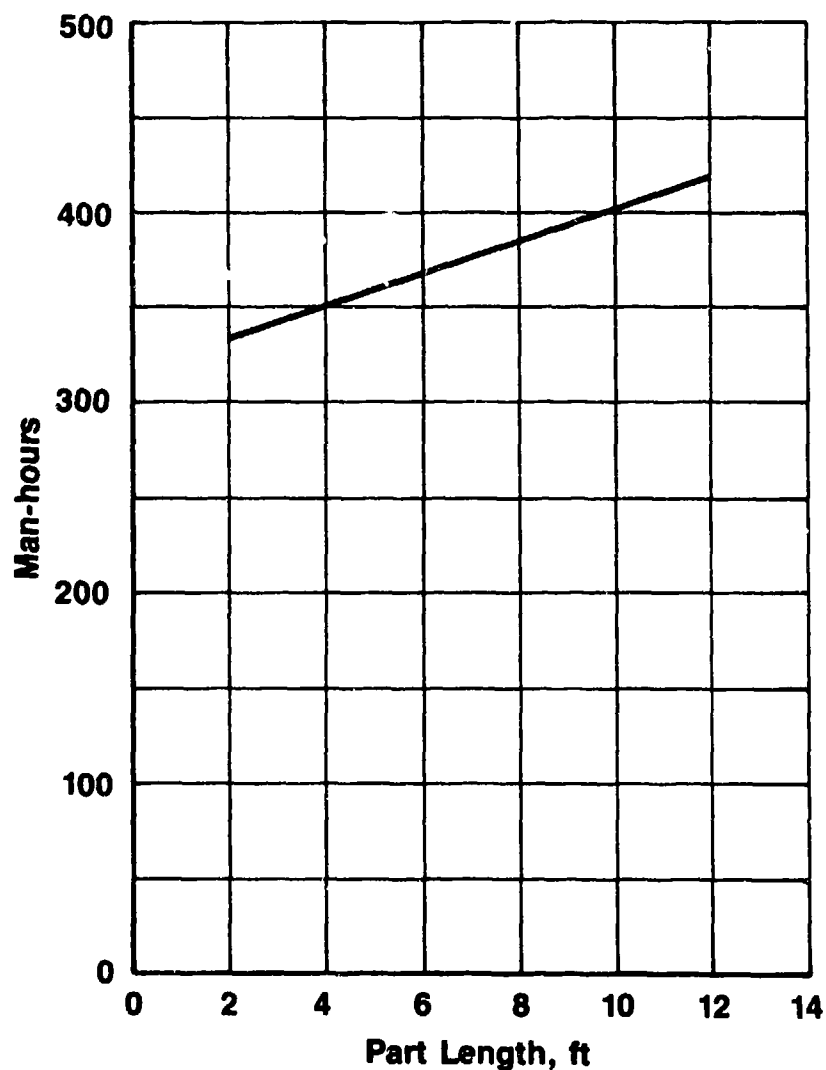
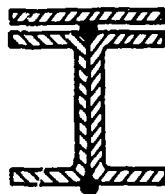
- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- Applies to curved/straight, constant/variable height sections, and a 2-8 foot radius of curvature.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE "I" SECTION RECURRING COST/PART



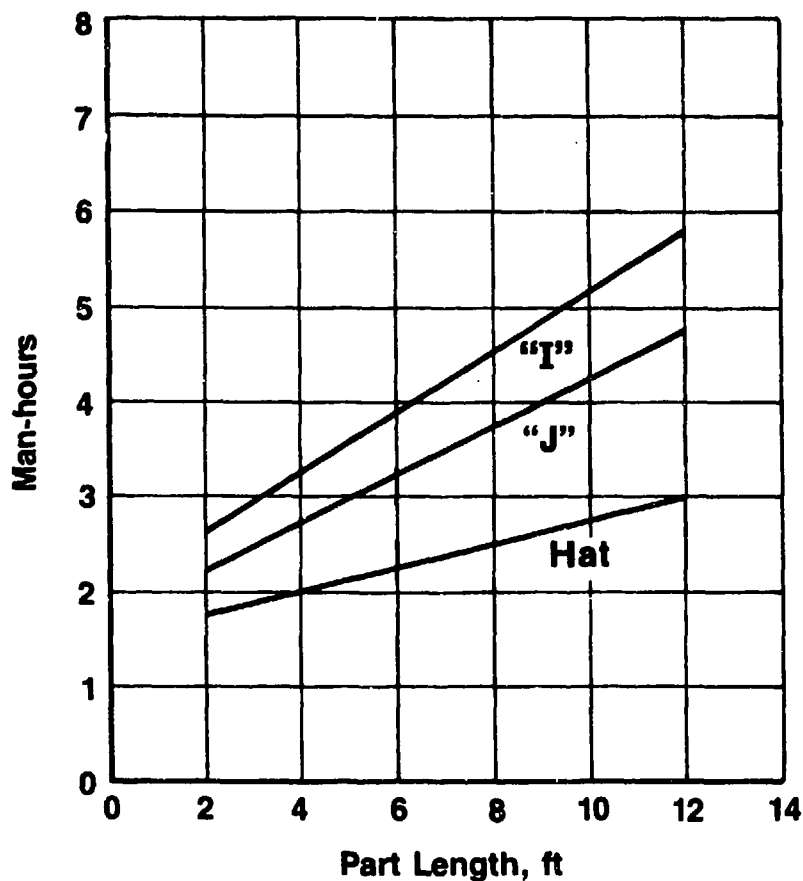
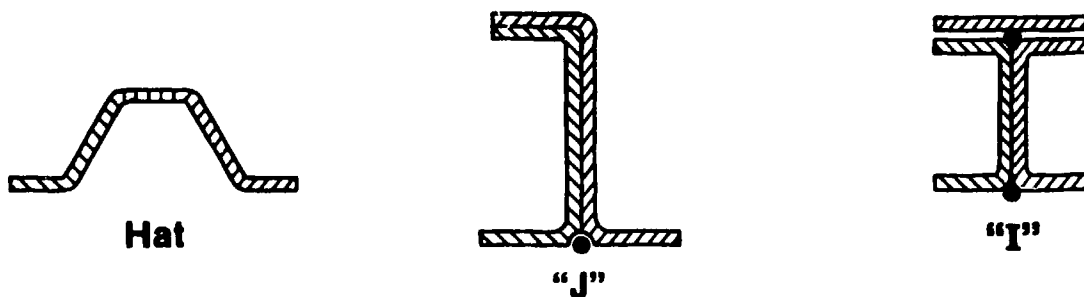
- Applies to laminates up to 32 plies.
- Applies to curved/straight, constant/variable height sections, and a 2-8 foot radius of curvature.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE "I" SECTION; NONRECURRING COST/PART



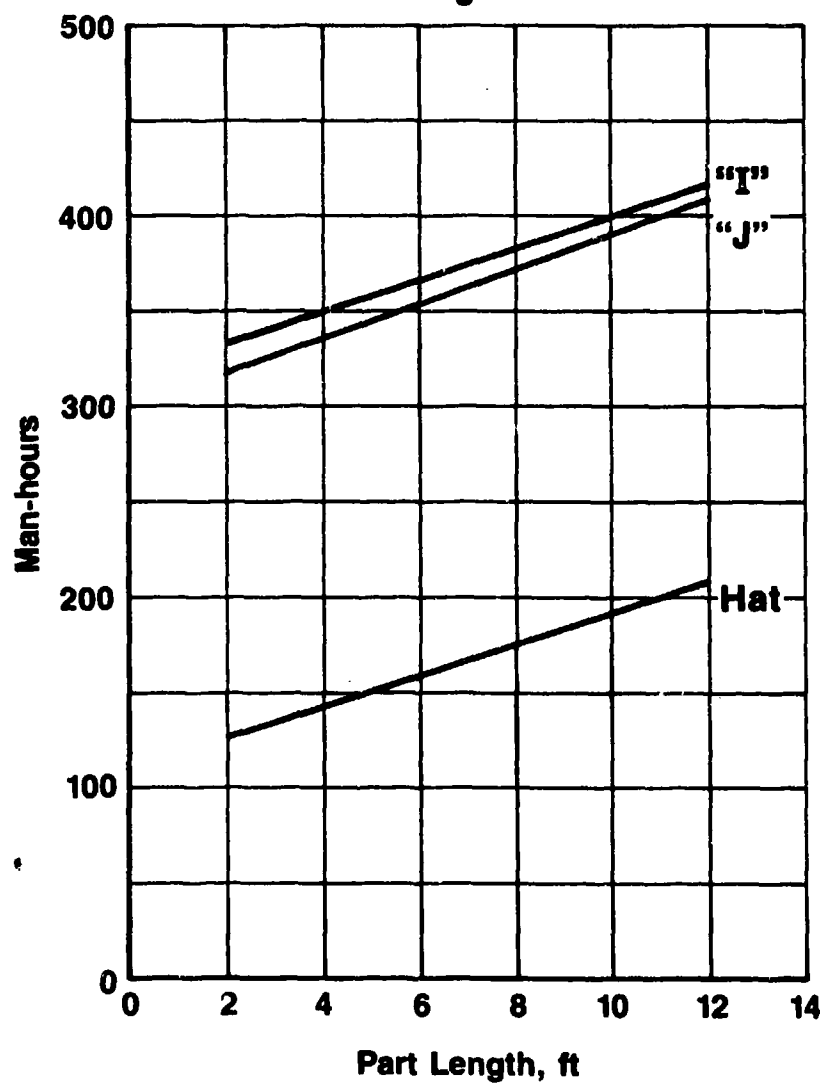
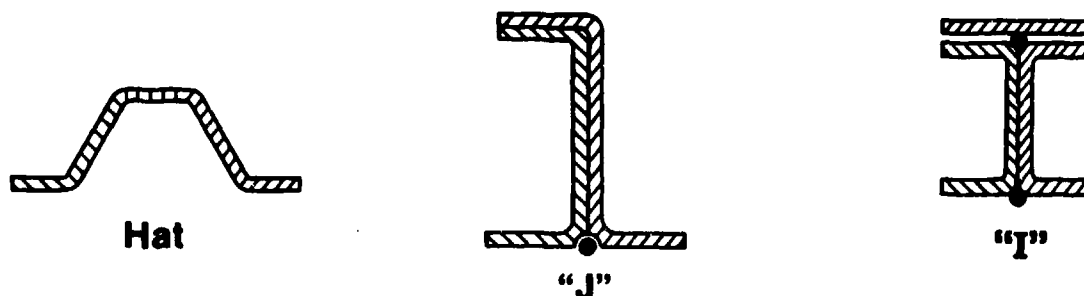
- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- Applies to curved/straight, constant/variable height sections, and a 2-8 foot radius of curvature.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE HAT, "J" AND "I" SECTIONS RECURRING COST/PART



Applies to laminates up to 32 plies.

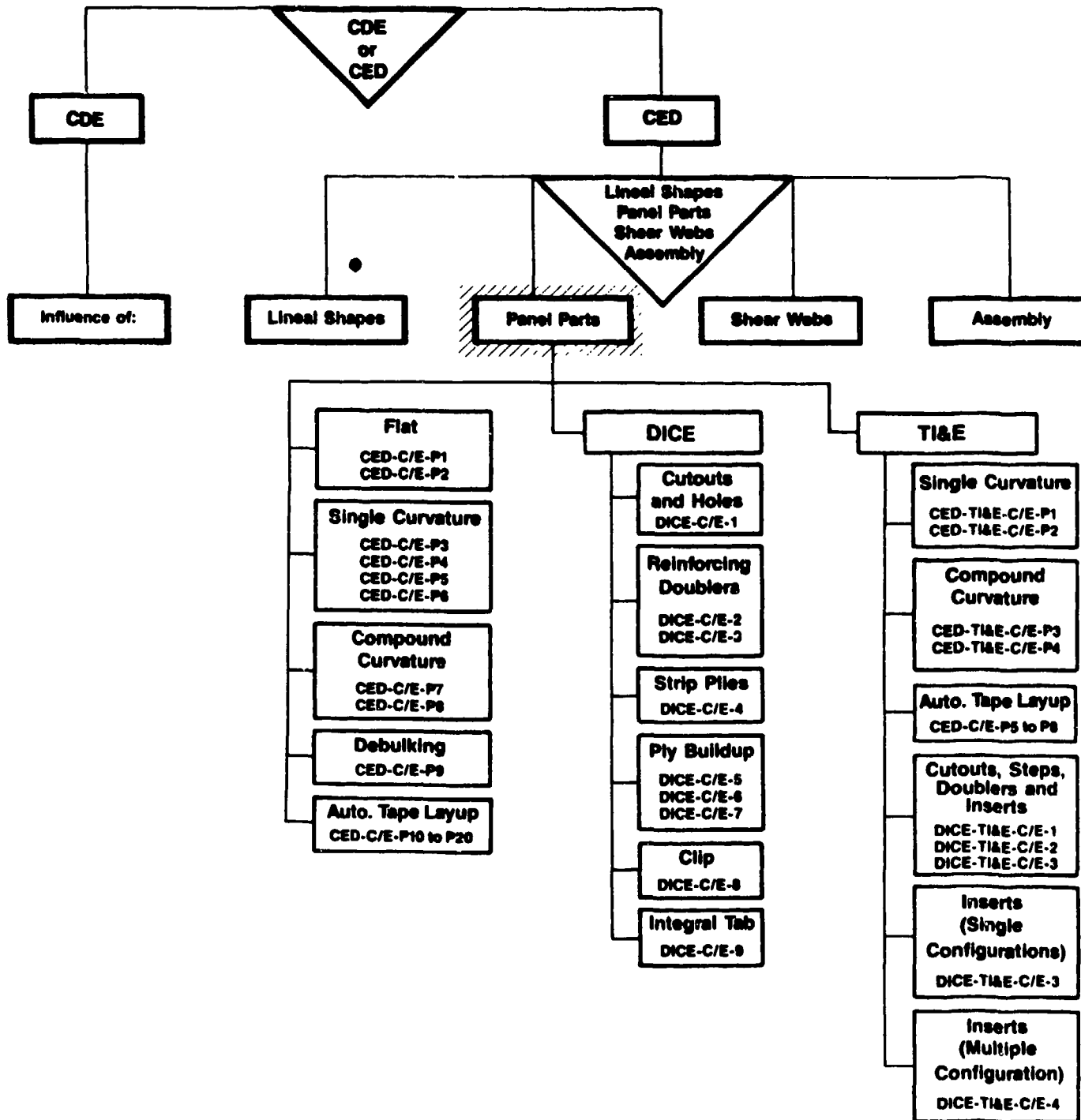
TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE HAT, "J" AND "I" SECTIONS NONRECURRING COST/PART



Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.

FORMAT SELECTION AID

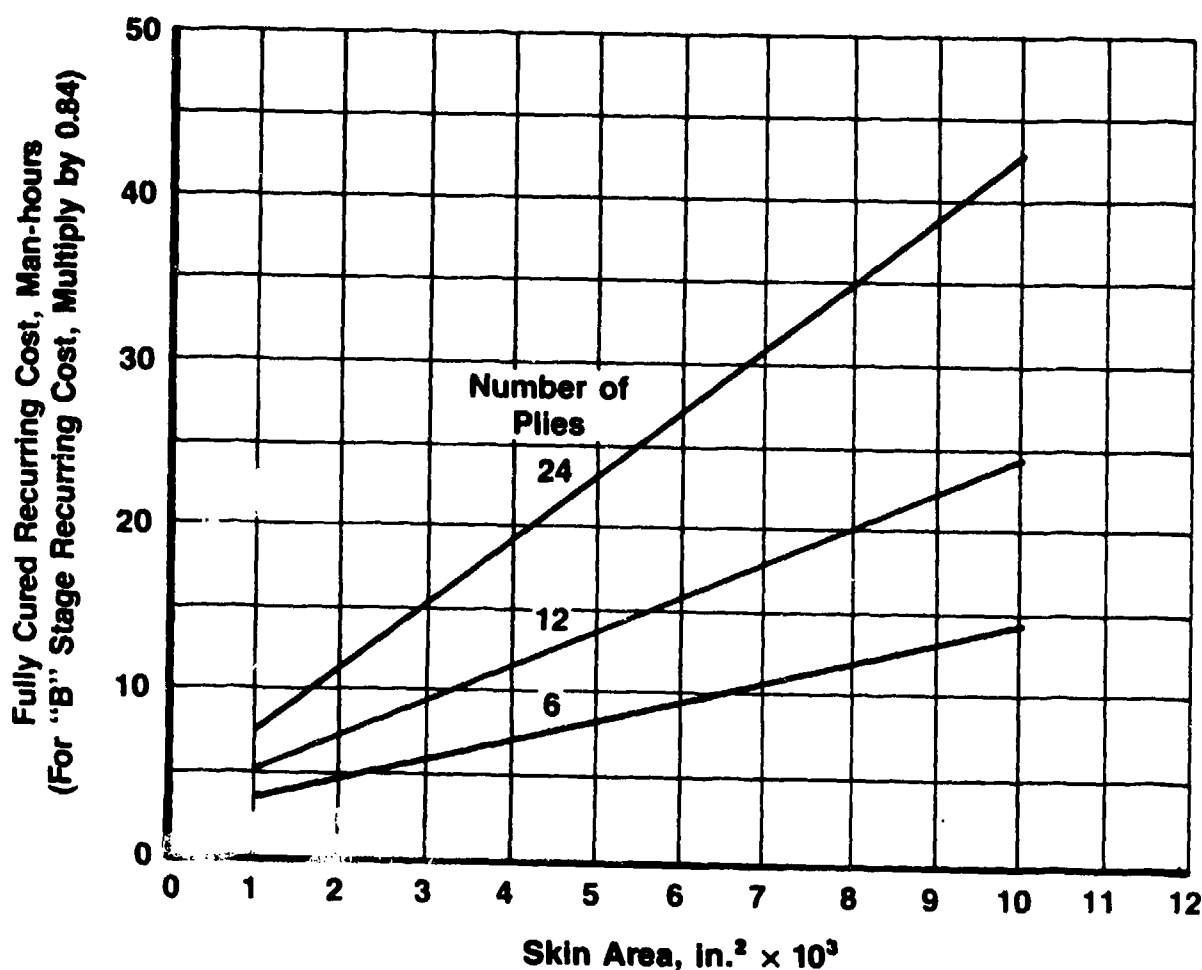
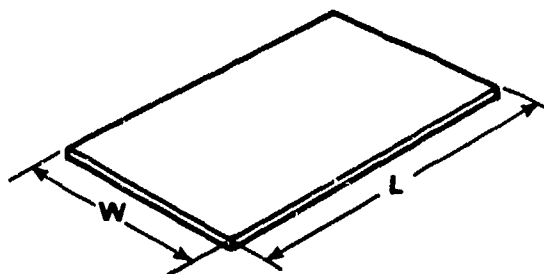
Advanced Composite Fabrication



COMPOSITE FLAT PANEL OR WEB UNIDIRECTIONAL TAPE; RECURRING COST/PART

Influenced by {

- Skin Area
- Number of Plies
- Cure Stage

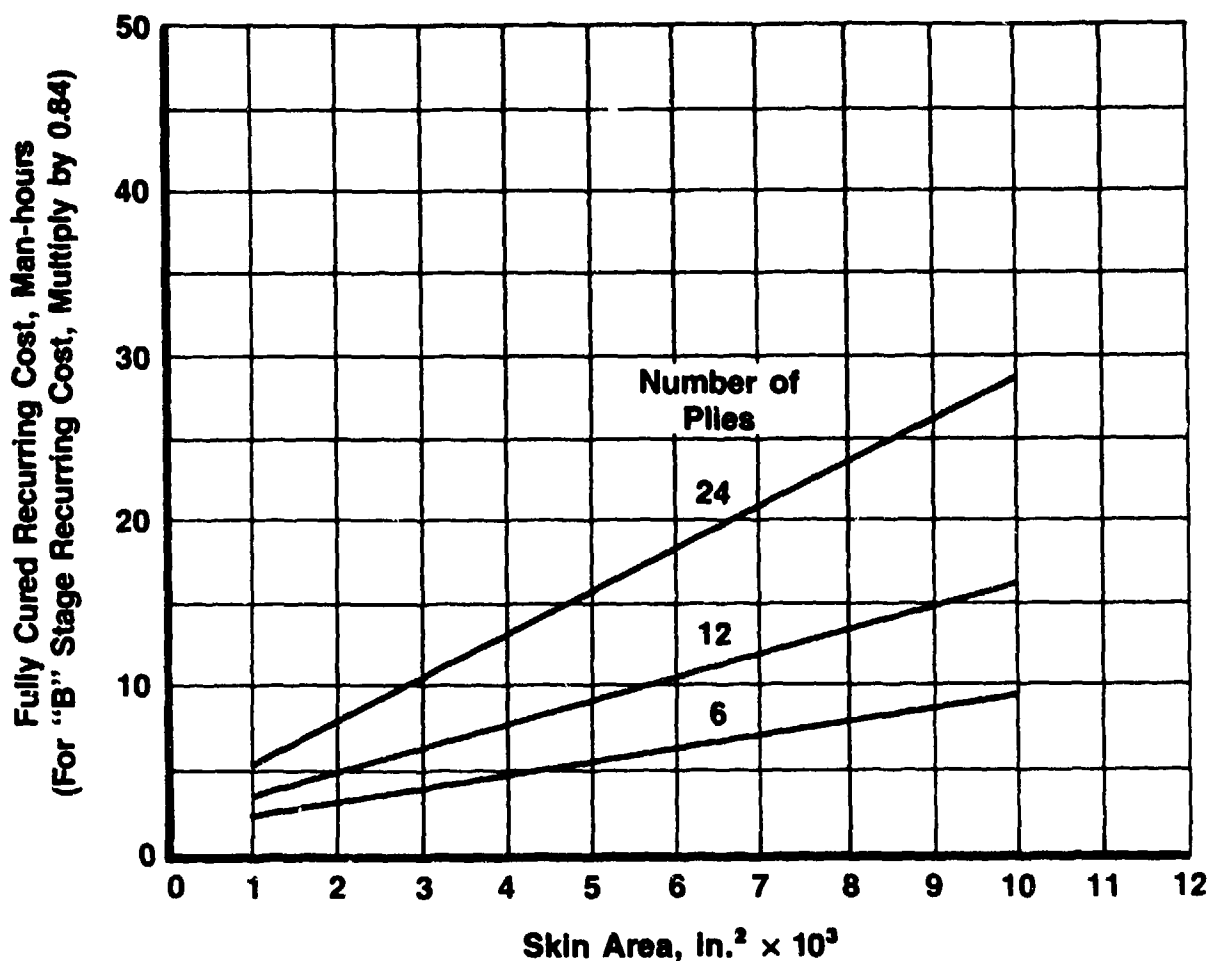
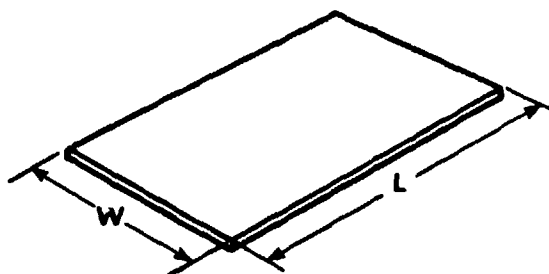


- For prepreg sheets, divide by quantity of prepreg stacks.
- For nonrecurring tooling costs and TI&E, use formats for single curvature skin.
- See ground rules for limitations and considerations.

COMPOSITE FLAT PANEL OR WEB WOVEN MATERIAL; RECURRING COST/PART

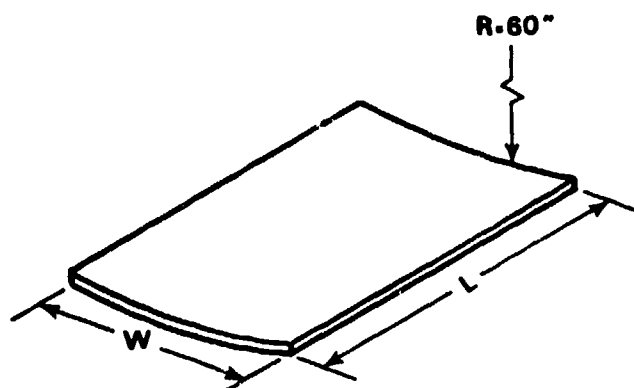
Influenced by {

- Skin Area
- Number of Piles
- Cure Stage



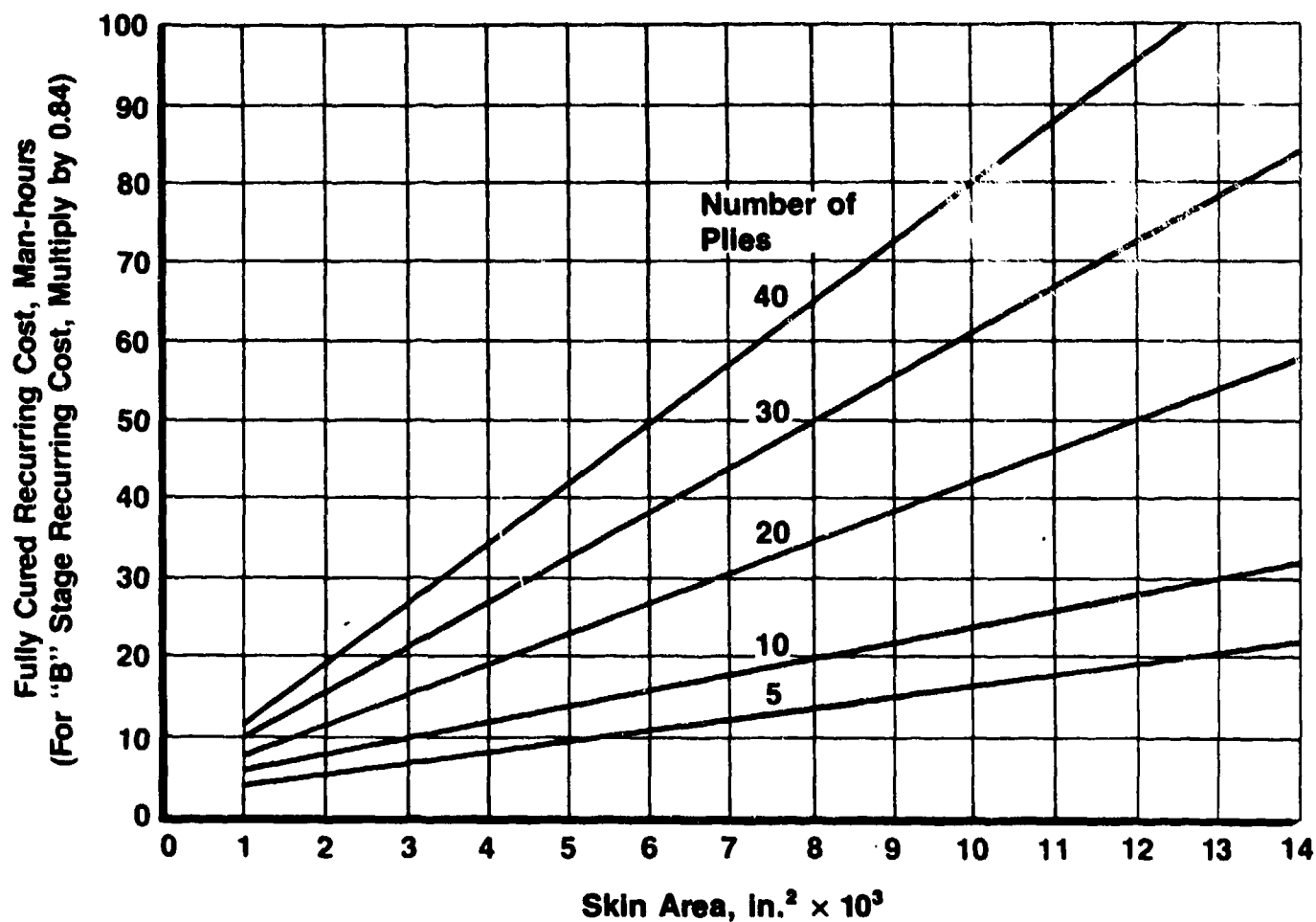
- For nonrecurring tooling costs and TI&E, use formats for single curvature skin.
- See ground rules for limitations and considerations.

COMPOSITE SINGLE CURVATURE PANEL MANUAL LAYUP; RECURRING COST/PART



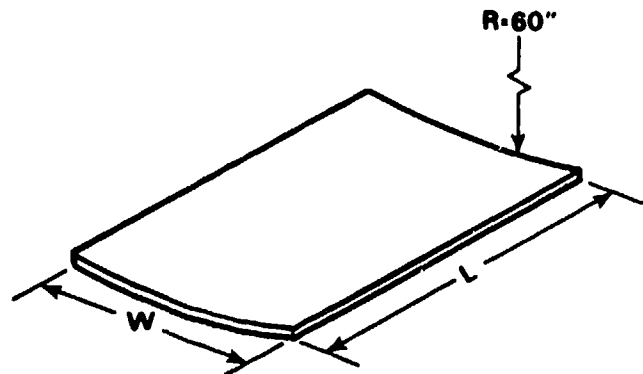
Influenced by {

- Skin Area
- Number of Plies
- Cure Stage



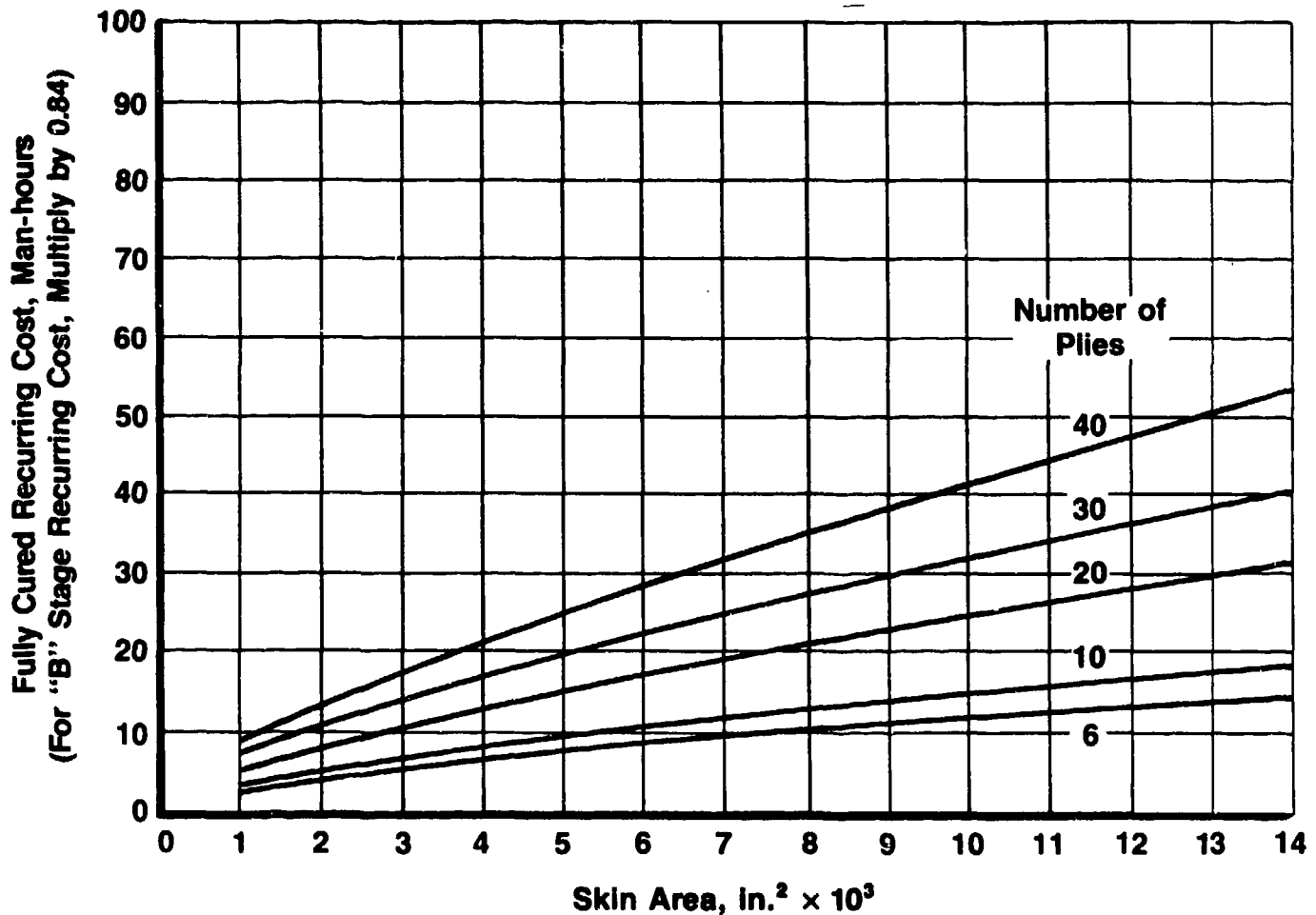
See ground rules for limitations and considerations.

COMPOSITE SINGLE CURVATURE PANEL NC - LAYUP; RECURRING COST/PART



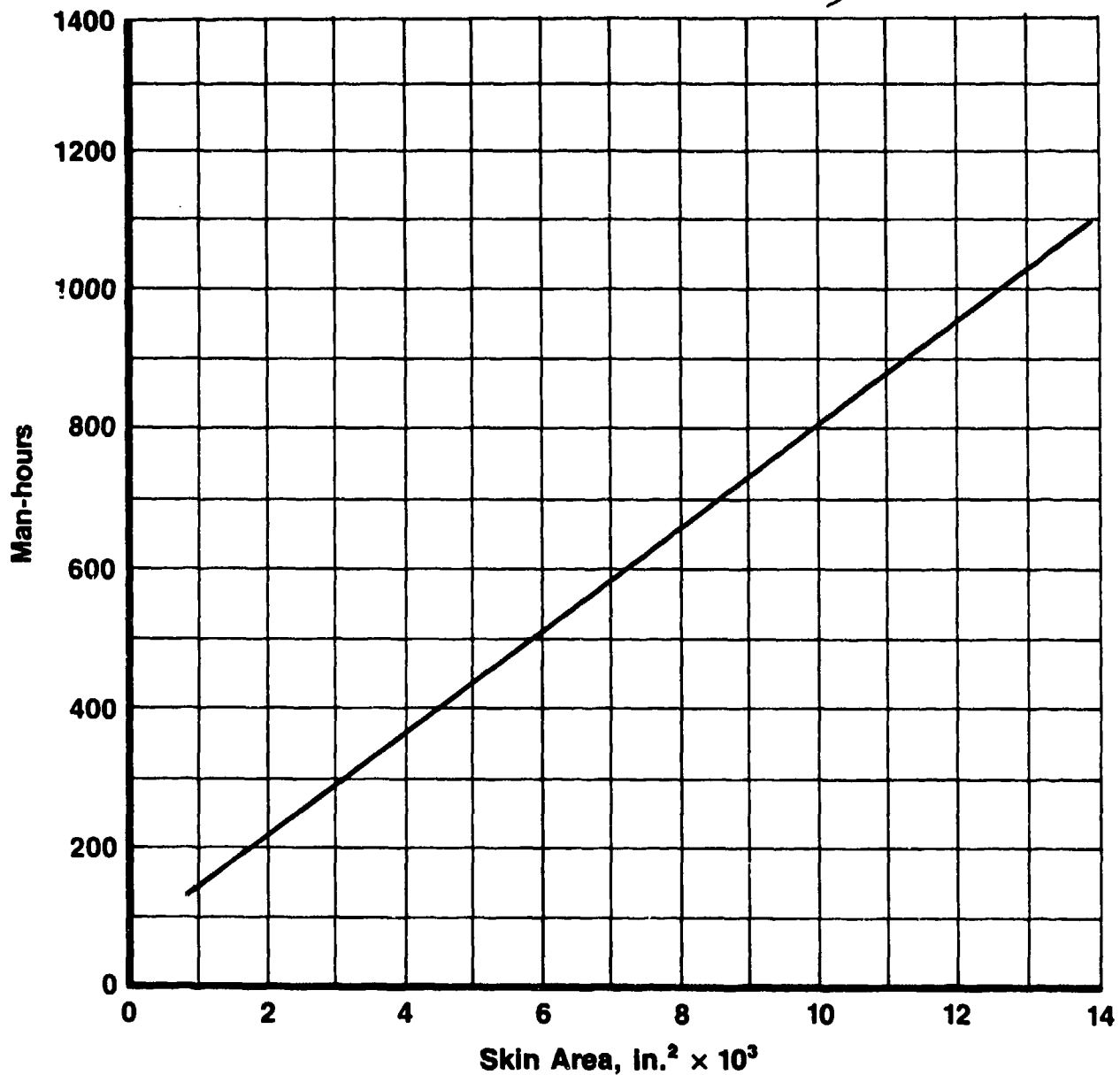
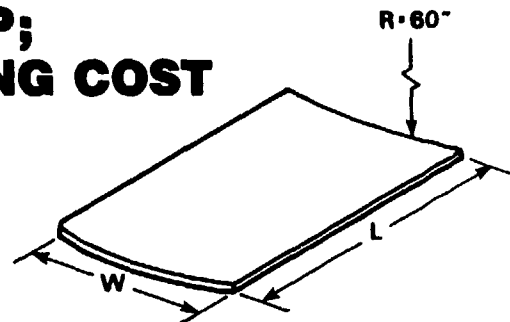
Influenced by {

- Skin Area
- Number of Plies
- Cure Stage



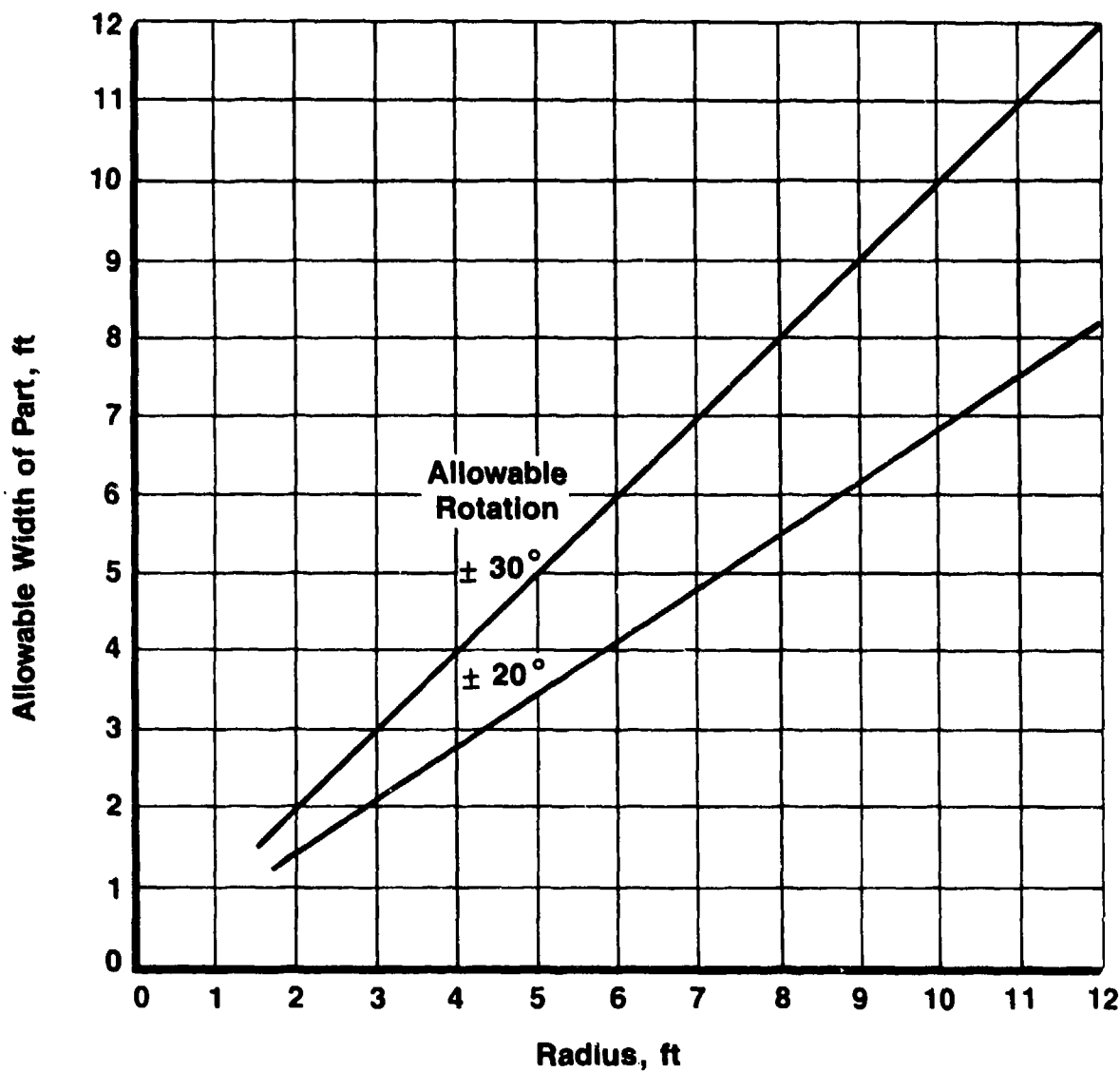
See ground rules for limitations and considerations.

COMPOSITE SINGLE CURVATURE SKIN MANUAL AND NC-LAYUP; NONRECURRING TOOLING COST



See ground rules for limitations and considerations.

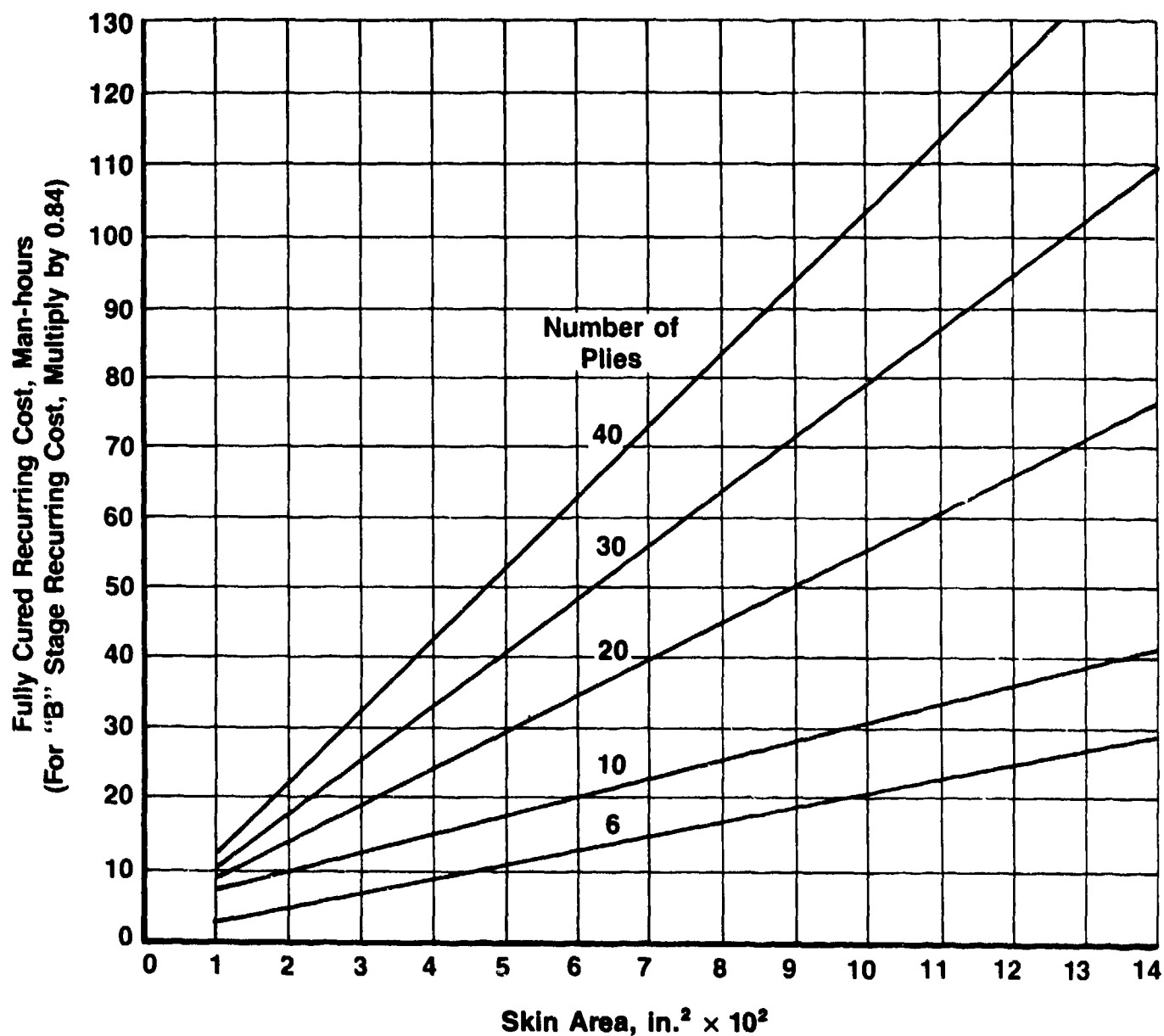
COMPOSITE PANEL NC-TAPE LAYUP; ALLOWABLE WIDTH OF PART



See ground rules for limitations and considerations.

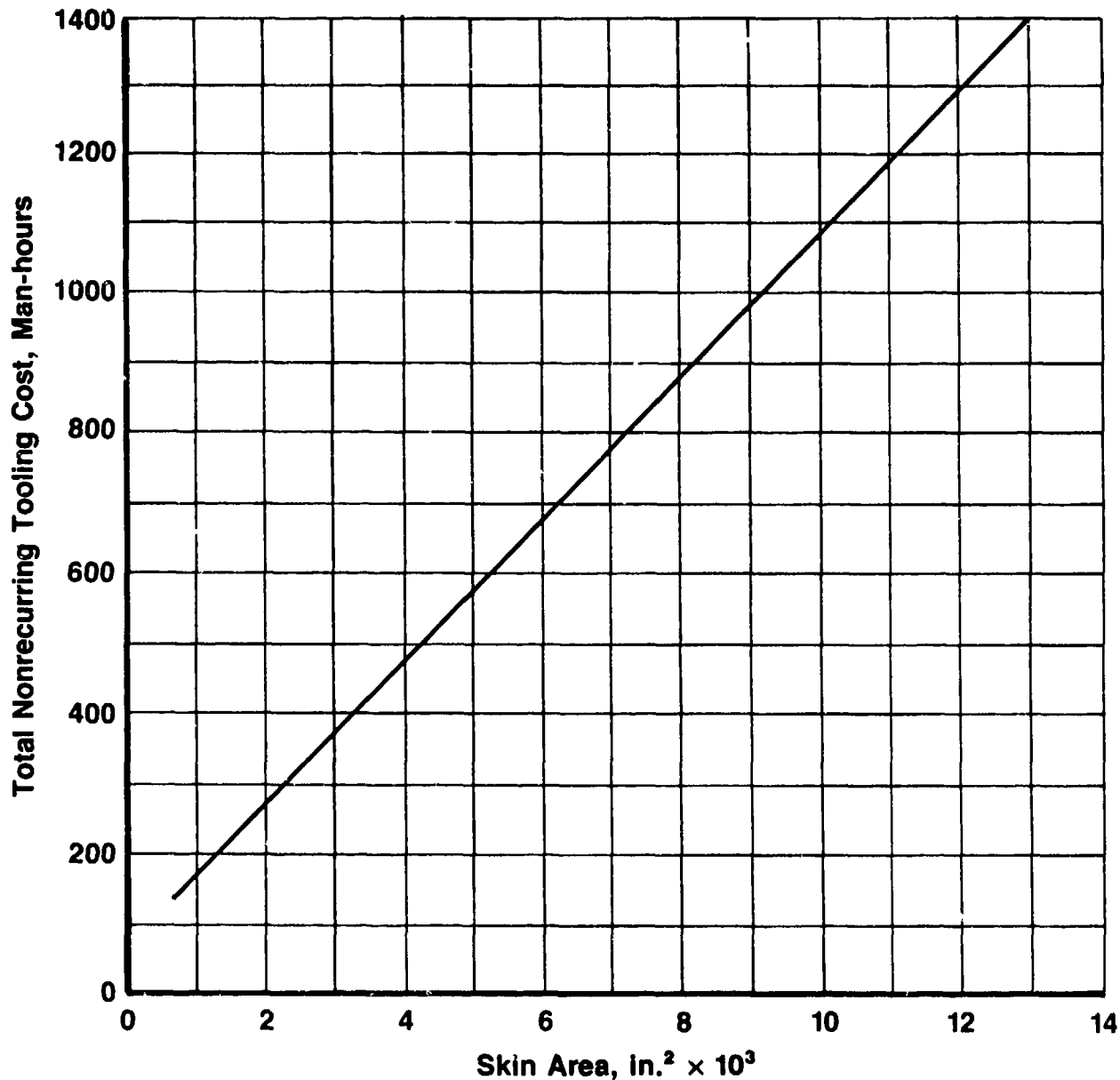
COMPOSITE COMPOUND C MANUFACTURE PANEL MANUAL LAYUP; RECURRING COST/PART

Influenced by {
• Skin Area
• Number of Plies
• Cure Stage



See ground rules for limitations and considerations.

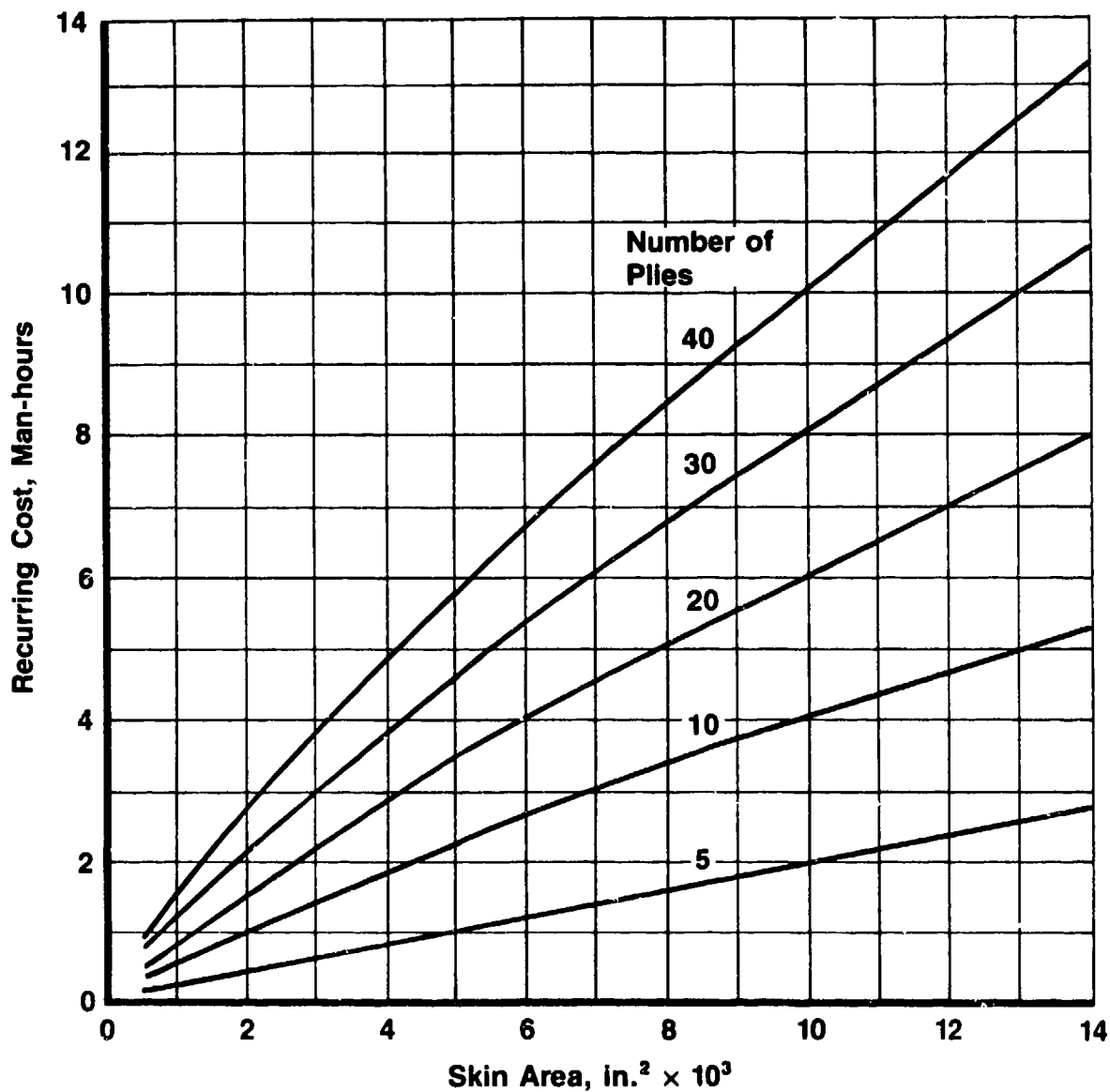
COMPOSITE COMPOUND CURVATURE SKIN MANUAL LAYUP; NONRECURRING TOOLING COST



See ground rules for limitations and considerations.

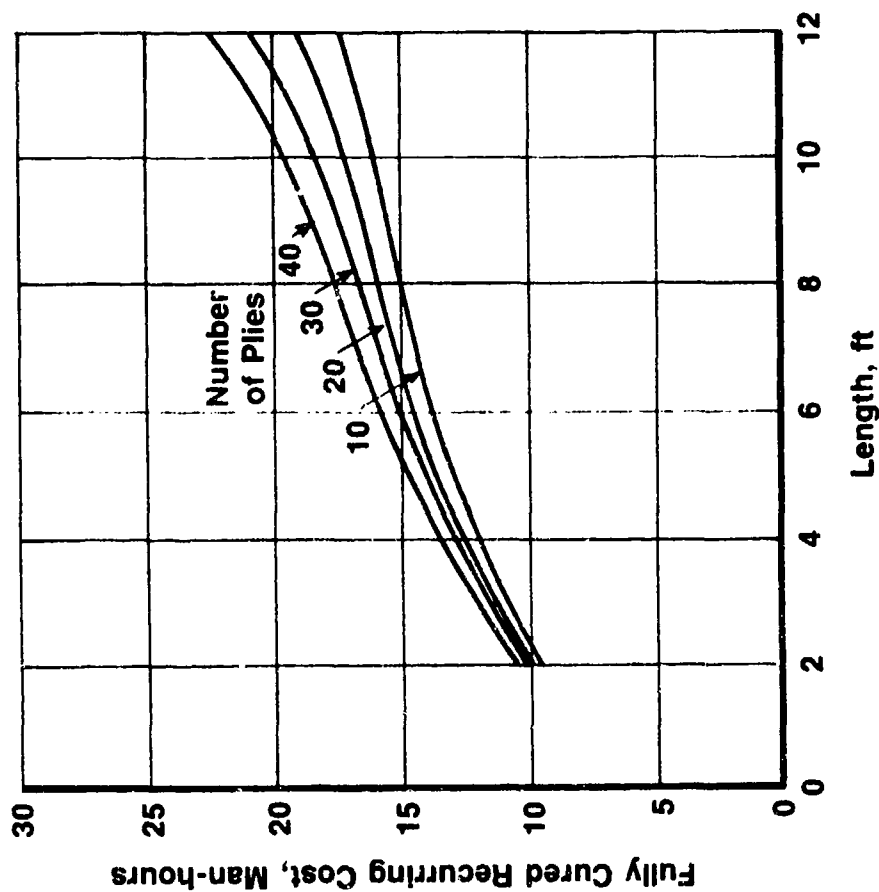
COMPOSITE DEBULKING COST; RECURRING COST/PART

Influenced by {
• Skin Area
• Number of Plies

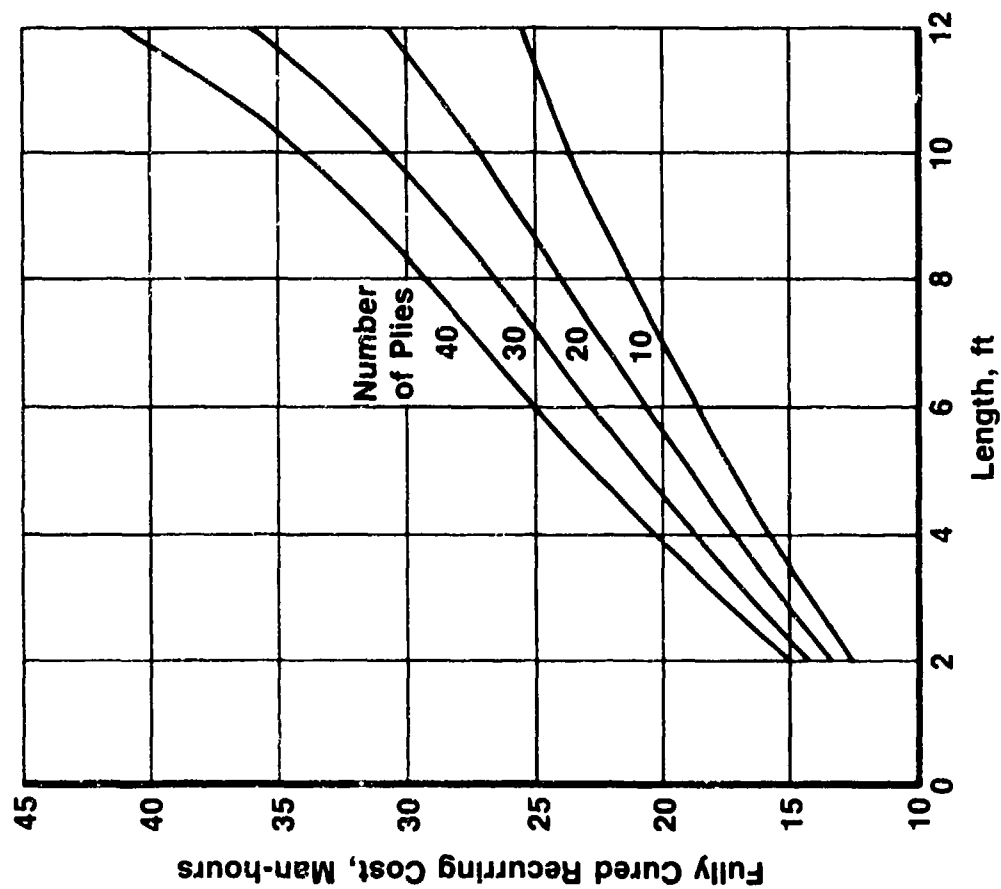


See ground rules for limitations and considerations.

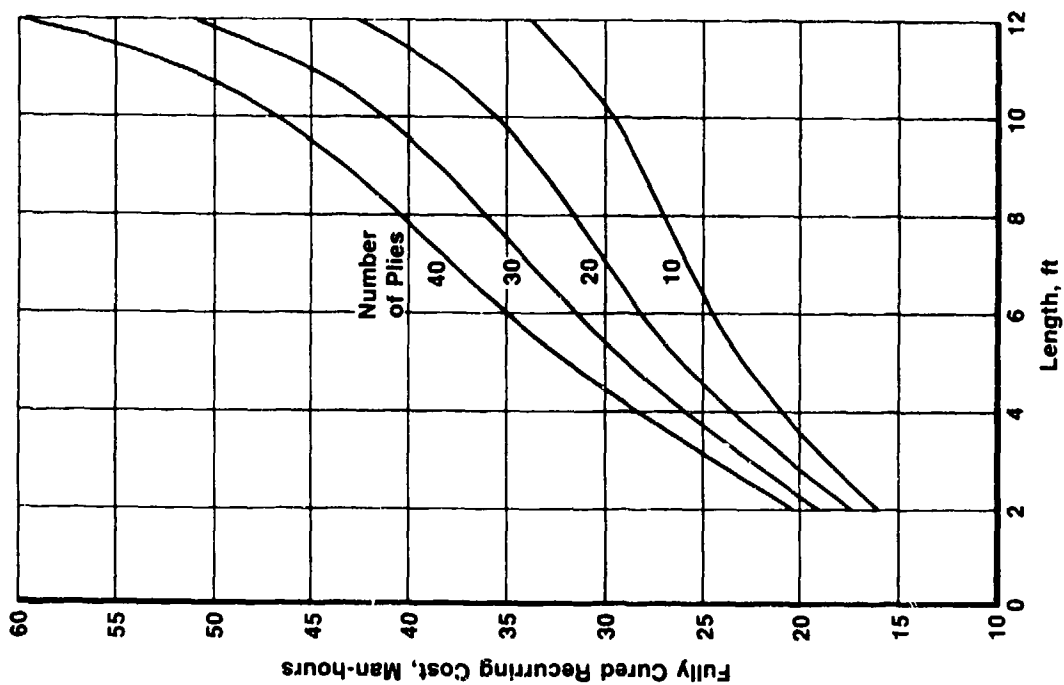
COMPOSITE SINGLE CURVATURE SKIN **AUTOMATED TAPE LAYUP; RECURRING COST/PART** • 2 ft Radius • 60° Segment



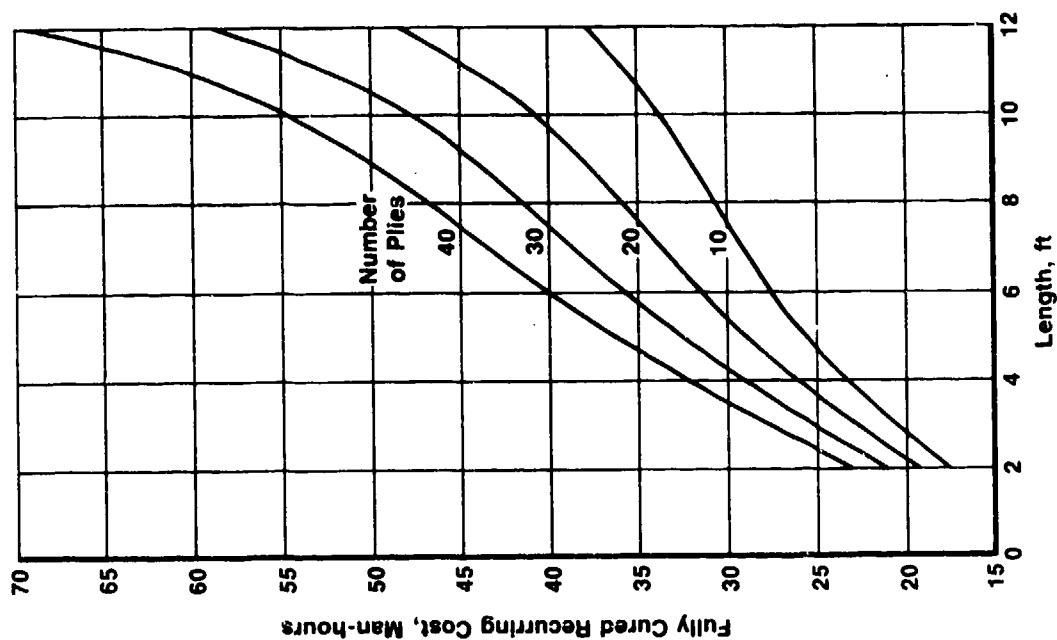
**COMPOSITE SINGLE CURVATURE SKIN
AUTOMATED TAPE LAYUP; RECURRING COST/PART
• 6 ft Radius • 60° Segment**



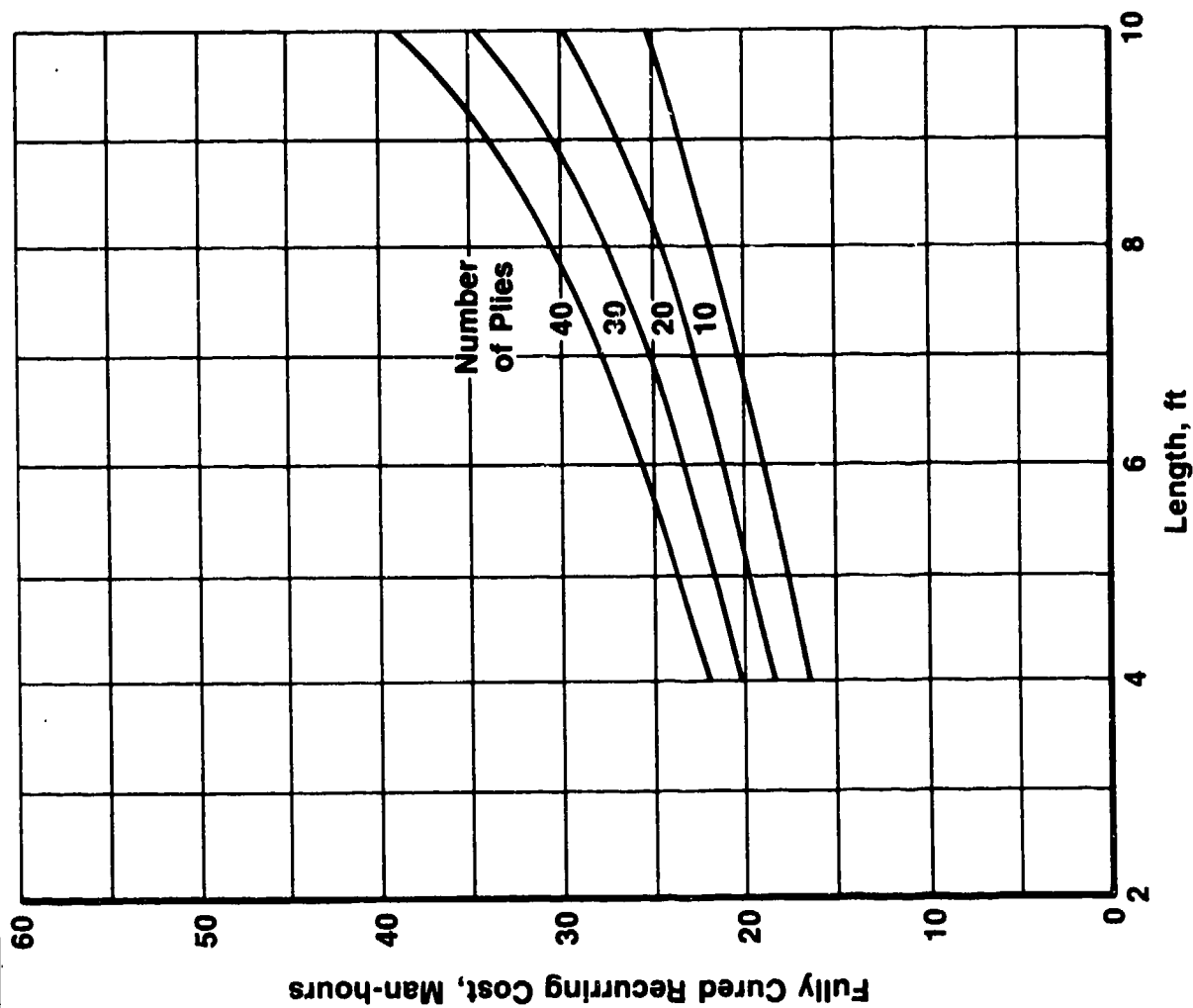
COMPOSITE SINGLE CURVATURE SKIN **AUTOMATED TAPE LAYUP; RECURRING COST/PART** • 10 ft Radius • 60° Segment



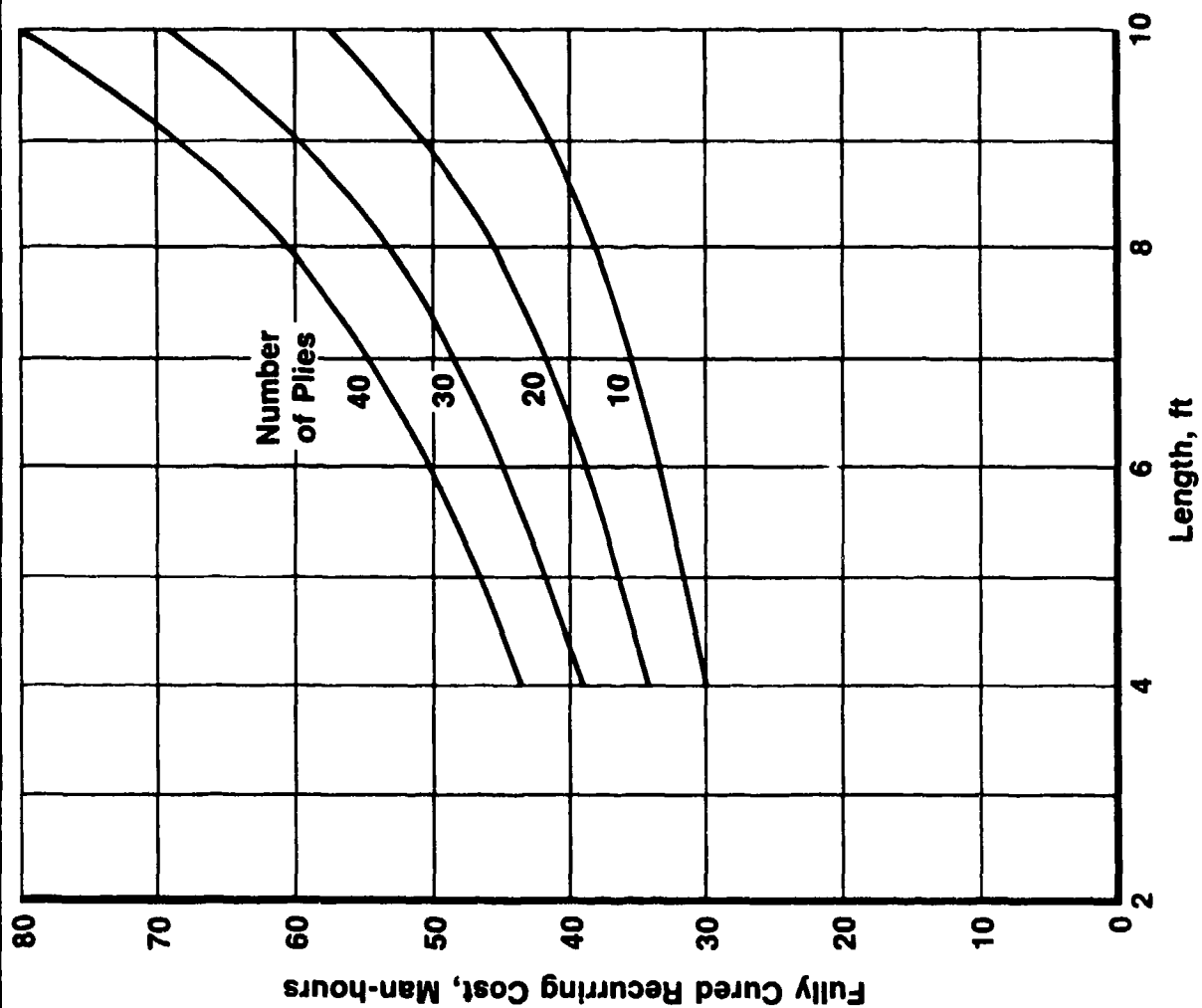
COMPOSITE SINGLE CURVATURE SKIN **AUTOMATED TAPE LAYUP; RECURRING COST/PART** • 12 ft Radius • 60° Segment



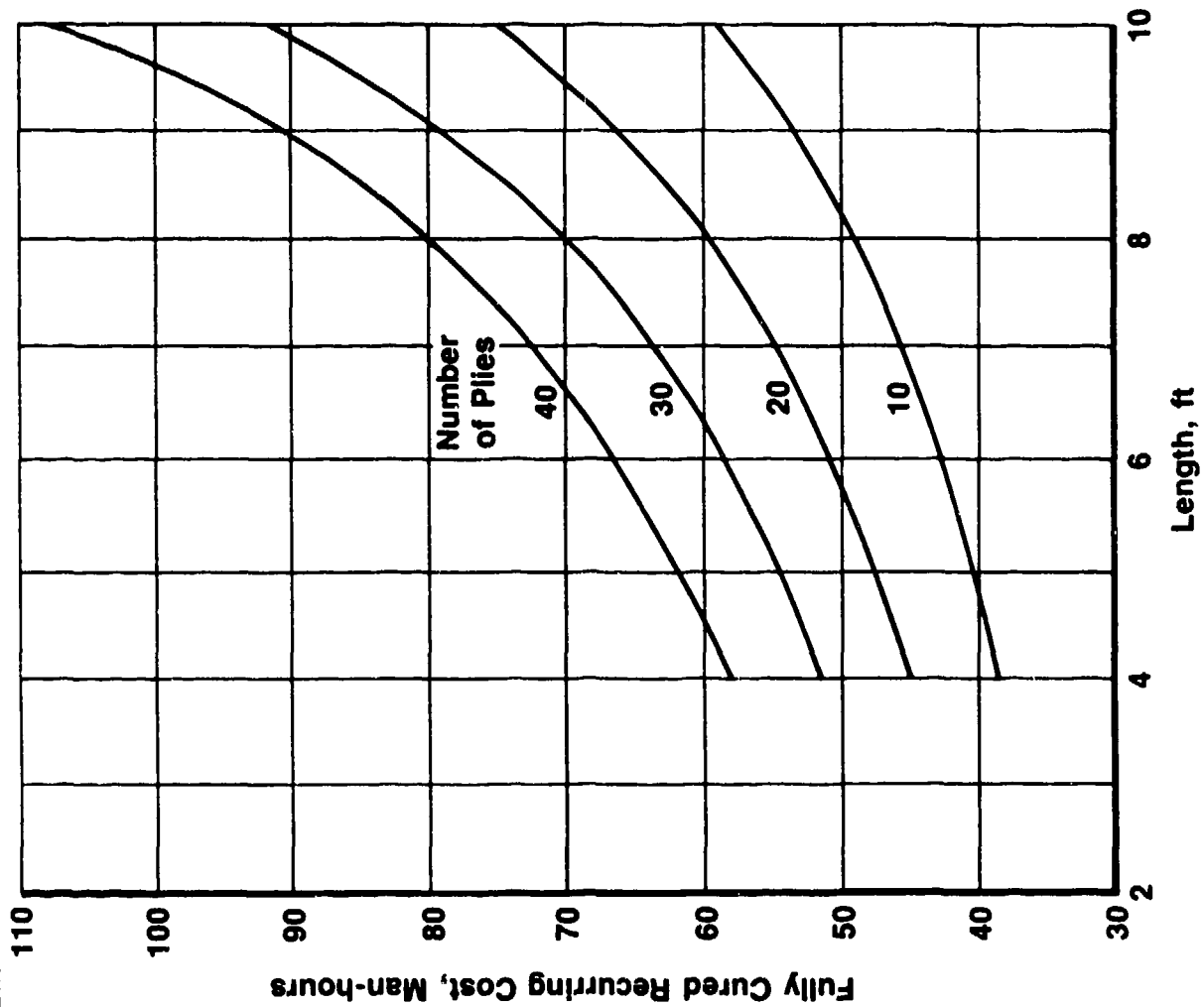
**COMPOSITE SINGLE CURVATURE SKIN
AUTOMATED TAPE LAYUP; RECURRING COST/PART
• 2 ft Radius • 240° Segment**



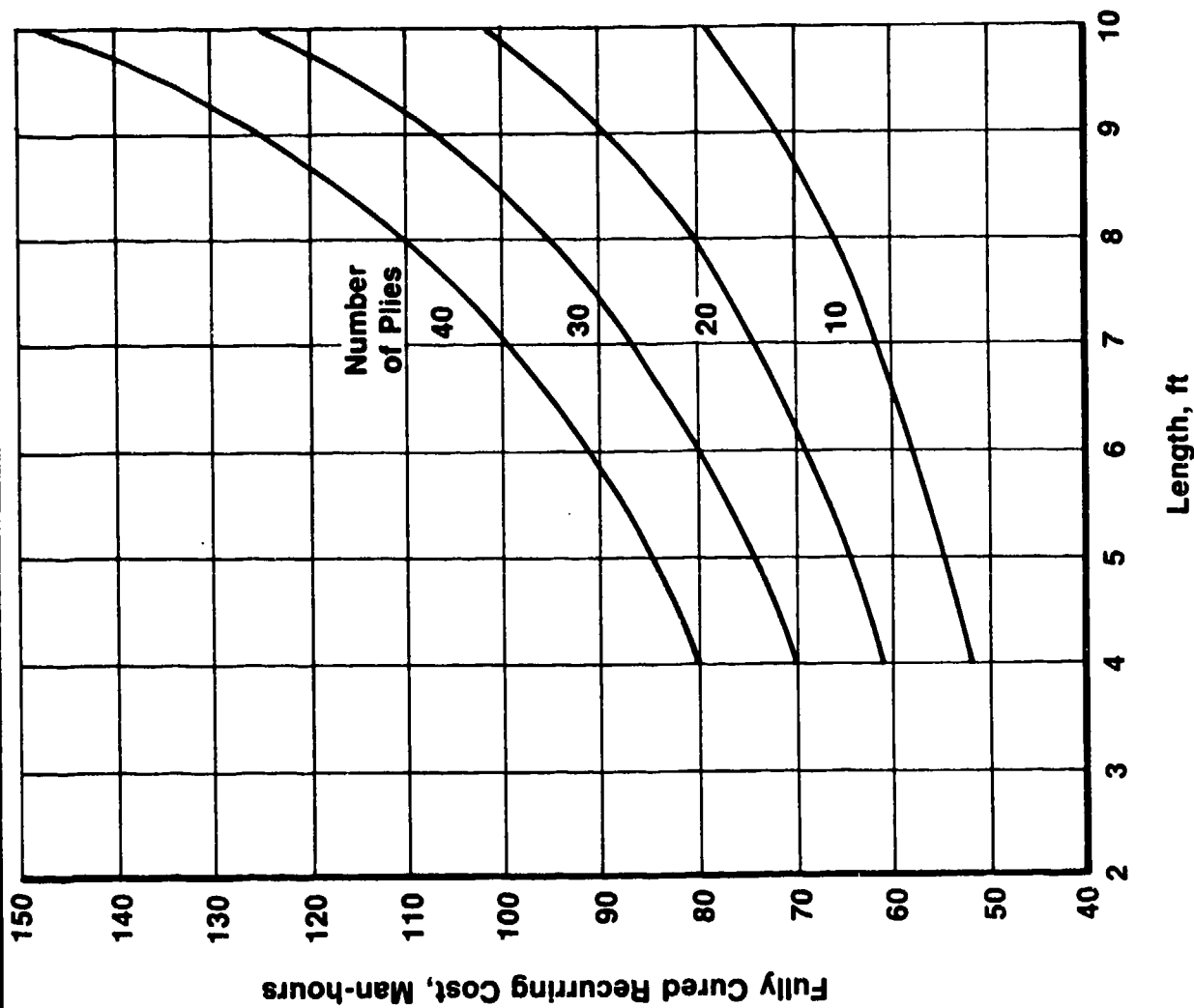
**COMPOSITE SINGLE CURVATURE SKIN
AUTOMATED TAPE LAYUP; RECURRING COST/PART**
• 5 ft Radius • 240° Segment



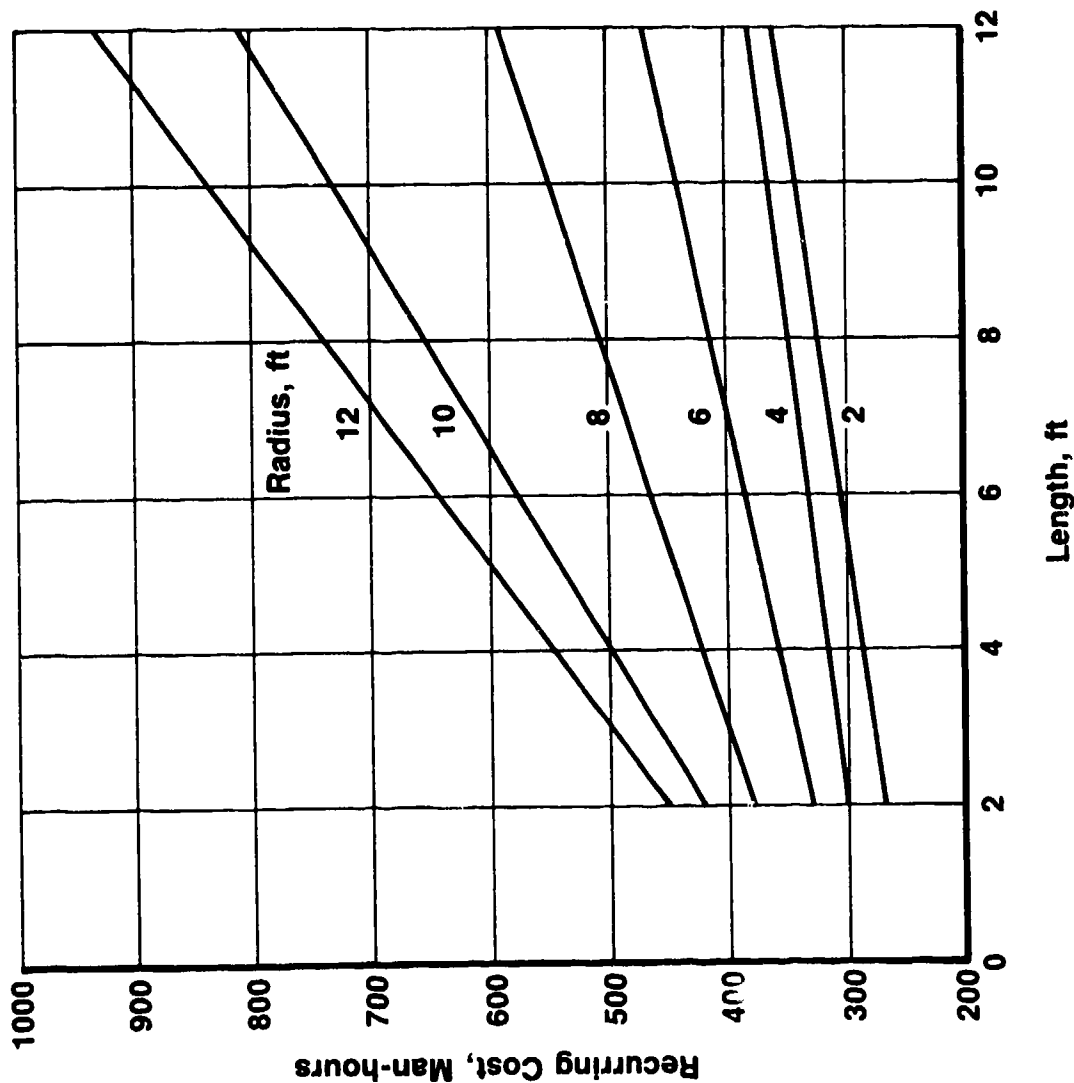
COMPOSITE SINGLE CURVATURE SKIN **AUTOMATED TAPE LAYUP; RECURRING COST/PART** • 7 ft Radius • 240° Segment



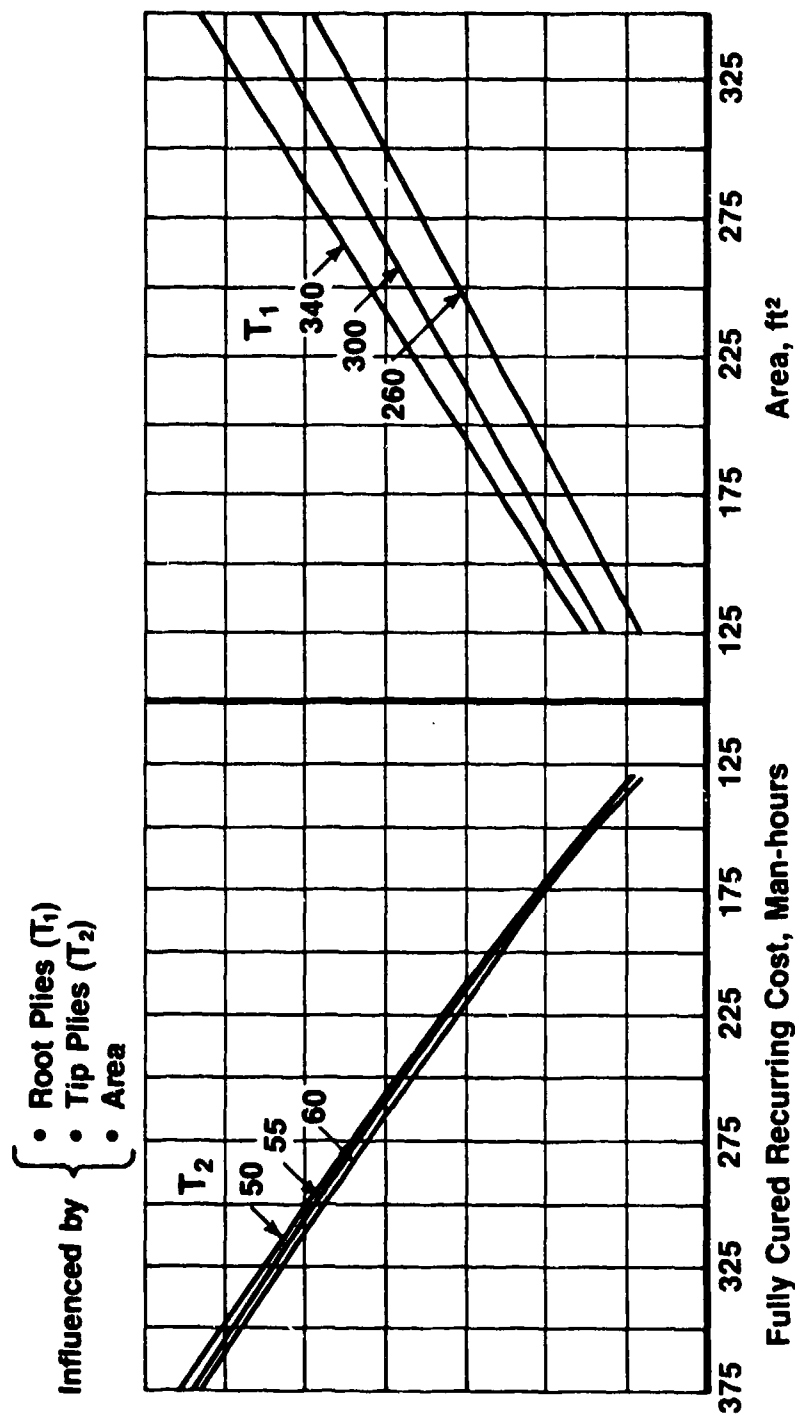
COMPOSITE SINGLE CURVATURE SKIN **AUTOMATED TAPE LAYUP; RECURRING COST/PART** • 10 ft Radius • 240° Segment



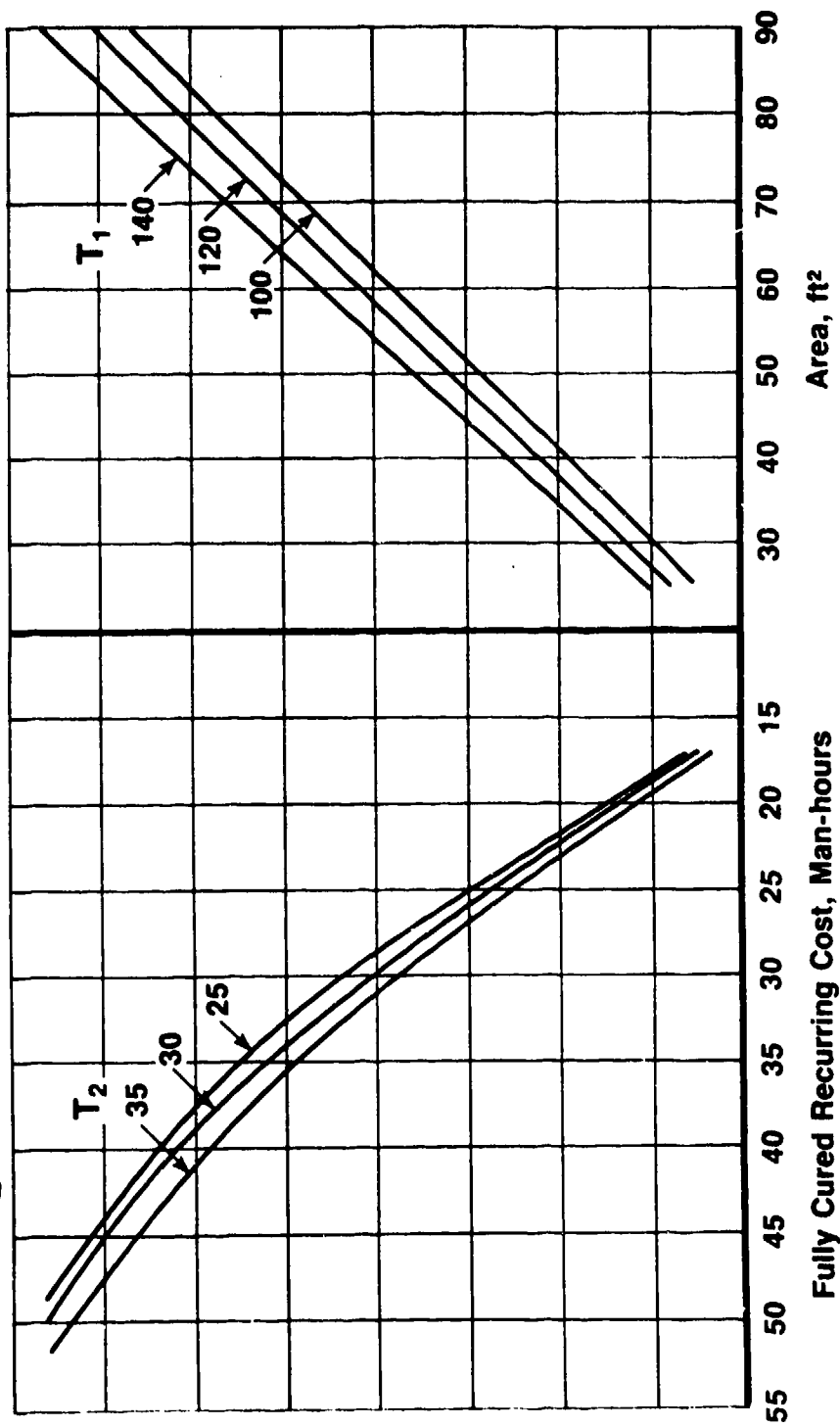
COMPOSITE SINGLE CURVATURE SKIN **AUTOMATED TAPE LAYUP; NONRECURRING TOOLING COST** • 2-12 ft Radii • 60° Segment



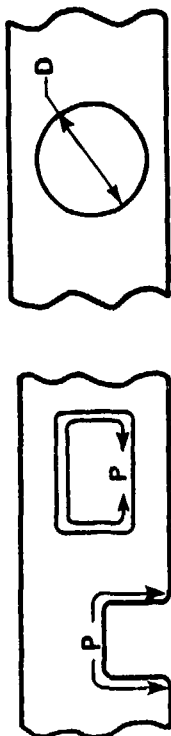
COMPOSITE TAPERED SKIN FOR WING AUTOMATED TAPE LAYUP; RECURRING COST/PART



Influenced by {
 • Root Plies (T_1)
 • Tip Plies (T_2)
 • Area

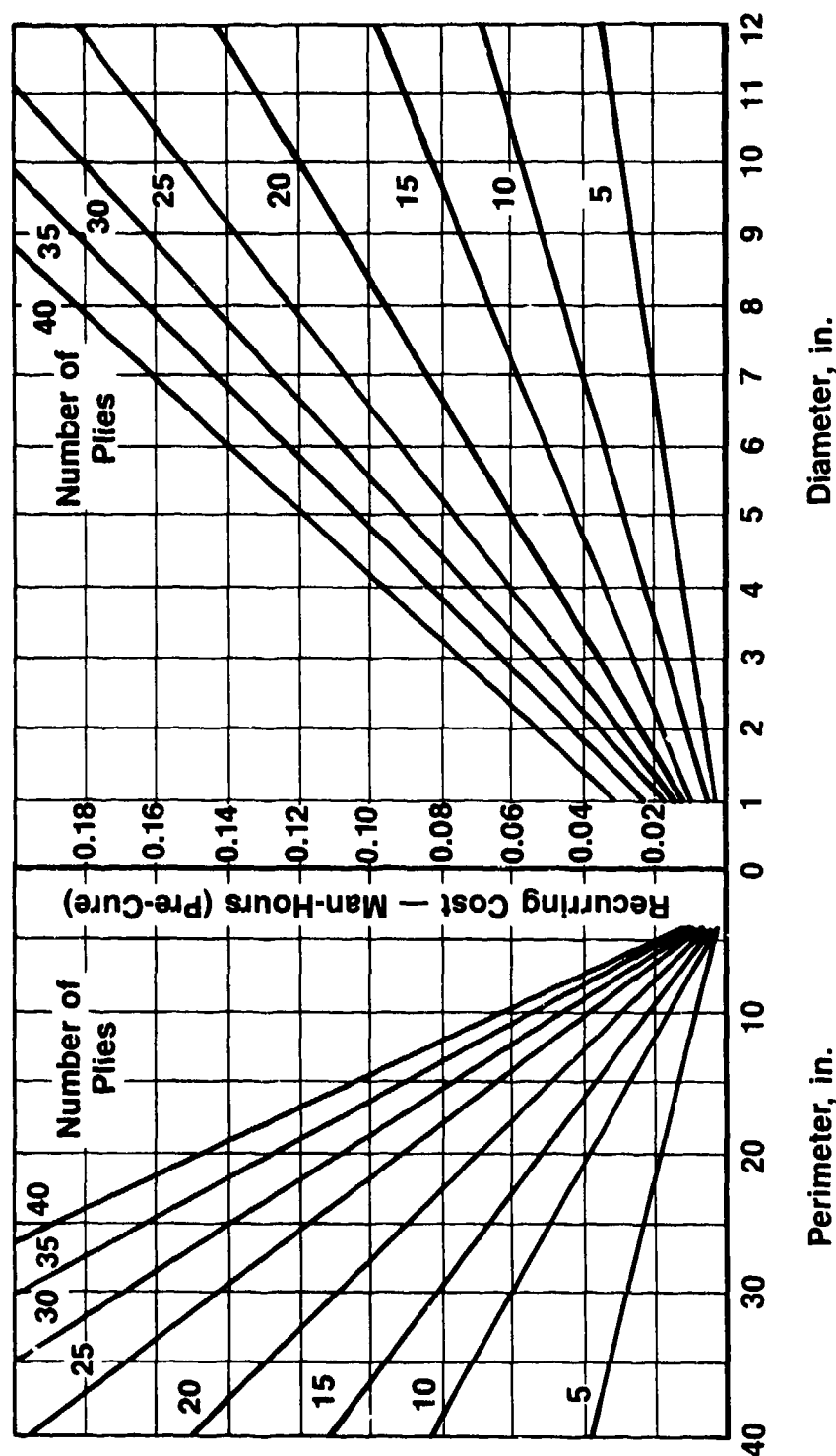


CUTOUTS AND HOLES; RECURRING COST/DETAIL



Influenced by {
• Hole Shape and Size
• Number of Plies

Cost Includes
Trim Only

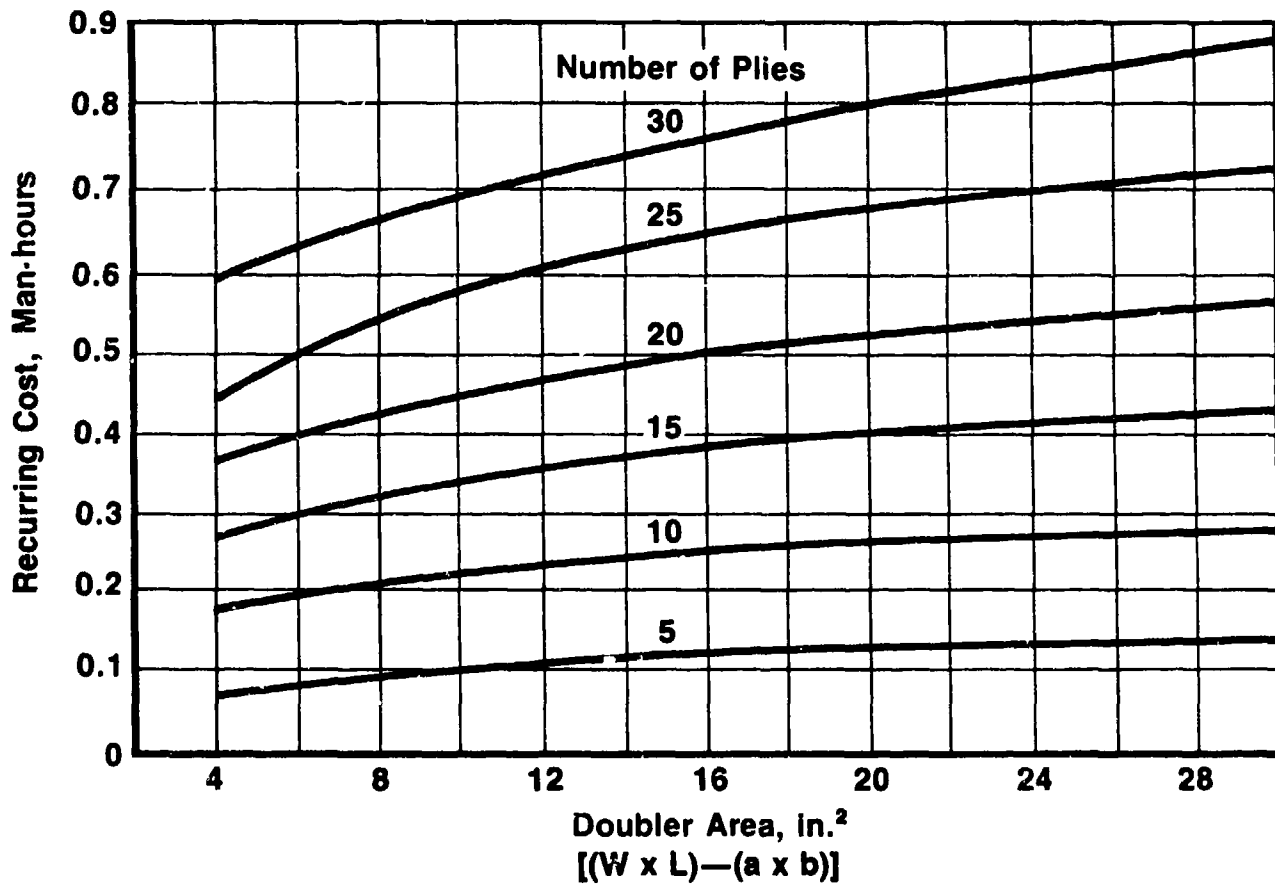
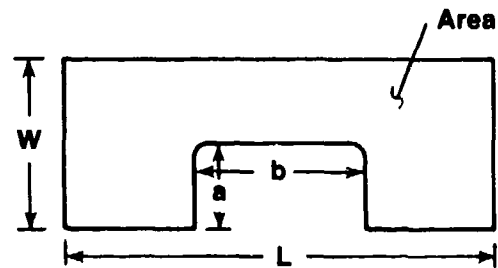


See ground rules for limitations and considerations.

COCURING OF REINFORCING DOUBLER FOR CUTOUT; RECURRING COST/DETAIL

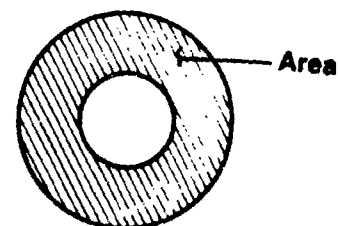
Influenced by {

- Area
- Number of Plies



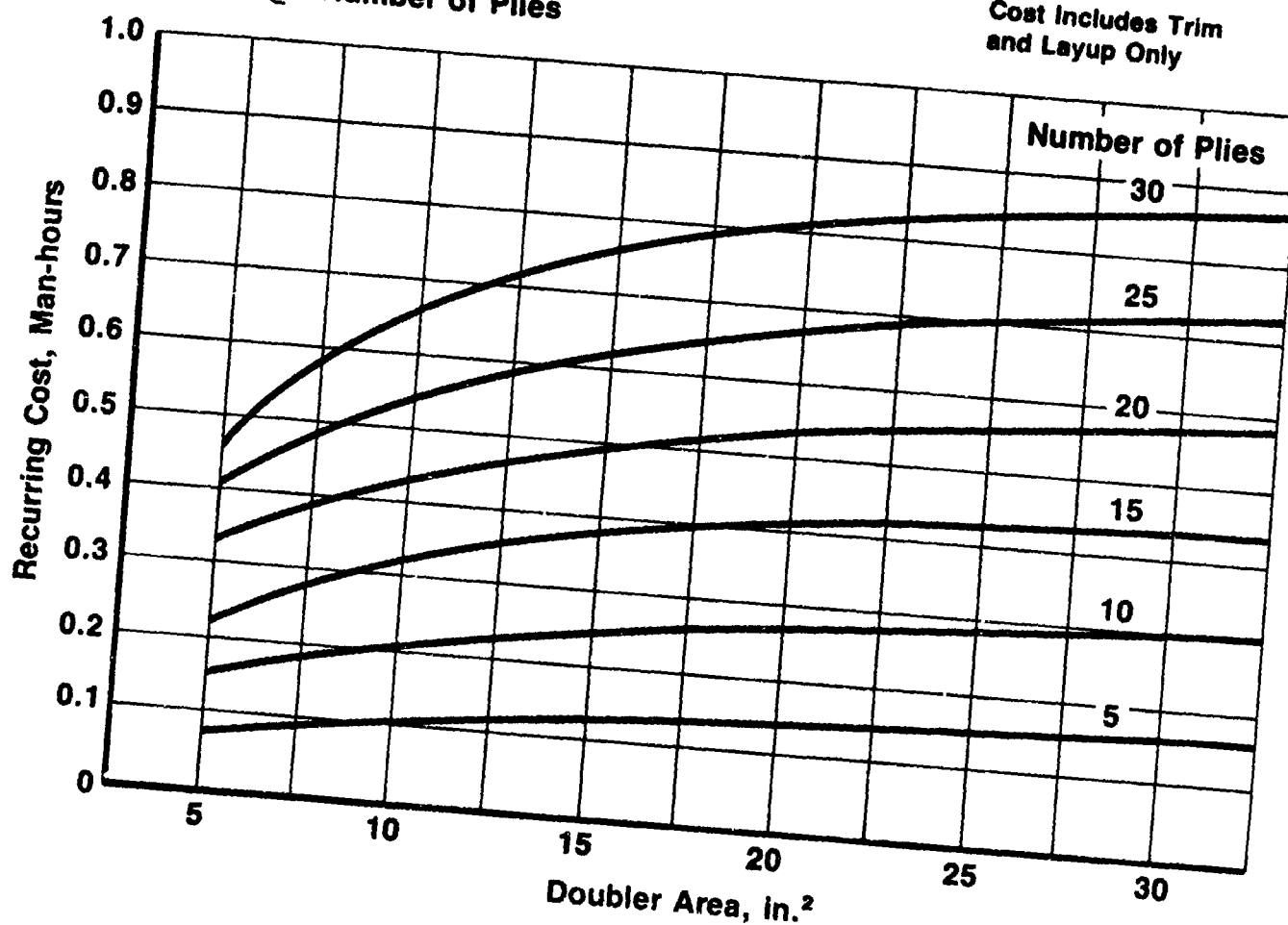
See ground rules for limitations and considerations.

COCURING OF HOLE REINFORCING DOUBLER; RECURRING COST/DETAIL



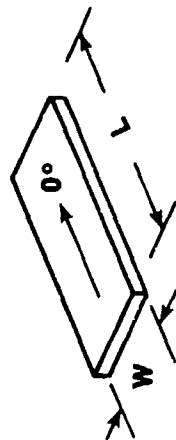
Influenced by {
• Area
• Number of Plies

Cost Includes Trim
and Layup Only

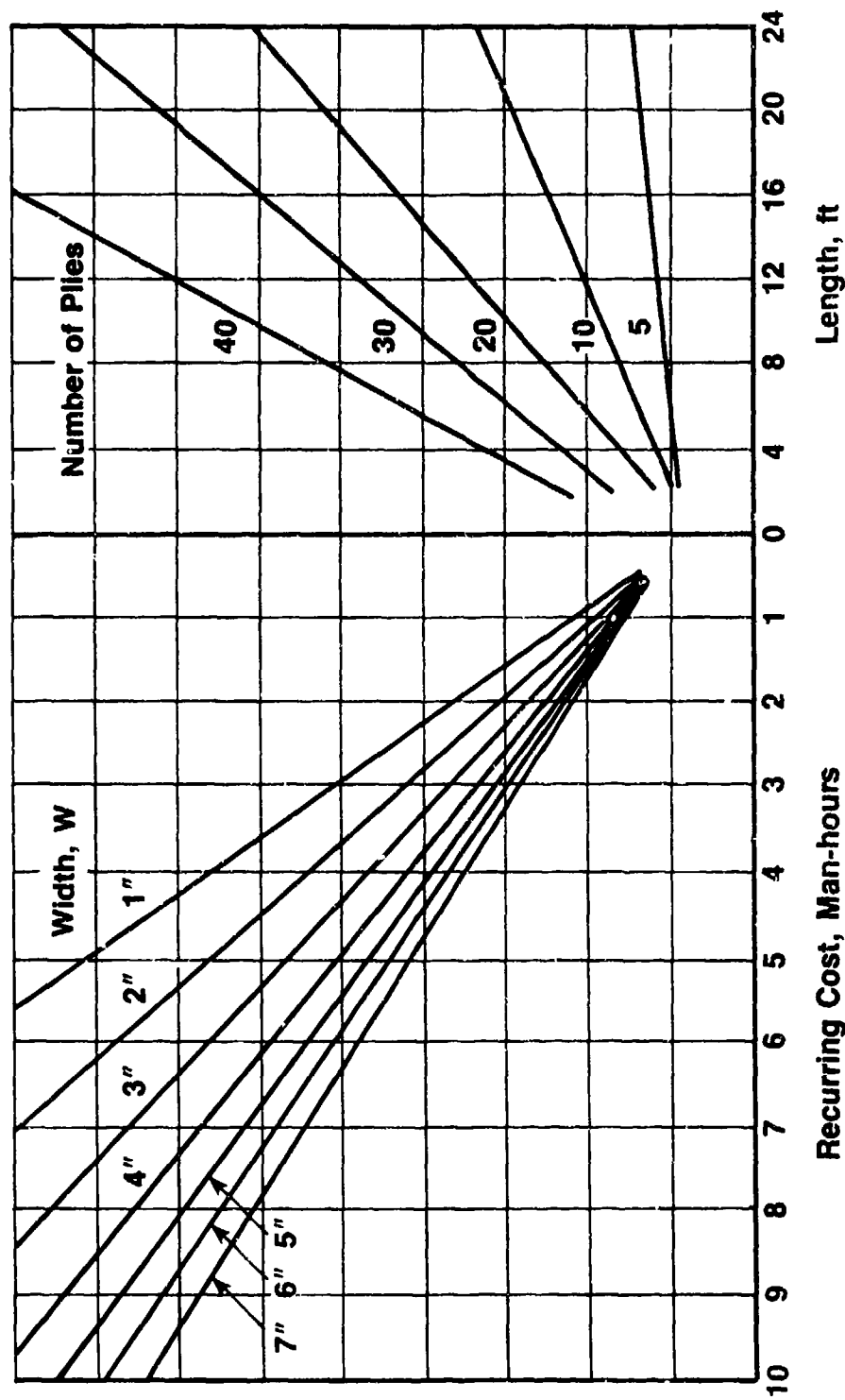


See ground rules for limitations and considerations.

STRIP PLIES (FLAT PARTS) FOR COCURING; RECURRING COST/PART



Influenced by { • Part Length
• Number of Plies
• Width

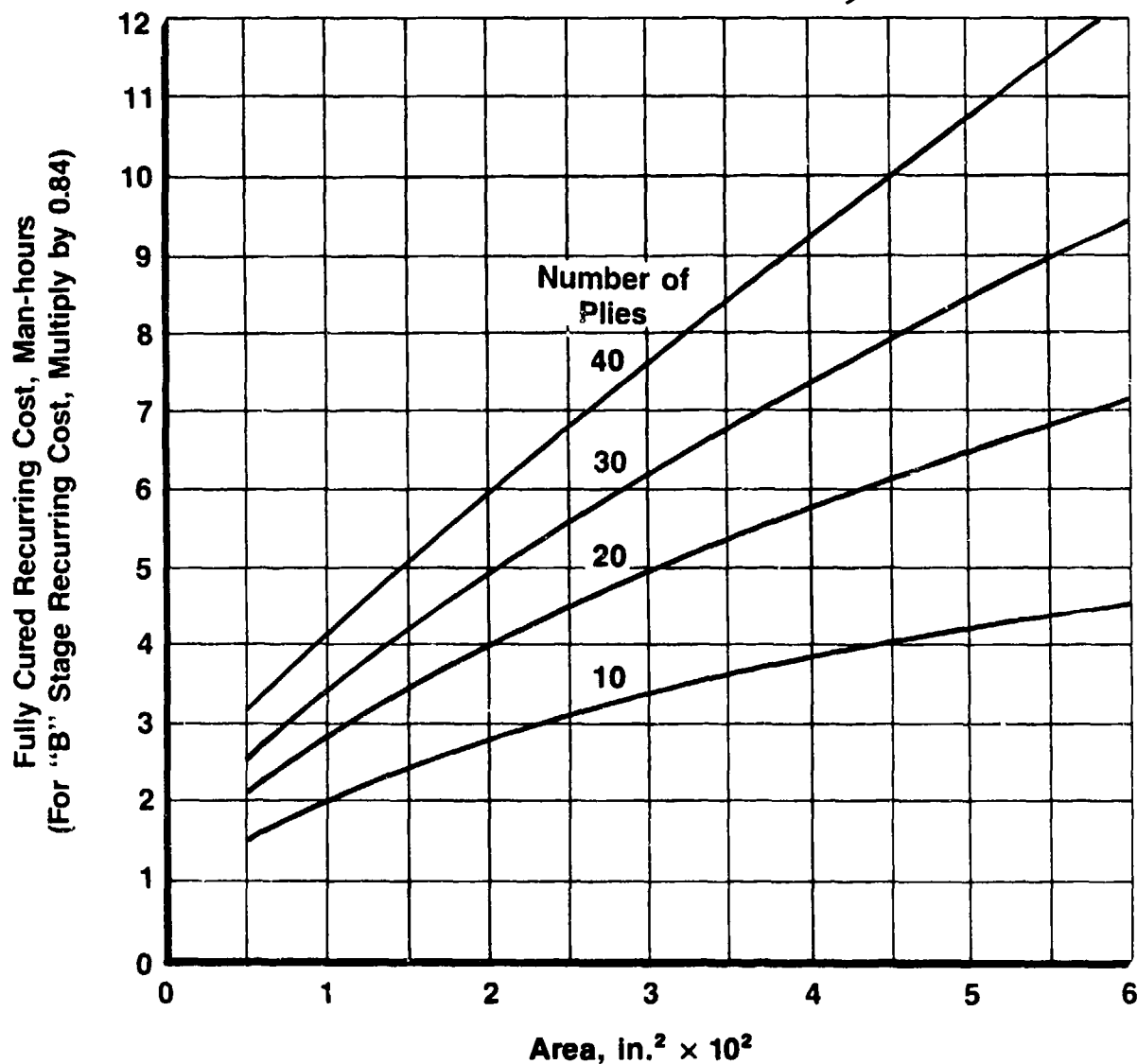
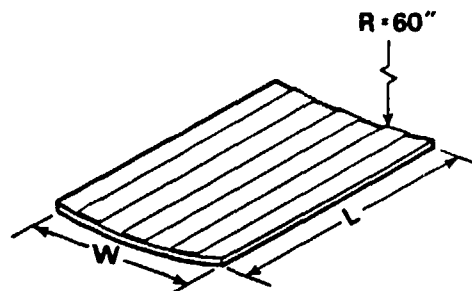


See ground rules for limitations and considerations.

COMPOSITE SINGLE CURVATURE PANEL PLY BUILDUP FOR LOCAL REINFORCEMENT MANUAL LAYUP; RECURRING COST/PART

Influenced by {

- Area
- Number of Plies
- Cure Stage

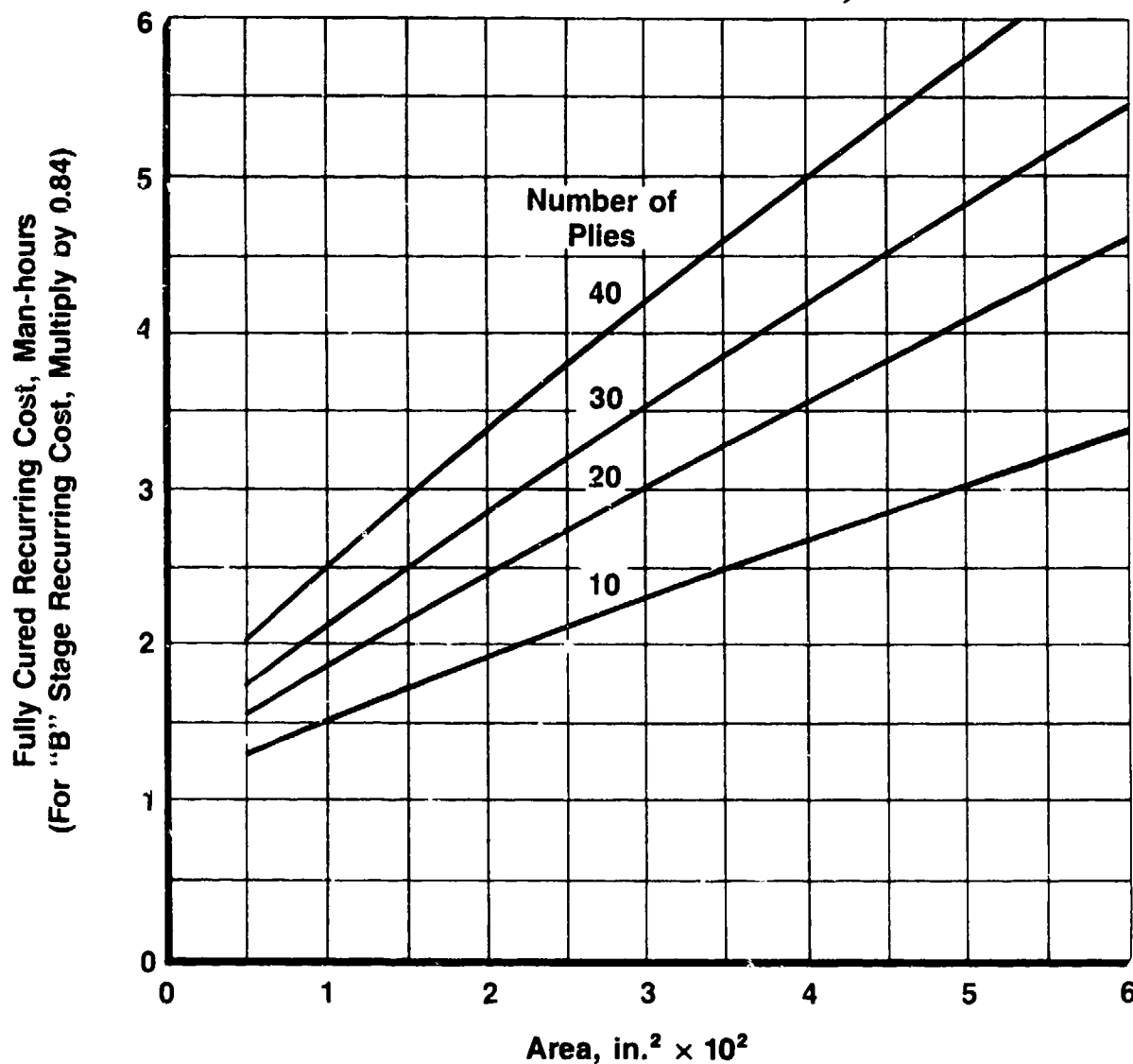
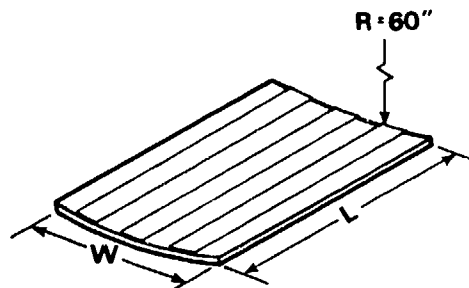


See ground rules for limitations and considerations.

COMPOSITE SINGLE CURVATURE PANEL PLY BUILDUP FOR LOCAL REINFORCEMENT NC - LAYUP; RECURRING COST/PART

Influenced by {

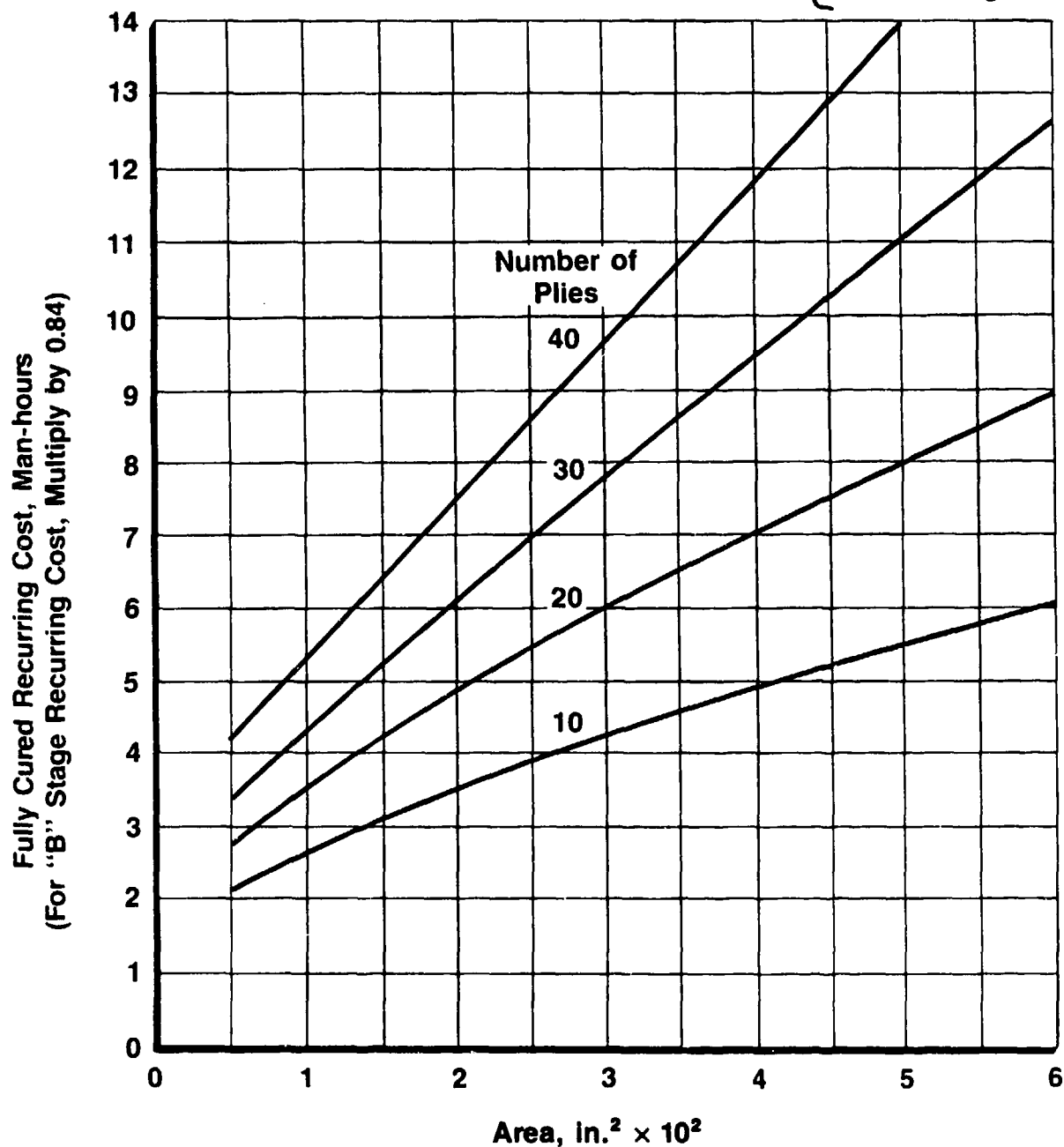
- Part Length
- Developed Width
- Bead Spacing



See ground rules for limitations and considerations.

COMPOSITE COMPOUND CURVATURE PANEL PLY BUILDUP FOR LOCAL REINFORCEMENT MANUAL LAYUP; RECURRING COST/PART

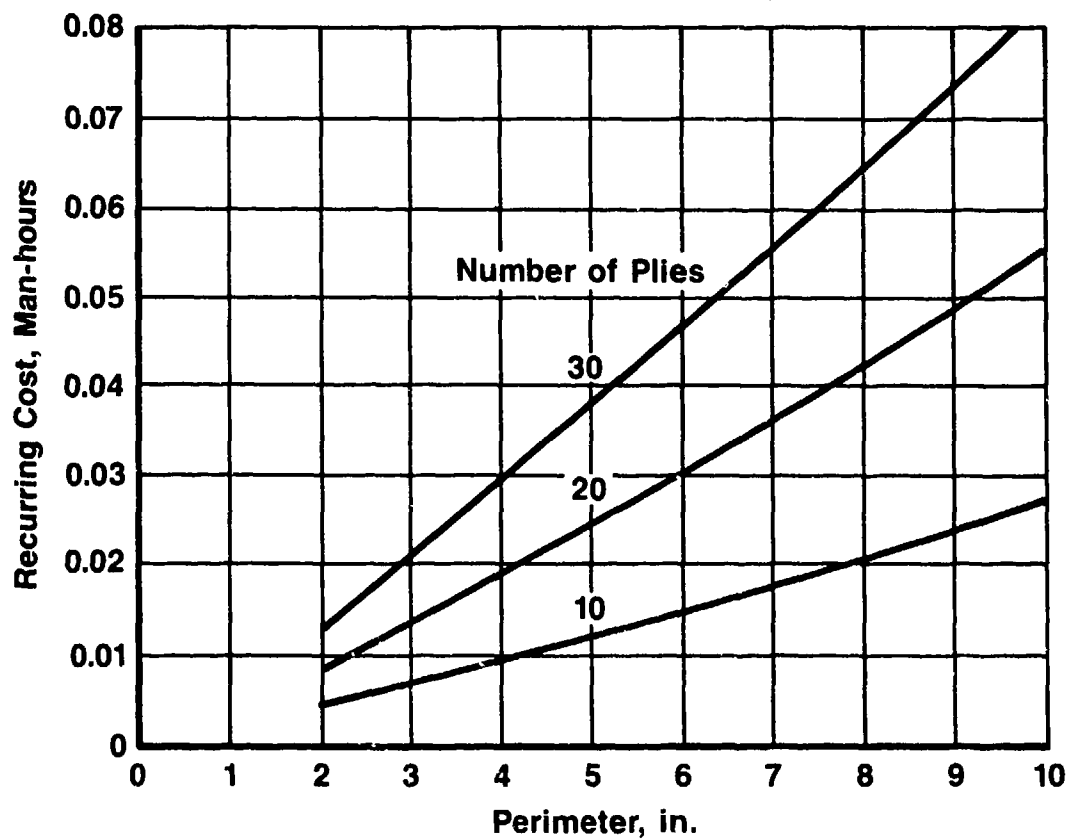
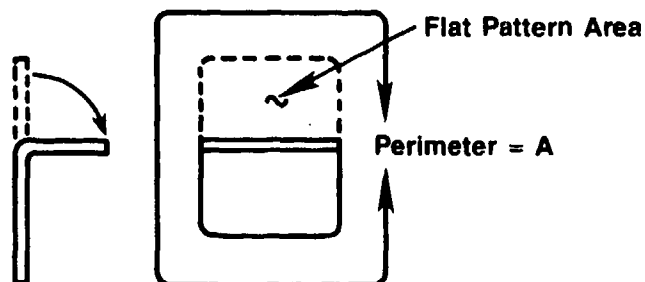
Influenced by {
• Area
• Number of Plies
• Cure Stage



See ground rules for limitations and considerations.

CLIP FOR COCURING; RECURRING COST/PART

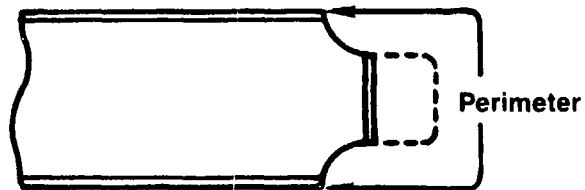
Influenced by { • Perimeter
• Number of Plies



See ground rules for limitations and considerations.

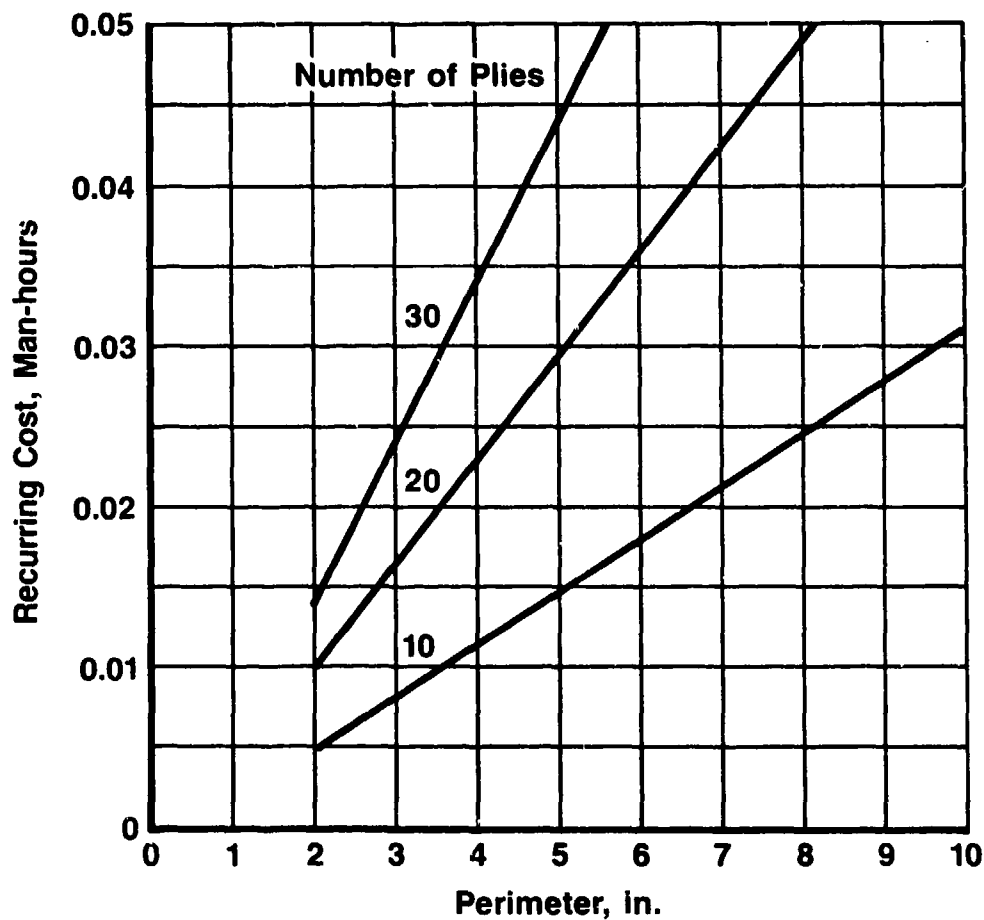
INTEGRAL TAB; RECURRING COST/DETAIL

Influenced by { • Perimeter
• Number of Plies



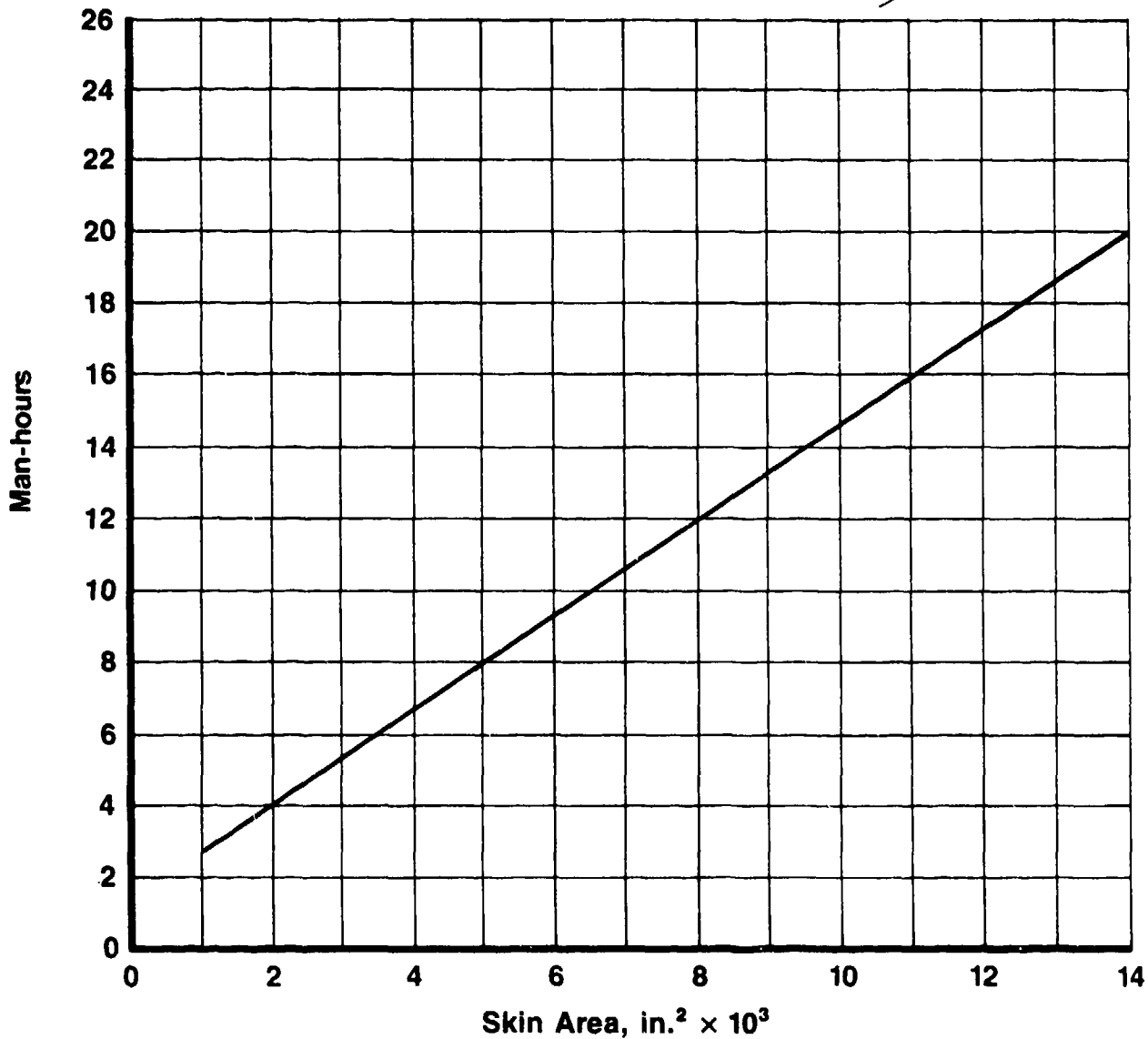
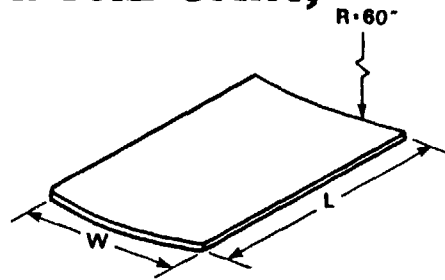
Perimeter

Cost Includes Trim Only



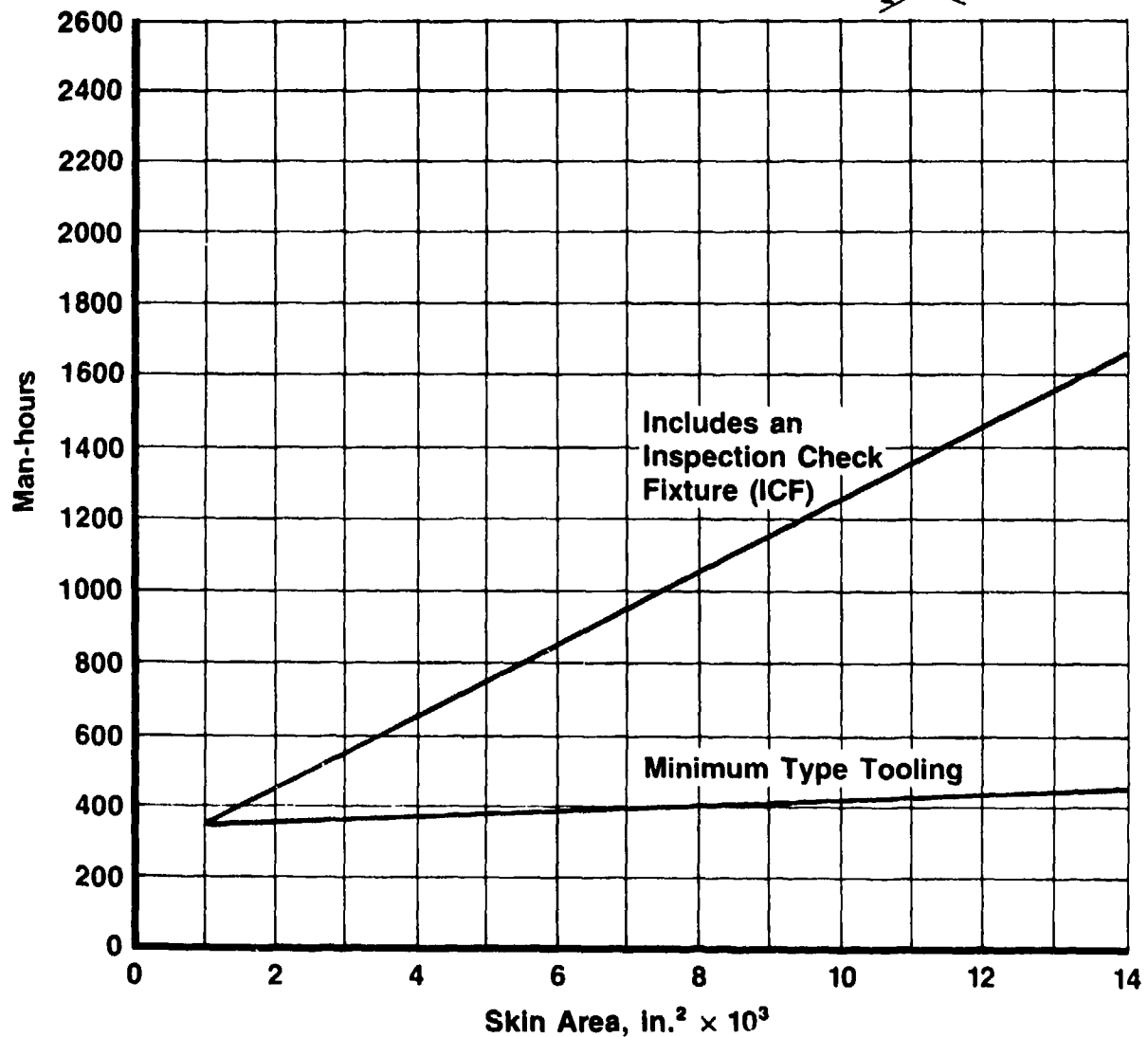
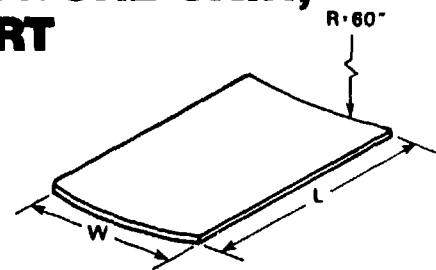
See ground rules for limitations and considerations.

TEST, INSPECTION, AND EVALUATION (TI&E) COMPOSITE SINGLE CURVATURE SKIN; RECURRING COST/PART



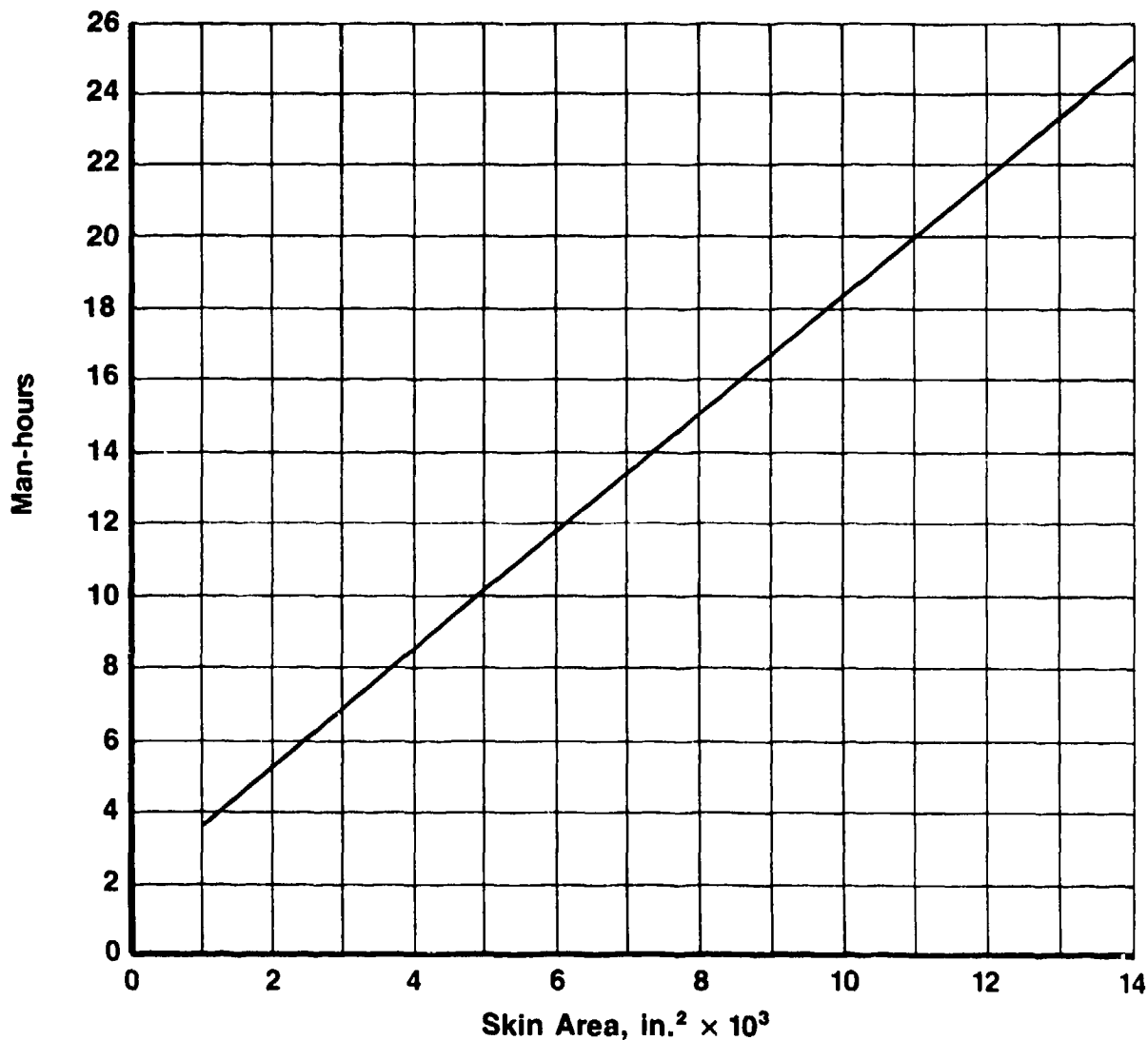
- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- See ground rules for limitations and considerations.

TEST, INSPECTION, AND EVALUATION (TI&E) COMPOSITE SINGLE CURVATURE SKIN; NONRECURRING COST/PART



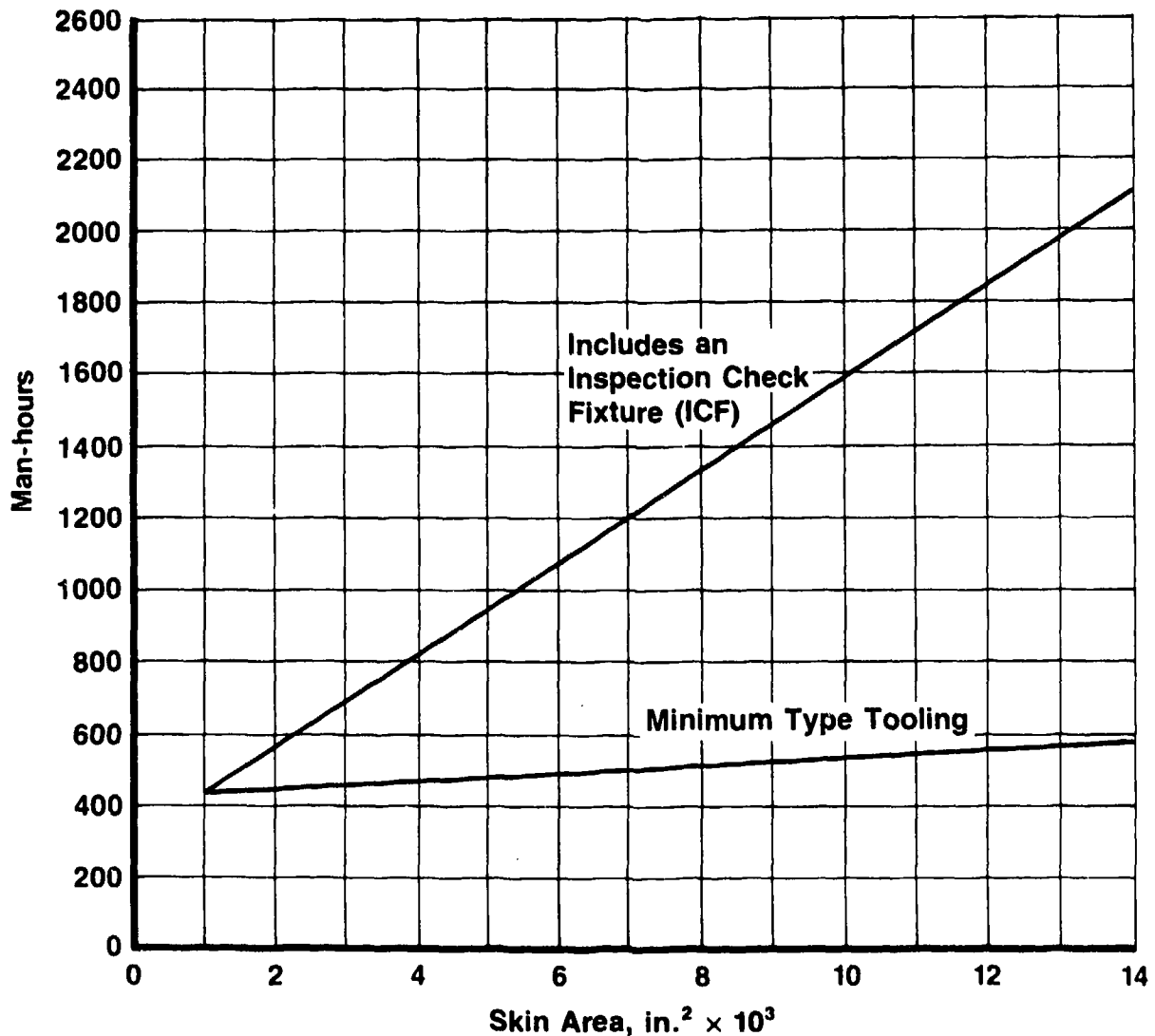
- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- See ground rules for limitations and considerations.

TEST, INSPECTION, AND EVALUATION (TI&E) COMPOSITE COMPOUND CURVATURE SKIN; RECURRING COST/PART



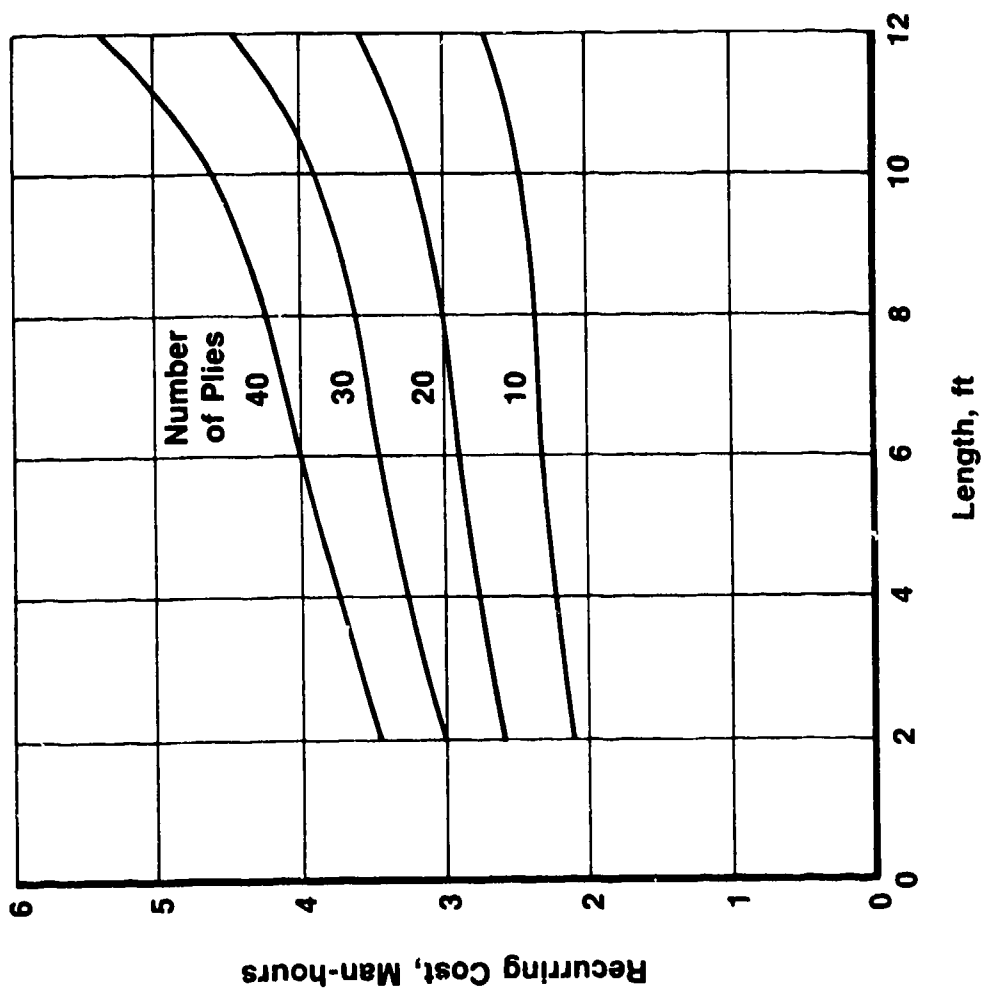
- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- See ground rules for limitations and considerations.

TEST, INSPECTION, AND EVALUATION (TI&E) COMPOSITE COMPOUND CURVATURE SKIN; NONRECURRING COST/PART

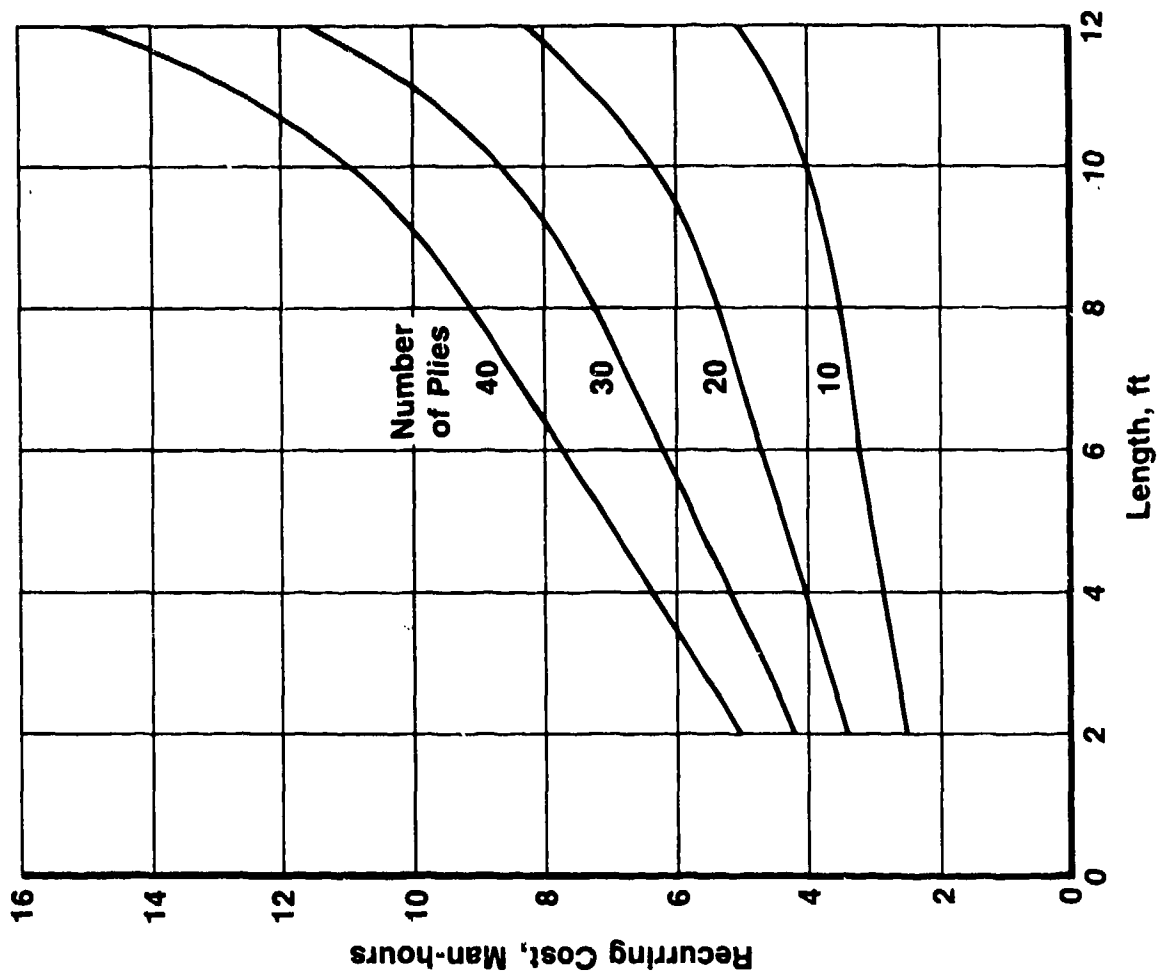


- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- See ground rules for limitations and considerations.

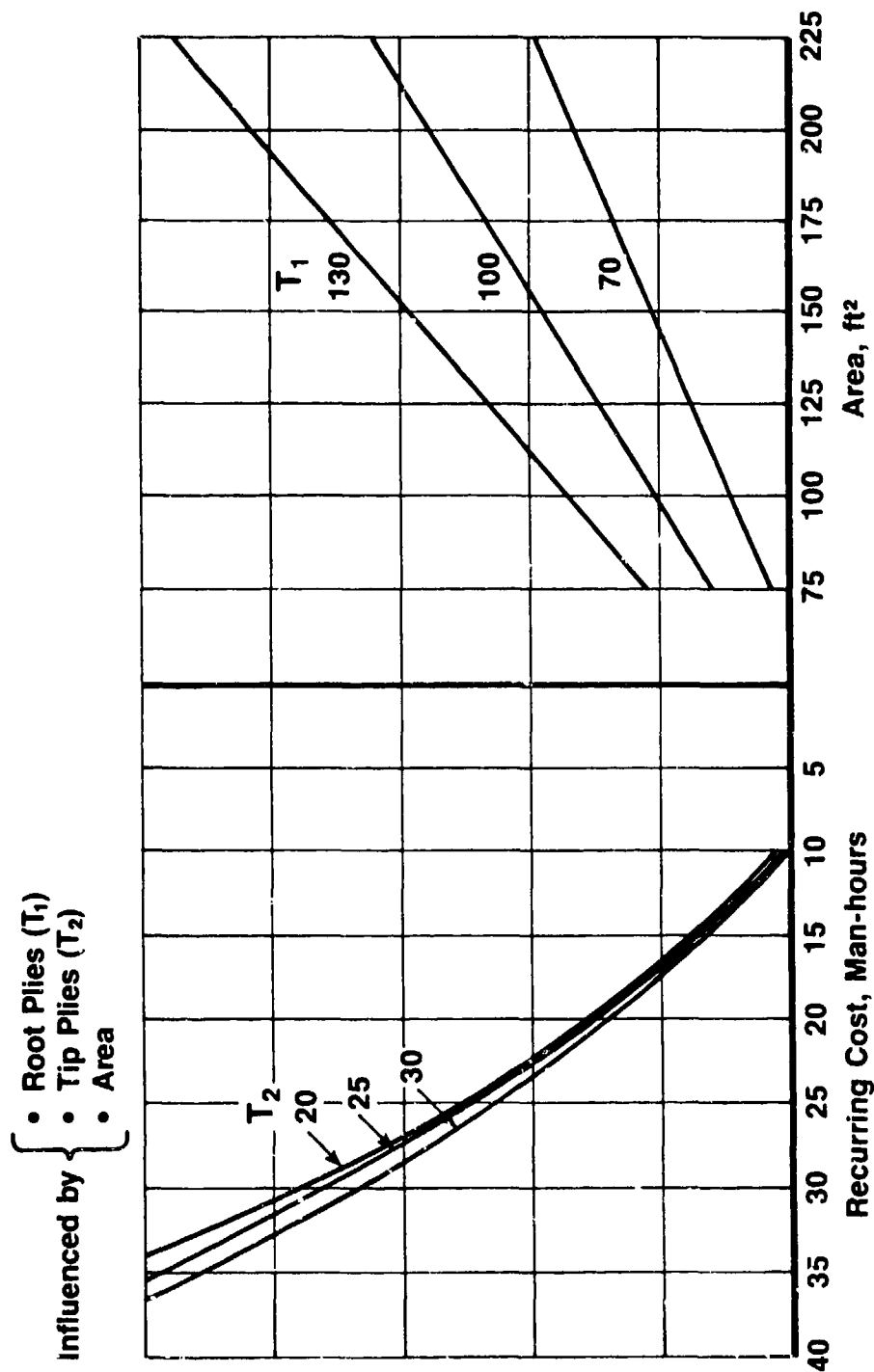
**TEST, INSPECTION & EVALUATION (TI&E)
COMPOSITE SINGLE CURVATURE SKIN
AUTOMATED TAPE LAYUP; RECURRING COST/PART**
• 2 ft Radius • 60° Segment



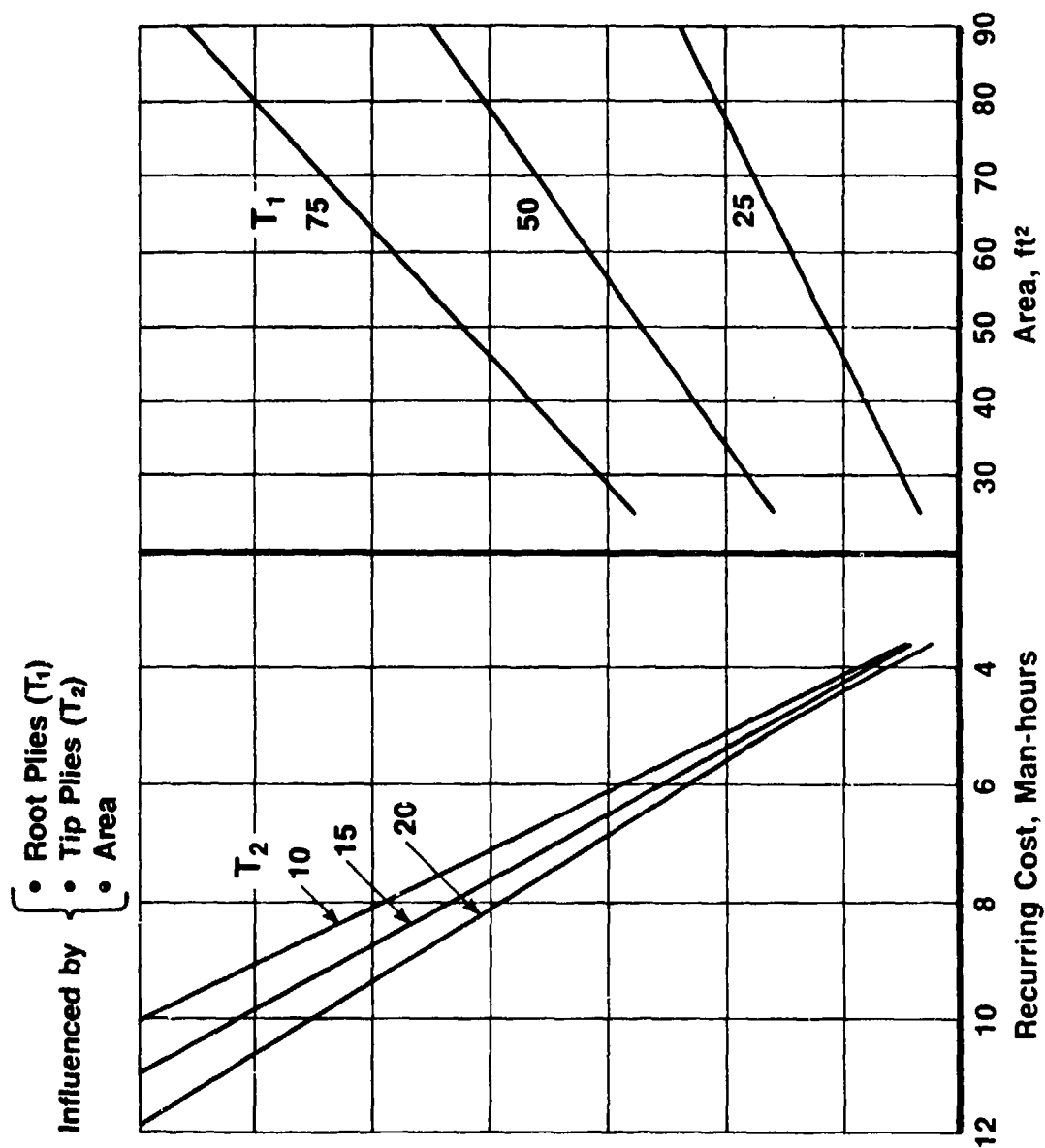
**TEST, INSPECTION & EVALUATION (TI&E)
COMPOSITE SINGLE CURVATURE SKIN
AUTOMATED TAPE LAYUP; RECURRING COST/PART**
• 10 ft Radius • 60° Segment



TEST, INSPECTION & EVALUATION (TI&E) COMPOSITE TAPERED SKIN FOR WING AUTOMATED TAPE LAYUP; RECURRING COST/PART

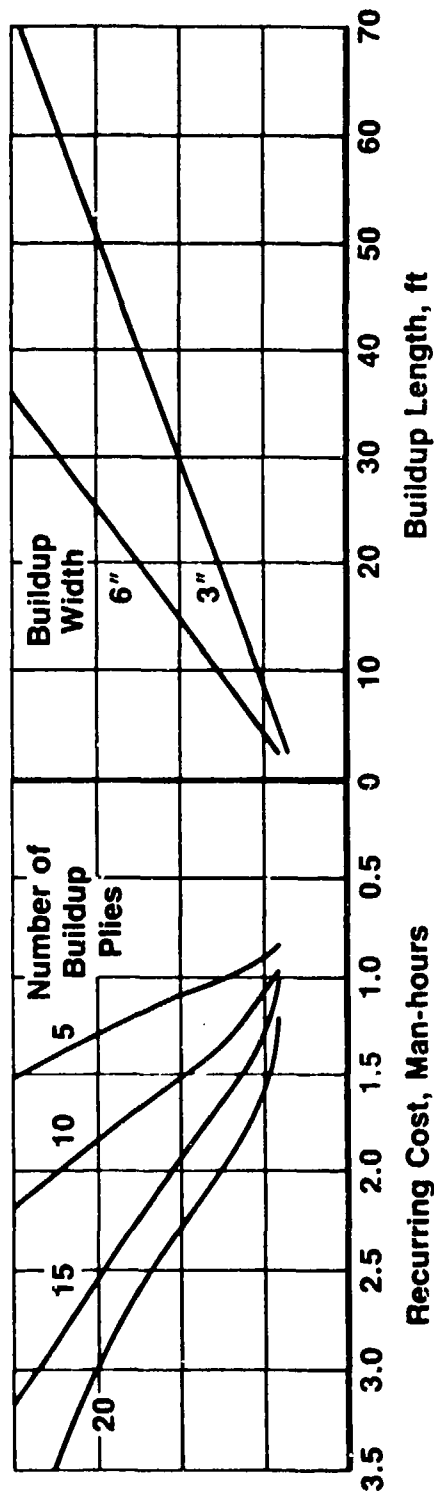


TEST, INSPECTION & EVALUATION (TI&E) COMPOSITE TAPERED SKIN FOR VERTICAL AND HORIZONTAL STABILIZERS AUTOMATED TAPE LAYUP; RECURRING COST/PART



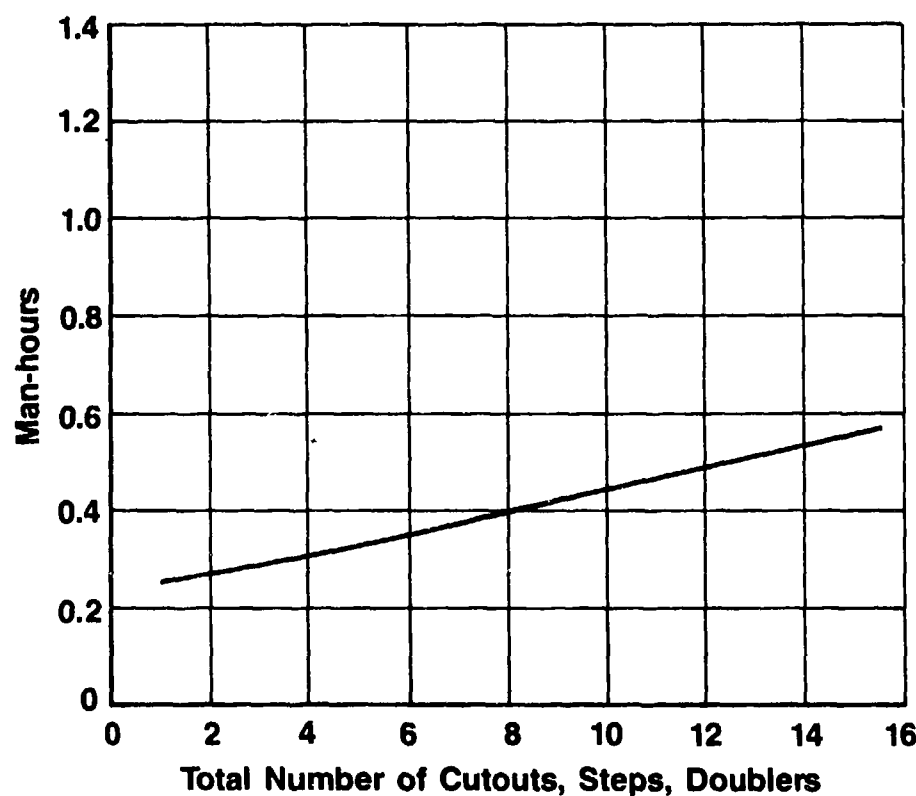
TEST, INSPECTION & EVALUATION (TI&E) PLY BUILDUP FOR LOCAL REINFORCEMENT AUTOMATED TAPE LAYOUT; RECURRING COST/PART

- Influenced by {
- Number of Plies (5-20)
 - Reinforcement Width (3-6 in.)
 - Buildup Length (to 60 ft)



TEST, INSPECTION AND EVALUATION (TI&E) OF COMPOSITES

RECURRING COST/PART FOR TI&E OF CUTOUTS, STEPS, AND DOUBLERS IN SINGLE CONFIGURATION APPLICATIONS

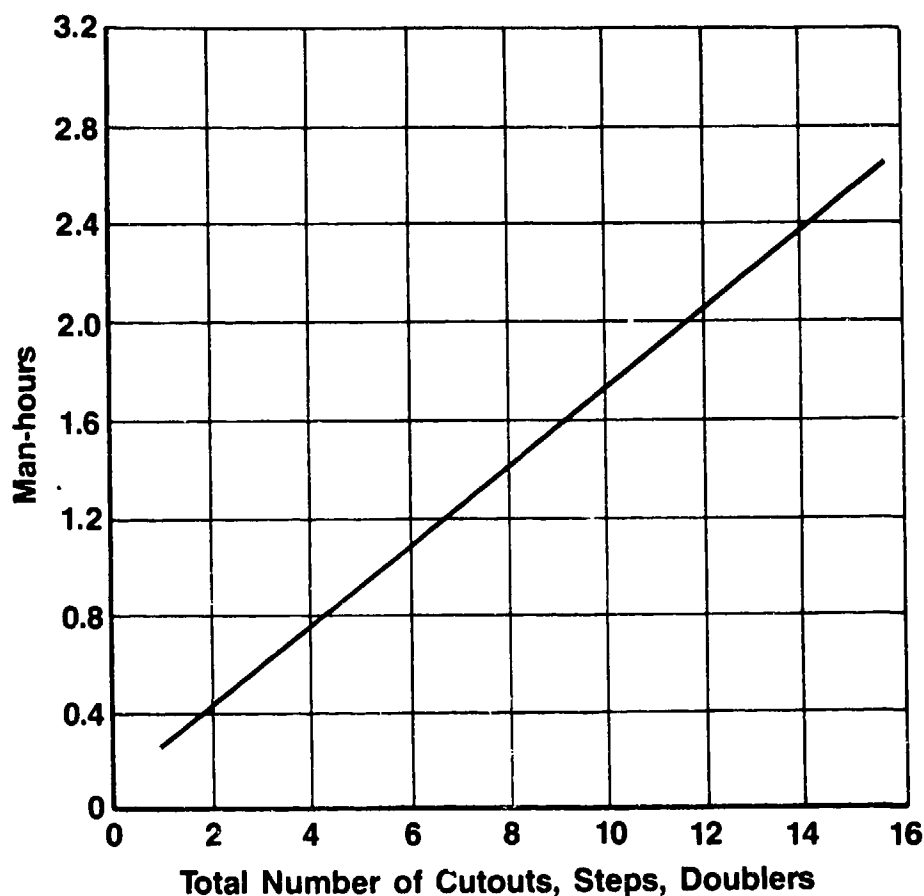


Assumptions

- (A) Each cutout, step, or doubler is of a different configuration.
- (B) Each cutout, step, or doubler exceeds base configuration by four plies.
- (C) Part repositioning is not required for NDT of DICE.
- (D) Size and configuration of parts do not significantly affect DICE man-hours.
- (E) Hours shown are the increase over a base part without DICE.

TEST, INSPECTION AND EVALUATION (TI&E) OF COMPOSITES

RECURRING COST/PART FOR TI&E OF CUTOUTS, STEPS, AND DOUBLERS IN MULTIPLE CONFIGURATION APPLICATIONS

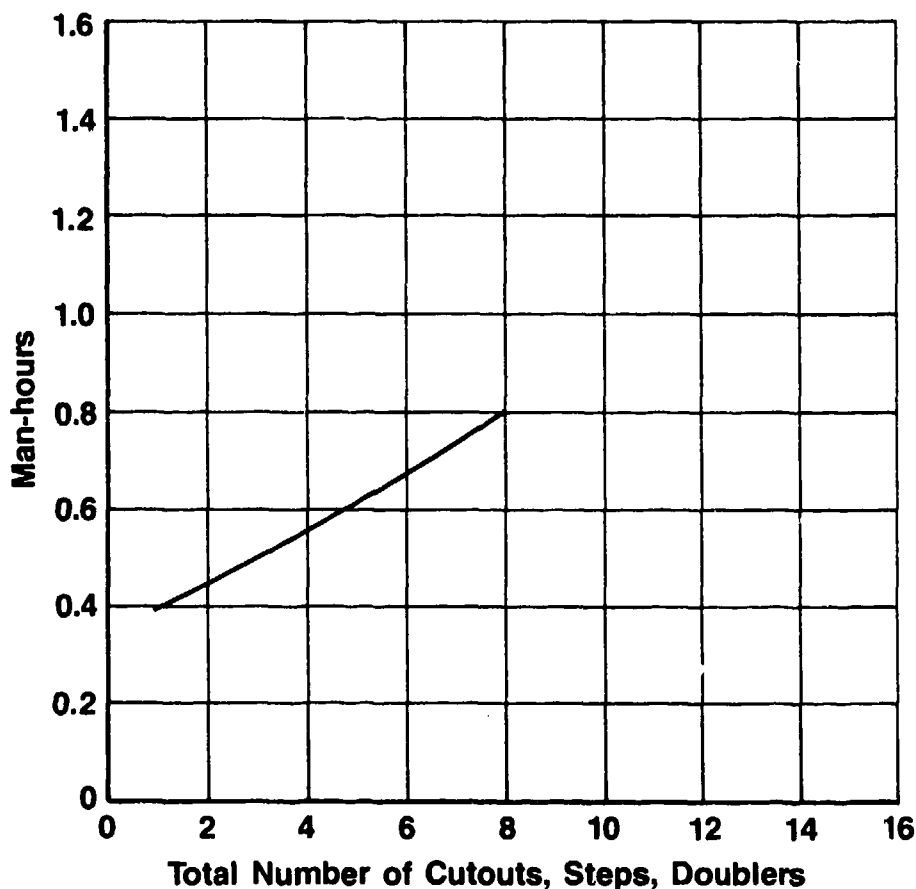


Assumptions

- (A) Each cutout, step, or doubler is of a different configuration.
- (B) Each cutout, step, or doubler exceeds base configuration by four plies.
- (C) Part repositioning is not required for NDT of DICE.
- (D) Size and configuration of parts do not significantly affect DICE man-hours.
- (E) Hours shown are the increase over a base part without DICE.

TEST, INSPECTION AND EVALUATION (TI&E) OF COMPOSITES

RECURRING COST/PART FOR TI&E OF INSERTS IN SINGLE CONFIGURATION APPLICATIONS

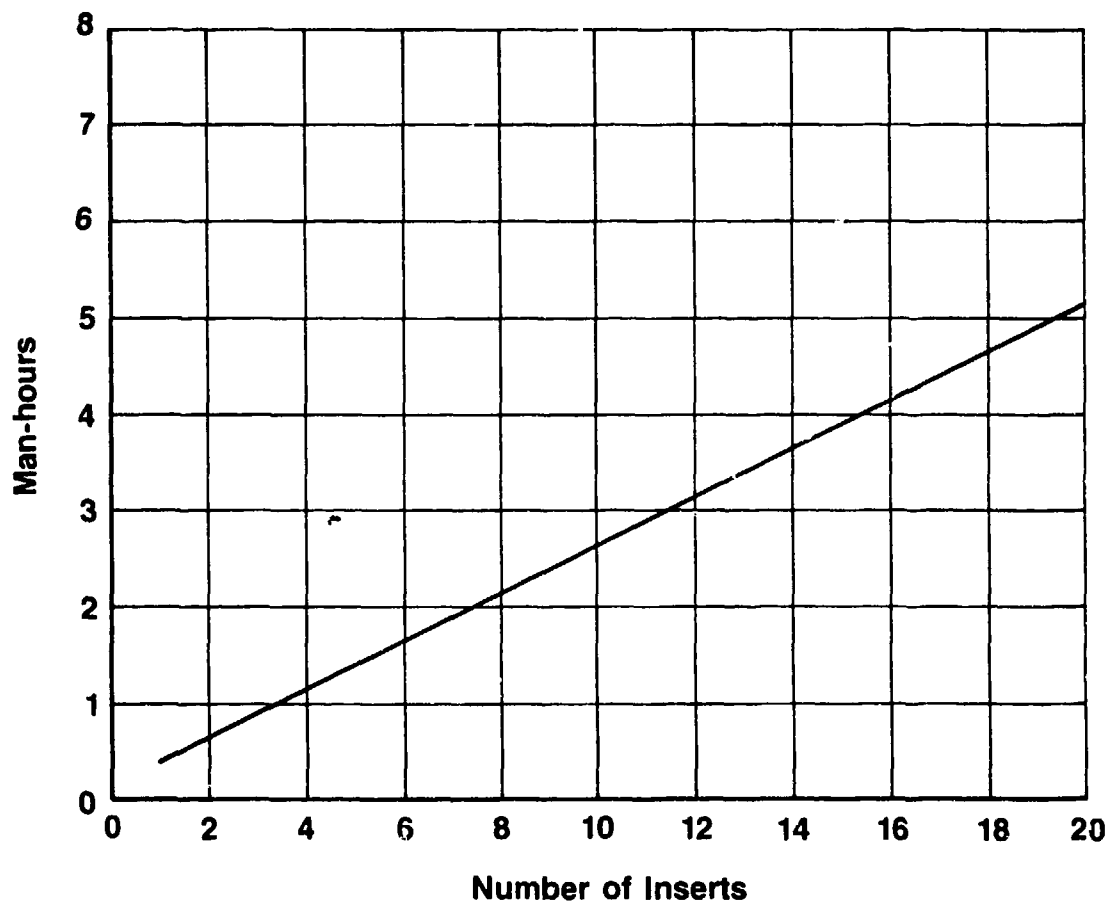


Assumptions

- (A) Each insert is of the same nongraphite material.
- (B) Part repositioning is not required for NDT of DICE.
- (C) Size and configuration of parts do not significantly affect DICE man-hours.
- (D) Hours shown are the increase over a base part without DICE.

TEST, INSPECTION AND EVALUATION (TI&E) OF COMPOSITES

RECURRING COST/PART FOR TI&E OF INSERTS IN MULTIPLE CONFIGURATION APPLICATIONS

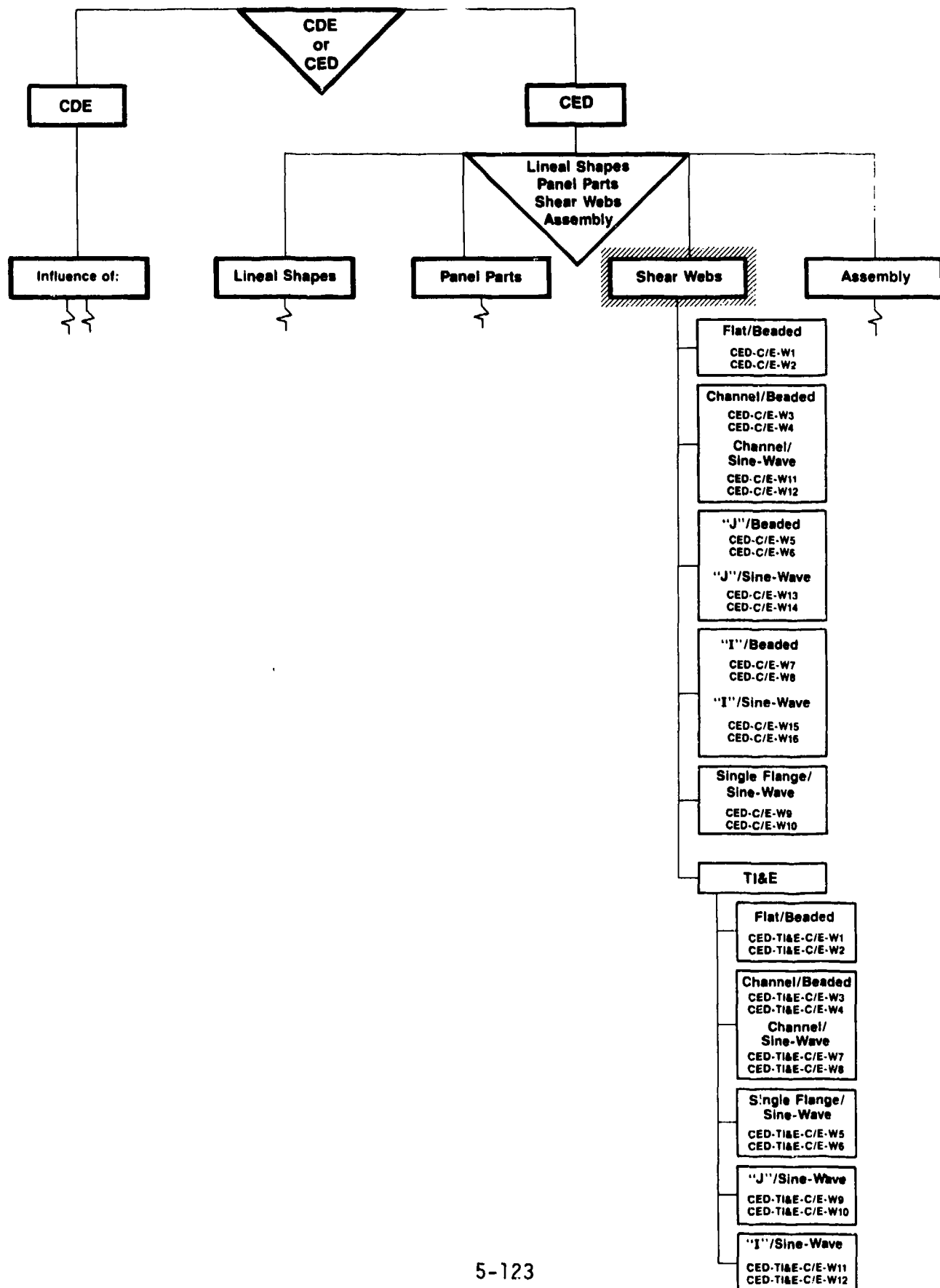


Assumptions

- (A) Each insert is of a different configuration (material and/or thickness)
- (B) Part repositioning is not required for NDT of DICE.
- (C) Size and configuration of parts do not significantly affect DICE man-hours.
- (D) Hours shown are the increase over a base part without DICE.

FORMAT SELECTION AID

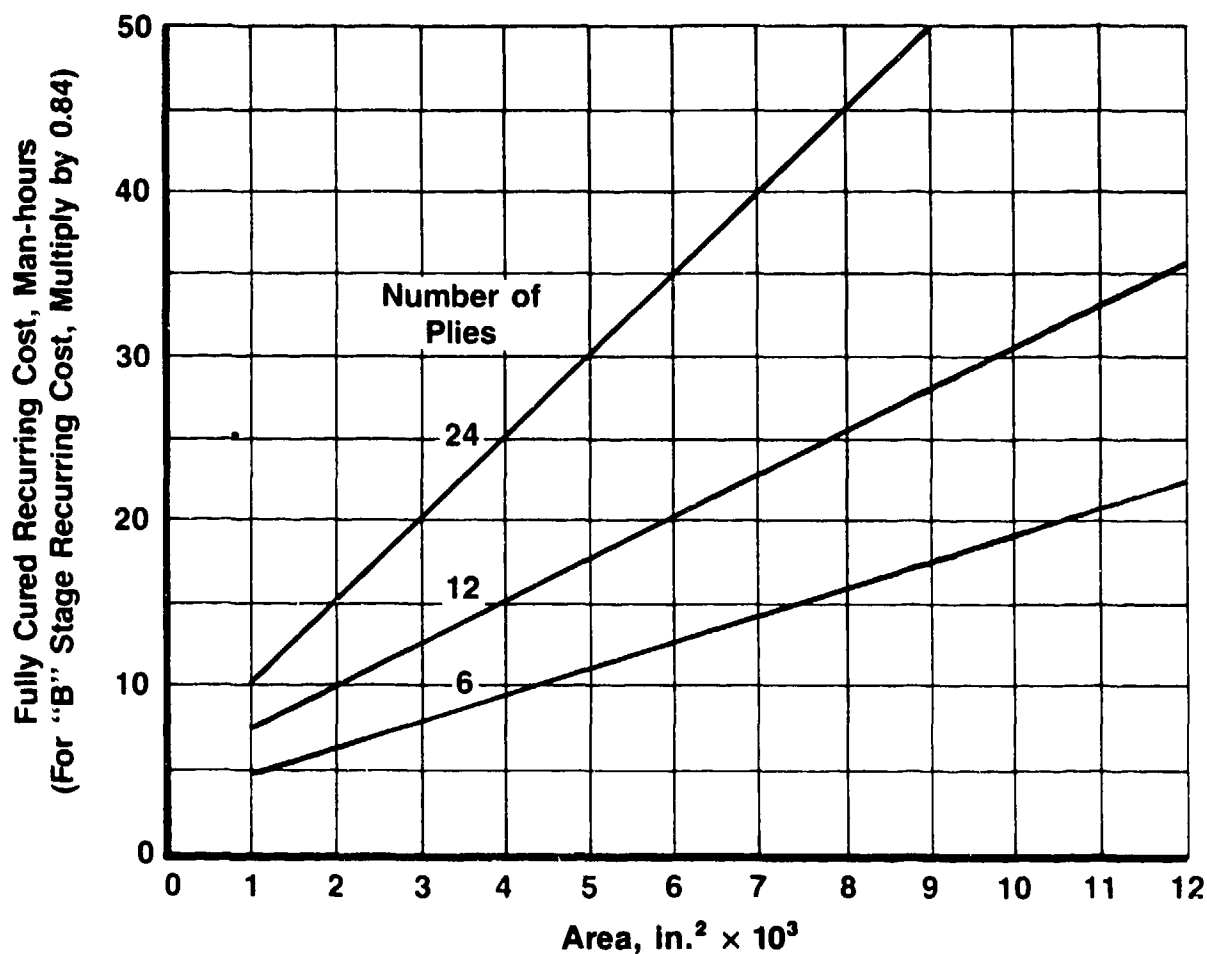
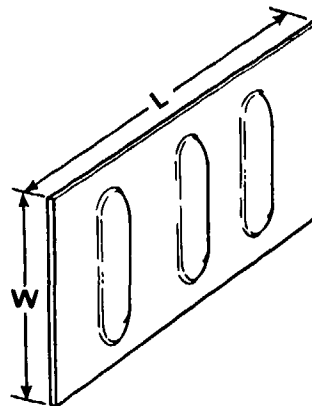
Advanced Composite Fabrication



COMPOSITE FLAT BEADED PANEL OR WEB WOVEN MATERIAL; RECURRING COST/PART

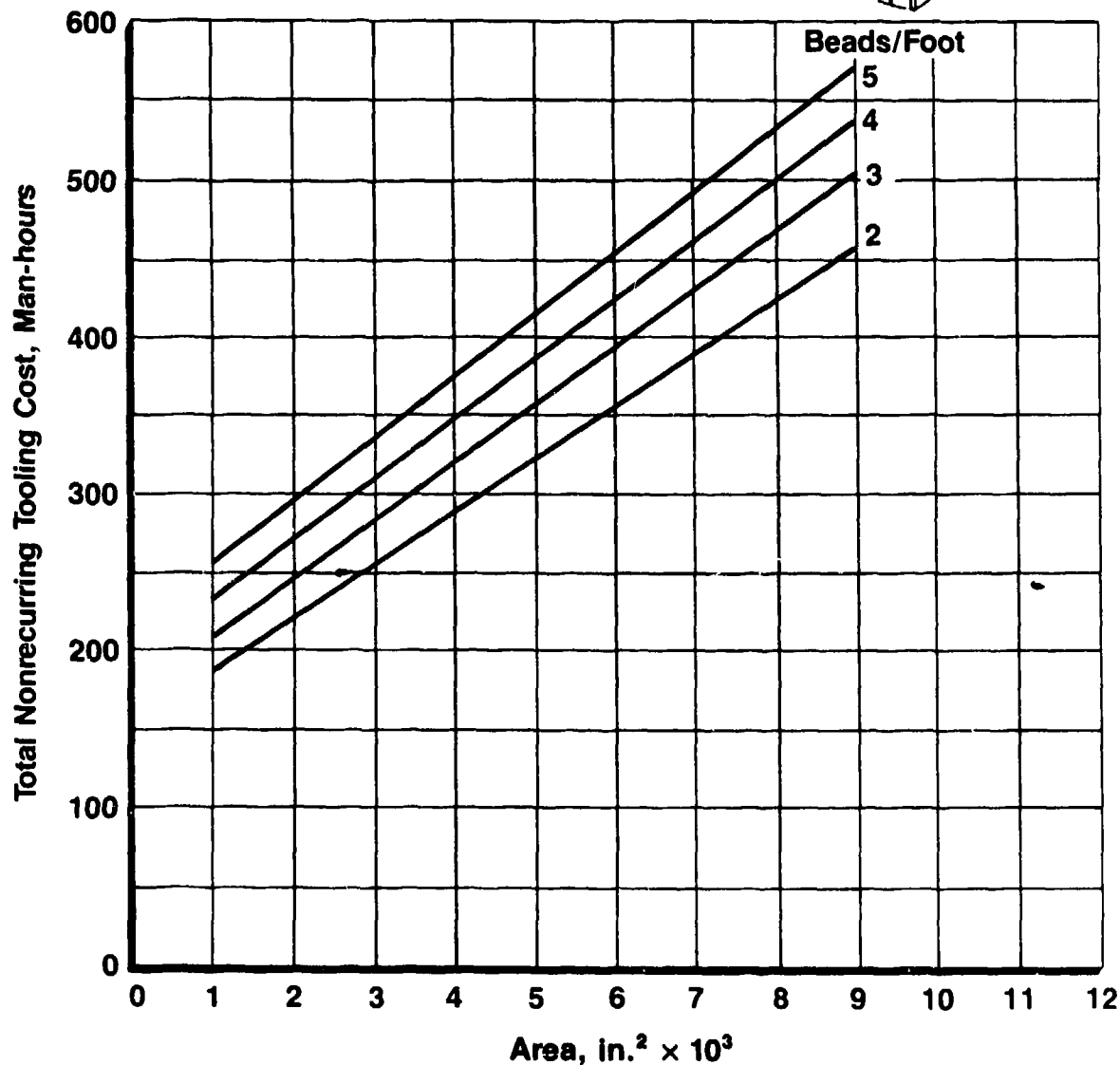
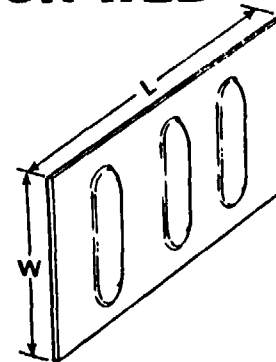
Influenced by {

- Area
- Number of Plies
- Cure Stage
- Bead Spacing



- Based on three beads per lineal foot. Add or subtract 7% for each bead per foot difference in spacing.
- See ground rules for limitations and considerations.

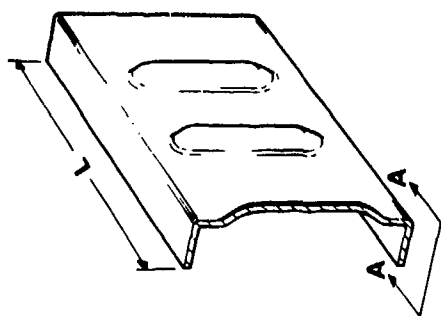
COMPOSITE FLAT BEADED PANEL OR WEB WOVEN MATERIAL; NONRECURRING COST/PART



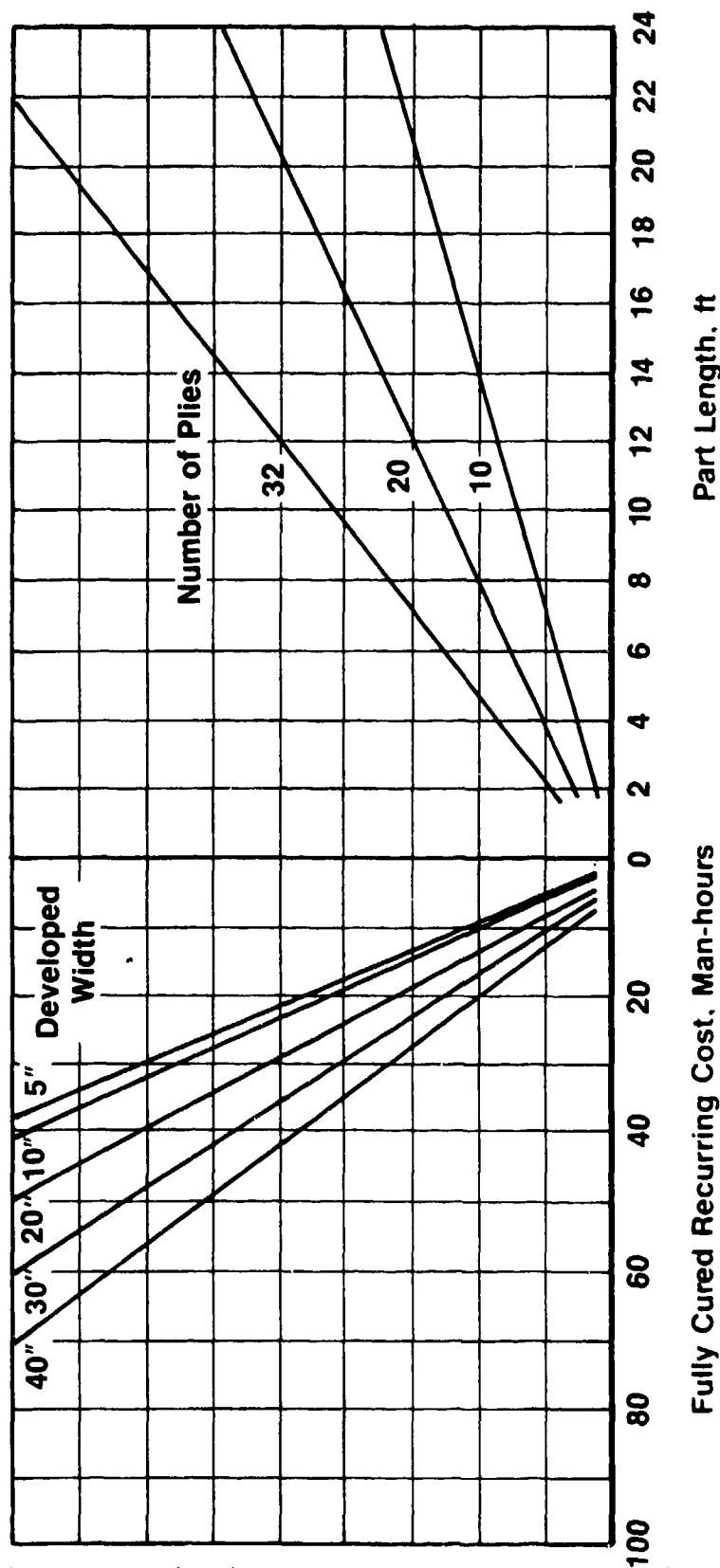
See ground rules for limitations and considerations.

COMPOSITE CHANNEL SECTION WITH BEADED WEB; RECURRING COST/PART

- Influenced by
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage
 - Bead Spacing



Section A-A



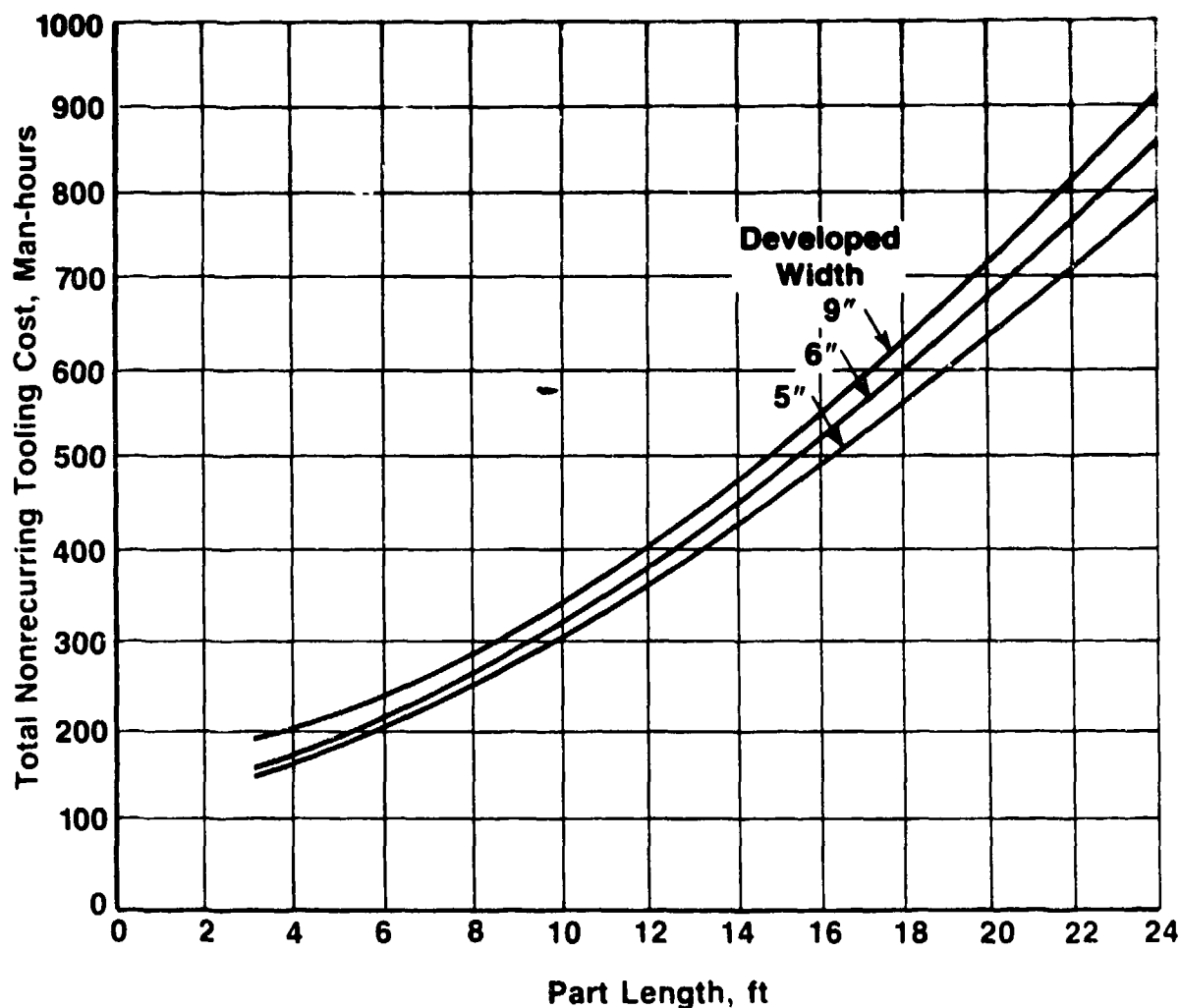
Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

- Based on three beads per lineal foot. Add or subtract 7% for each bead per foot difference in spacing.
- See ground rules for limitations and considerations.

COMPOSITE CHANNEL SECTION WITH BEADED WEB; TOTAL NONRECURRING TOOLING COST

Influenced by {
• Part Length
• Developed Width

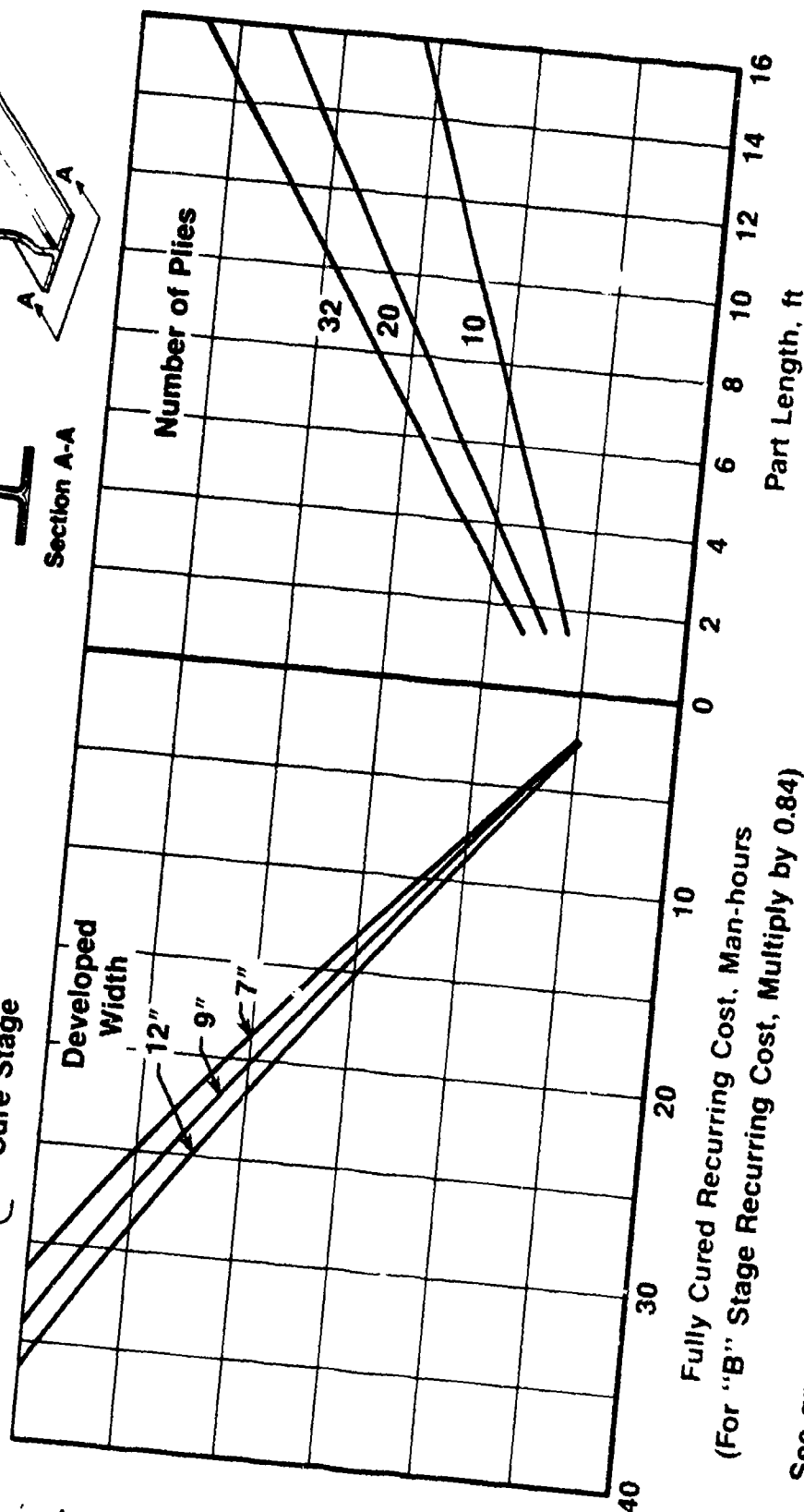
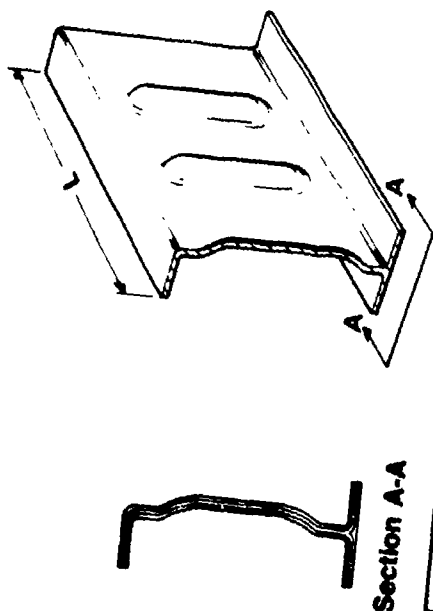
Section A-A



See ground rules for limitations and considerations.

COMPOSITE "J" SECTION WITH BEADED WEB AND UNSYMMETRICAL FLANGES; RECURRING COST/PART

- Influenced by
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



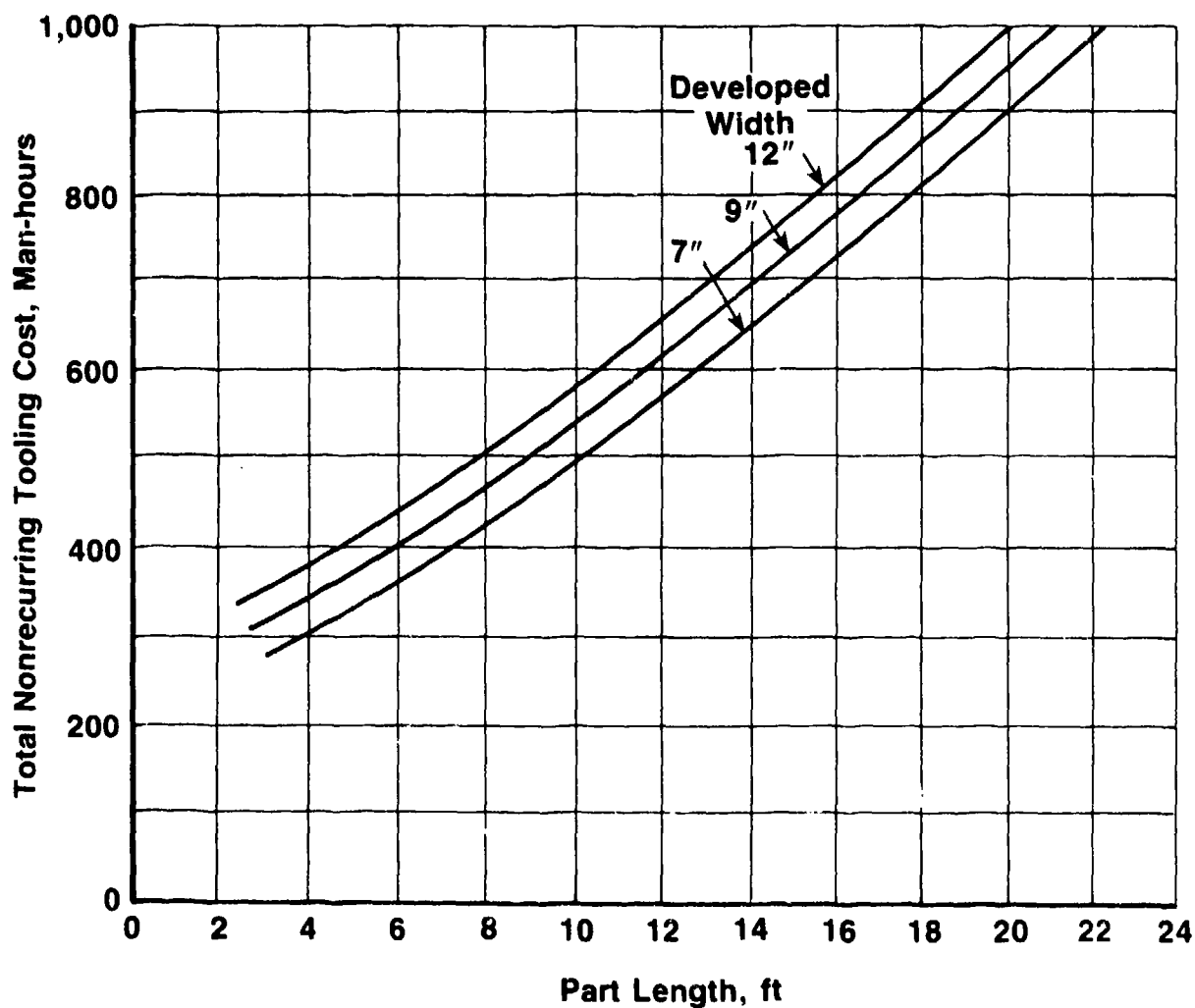
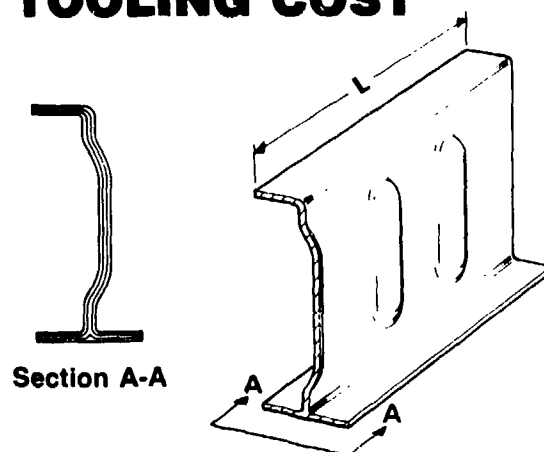
Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

See ground rules for limitations and considerations.

COMPOSITE "U" SECTION WITH BEADED WEB AND UNSYMMETRICAL FLANGES; TOTAL NONRECURRING TOOLING COST

Influenced by {

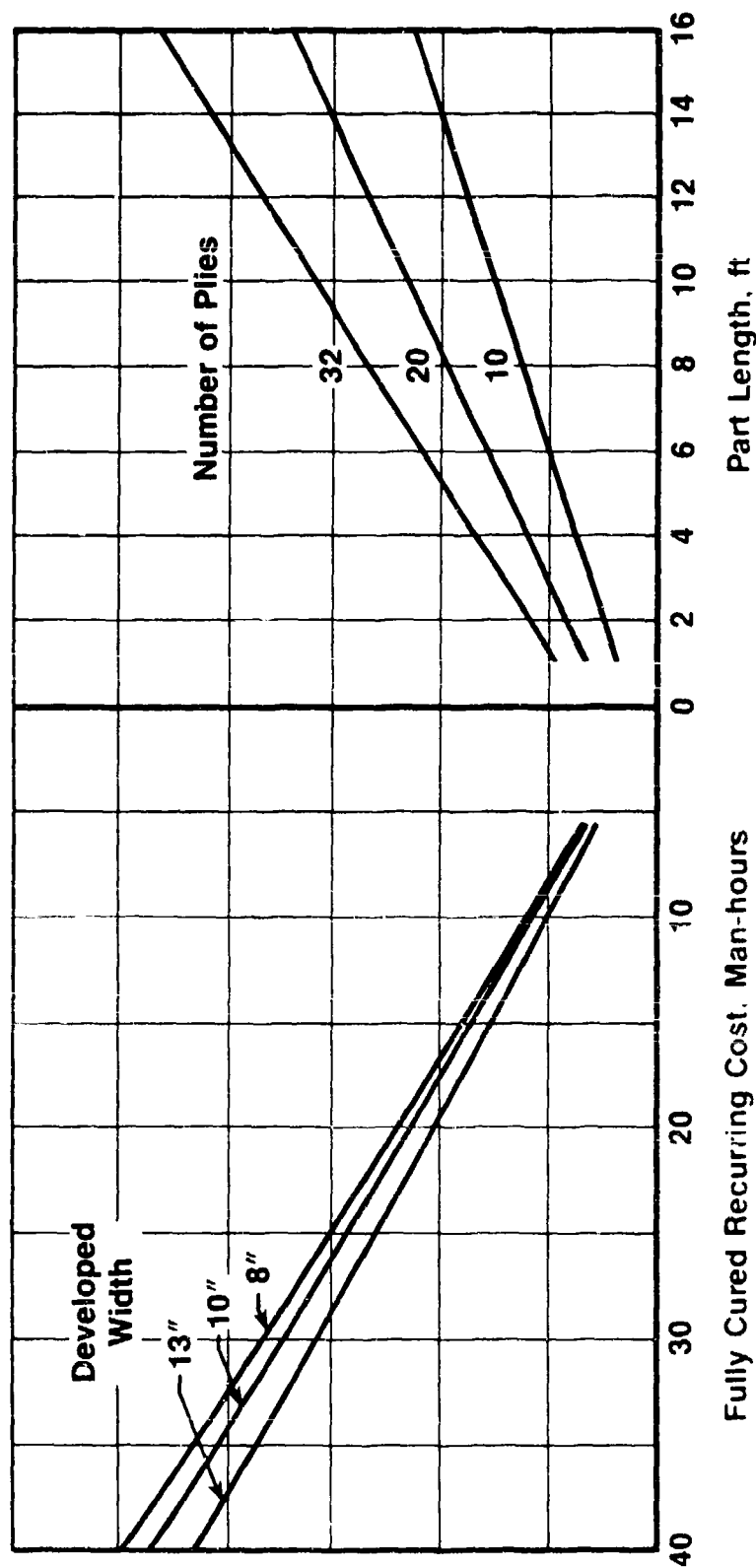
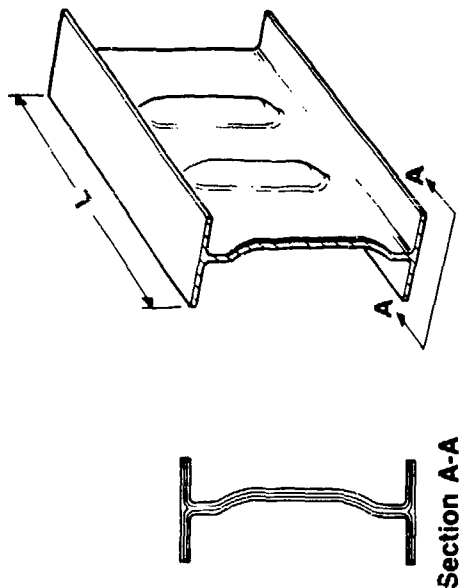
- Part Length
- Developed Width



See ground rules for limitations and considerations.

COMPOSITE "I" SECTION WITH BEADED WEB; RECURRING COST/PART

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



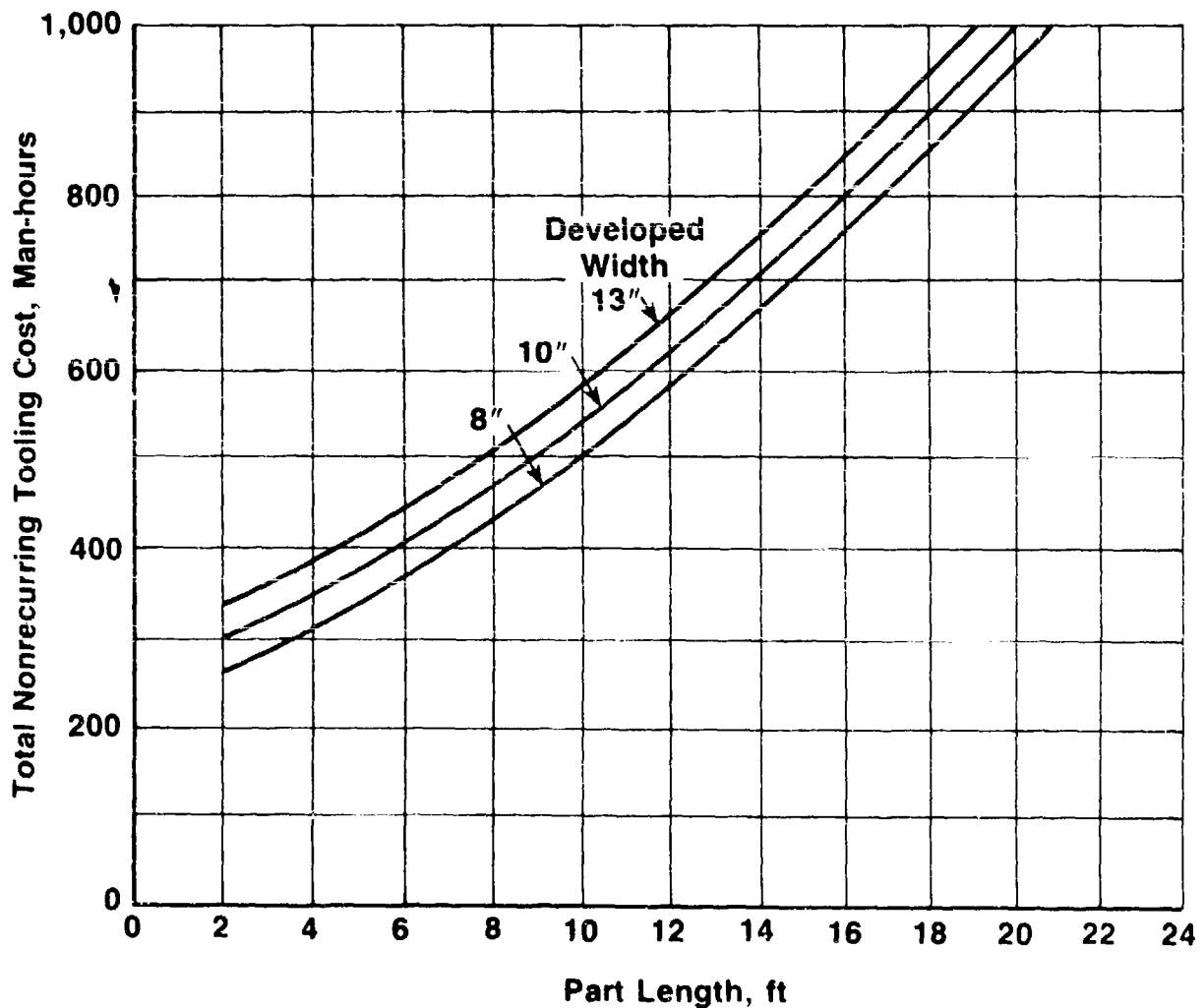
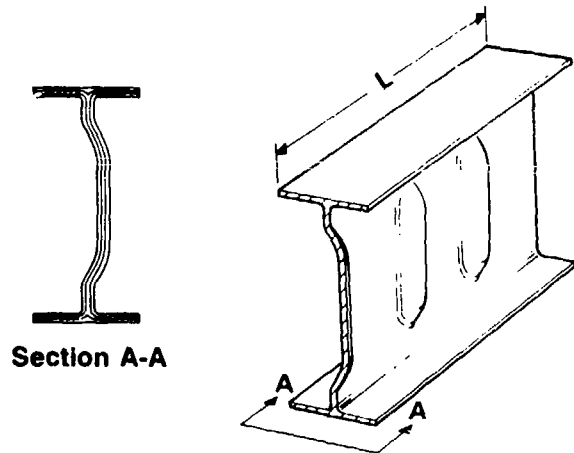
Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

See ground rules for limitations and considerations.

COMPOSITE "I" SECTION WITH BEADED WEB; TOTAL NONRECURRING TOOLING COST

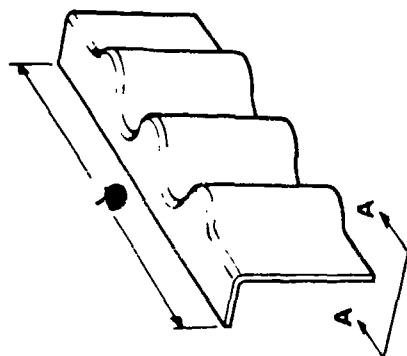
Influenced by {

- Part Length
- Developed Width



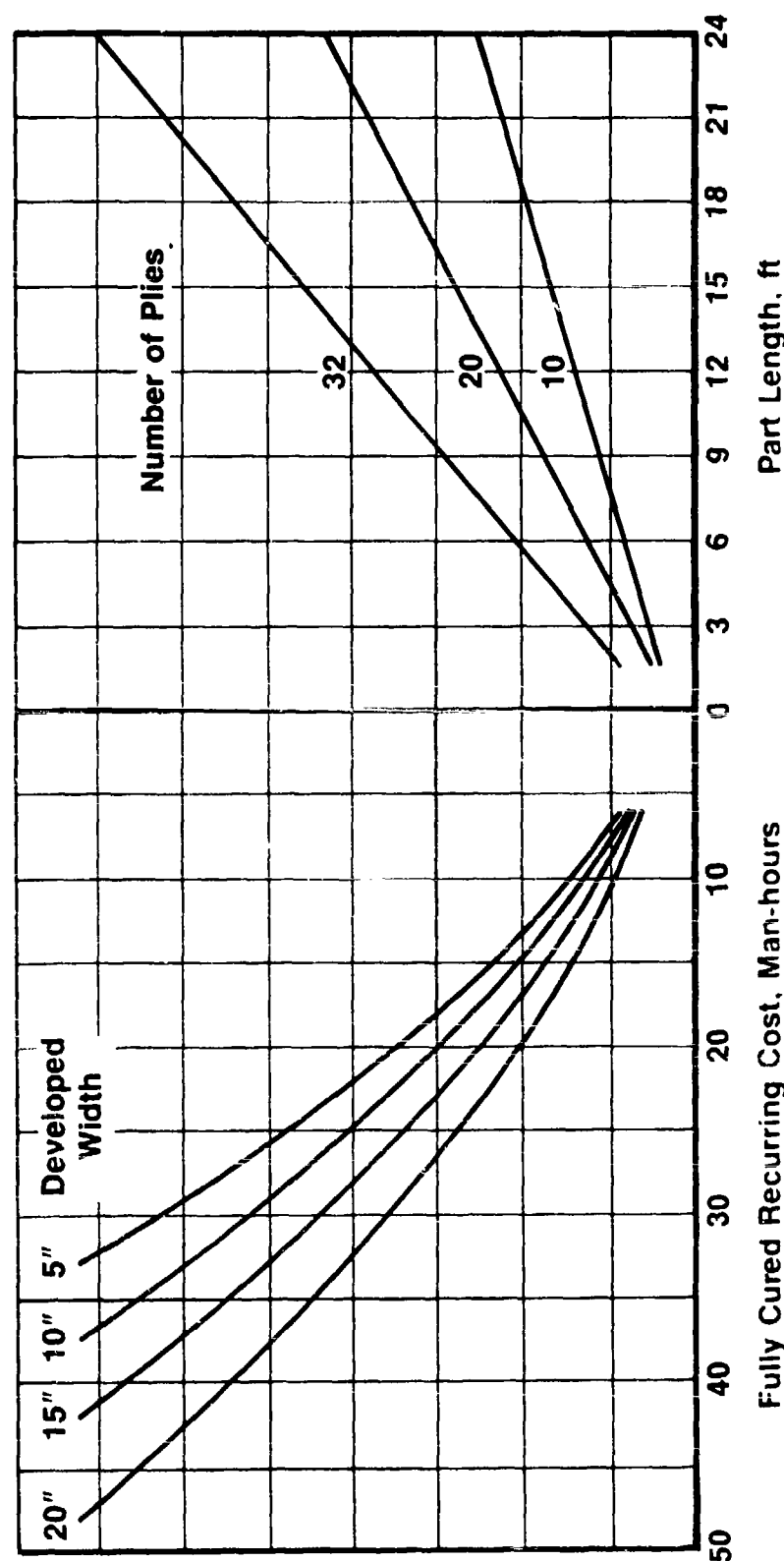
See ground rules for limitations and considerations.

COMPOSITE SINE-WAVE SECTION WITH ONE FLANGE ONLY; RECURRING COST/PART



Section A-A

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Width



Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

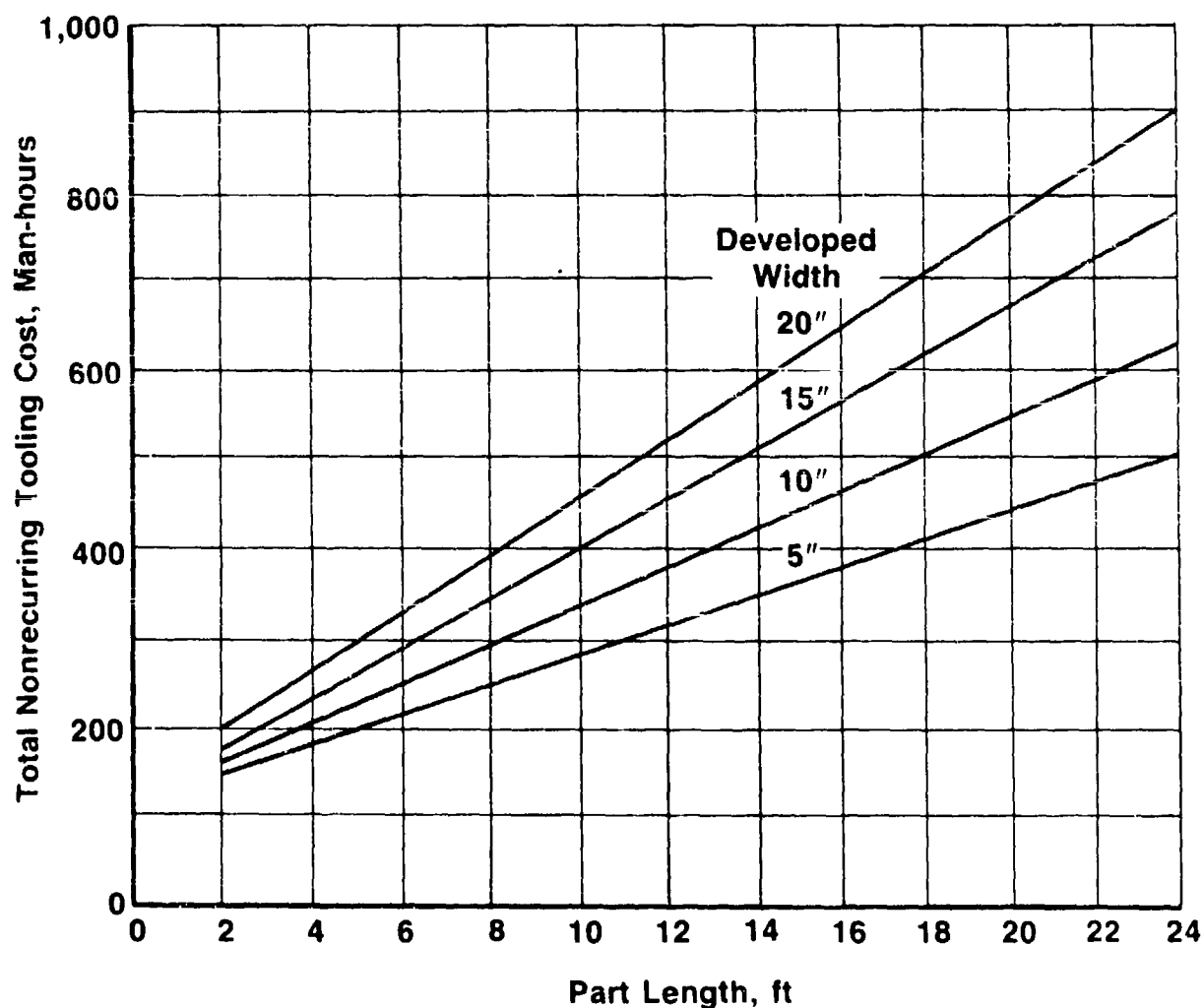
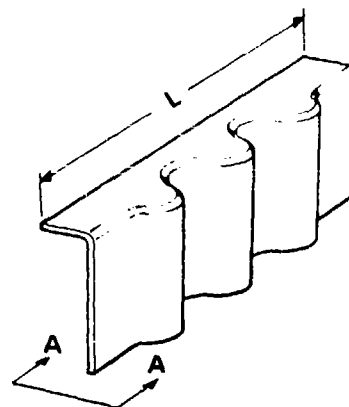
See ground rules for limitations and considerations.

COMPOSITE SINE-WAVE SECTION WITH ONE FLANGE ONLY; TOTAL NONRECURRING TOOLING COST

Influenced by {

- Part Length
- Developed Width

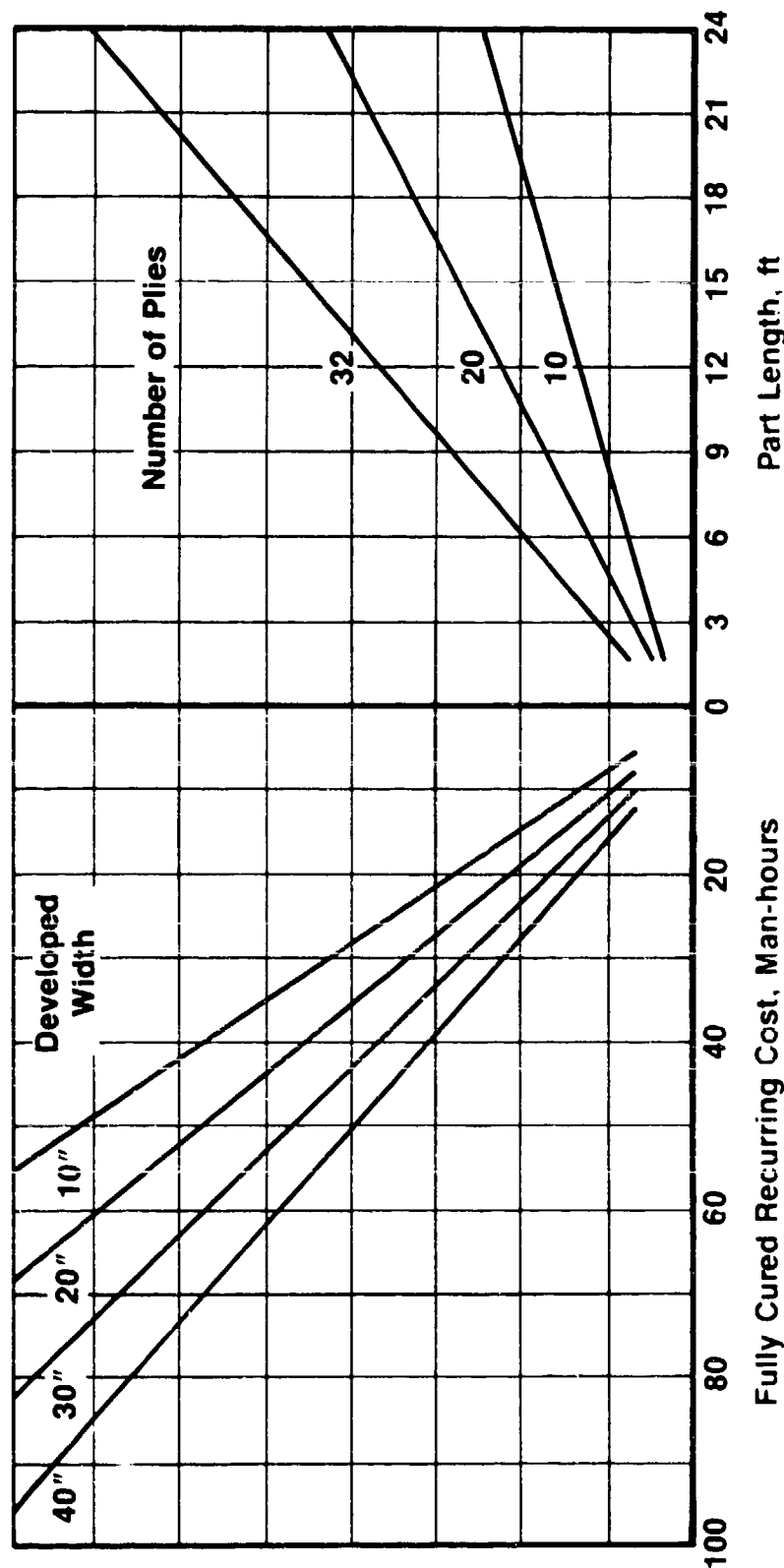
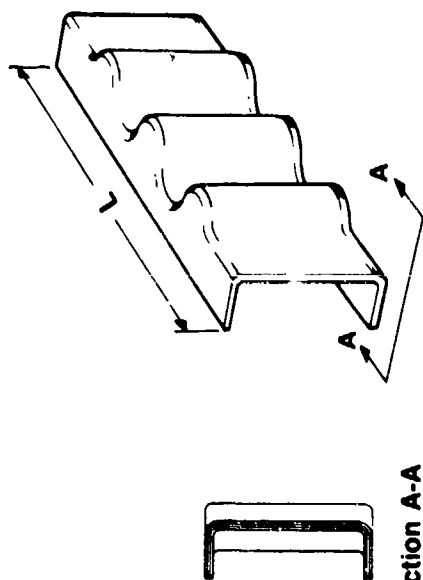
Section A-A



See ground rules for limitations and considerations.

COMPOSITE SINE-WAVE SECTION WITH TWO FLANGES; RECURRING COST/PART

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Width



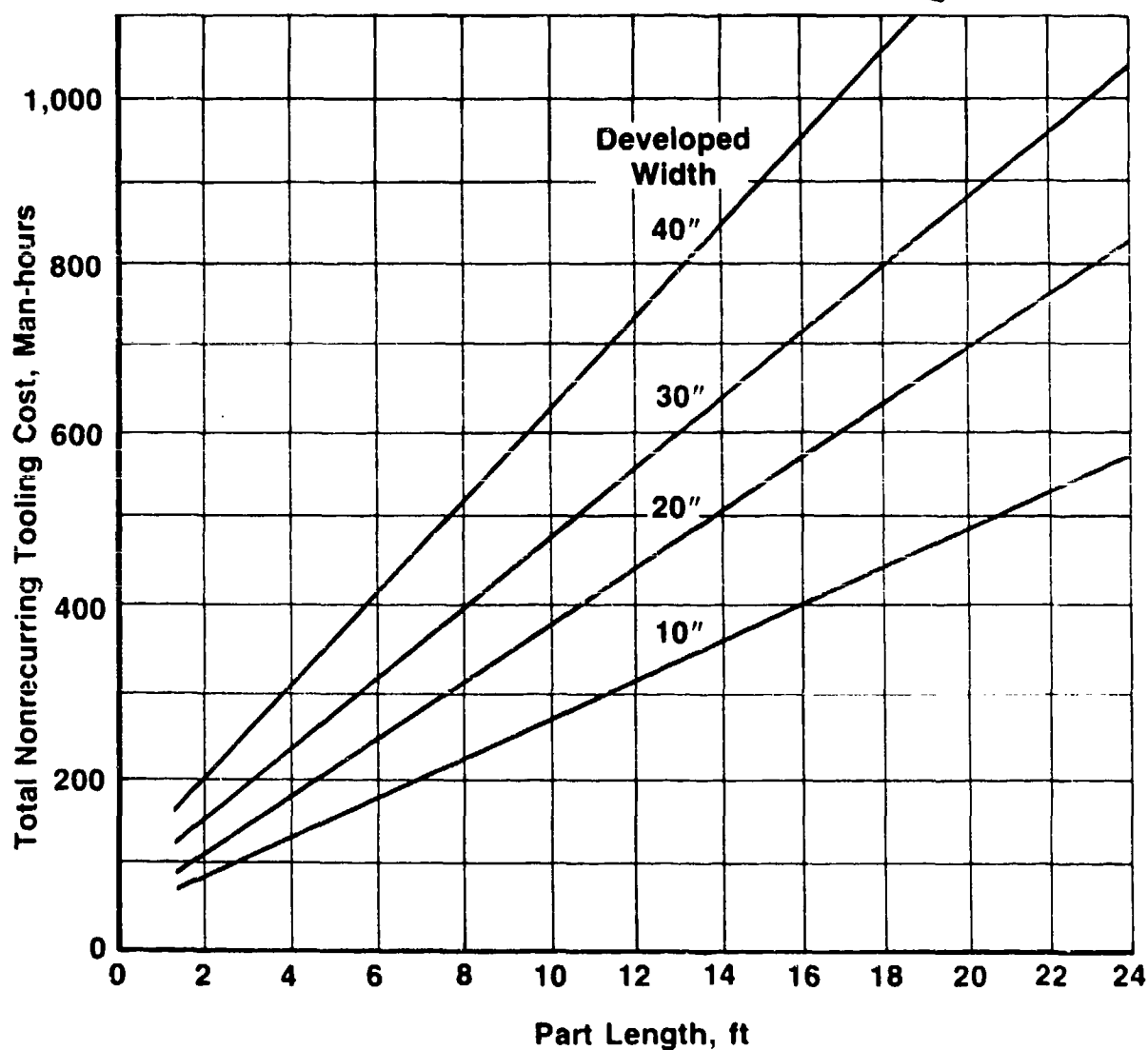
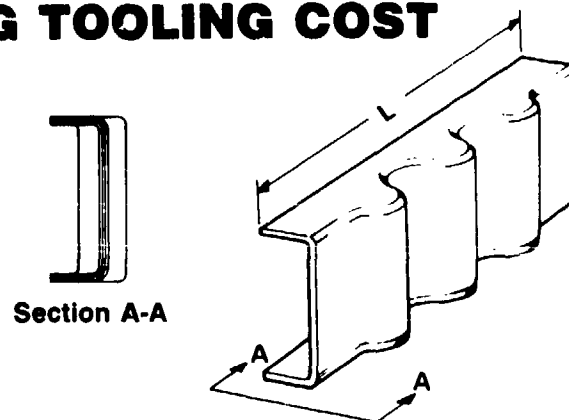
Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

See ground rules for limitations and considerations.

COMPOSITE SINE-WAVE SECTION WITH TWO FLANGES; TOTAL NONRECURRING TOOLING COST

Influenced by {

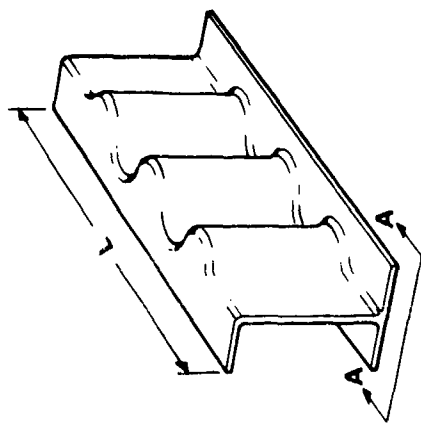
- Part Length
- Developed Width



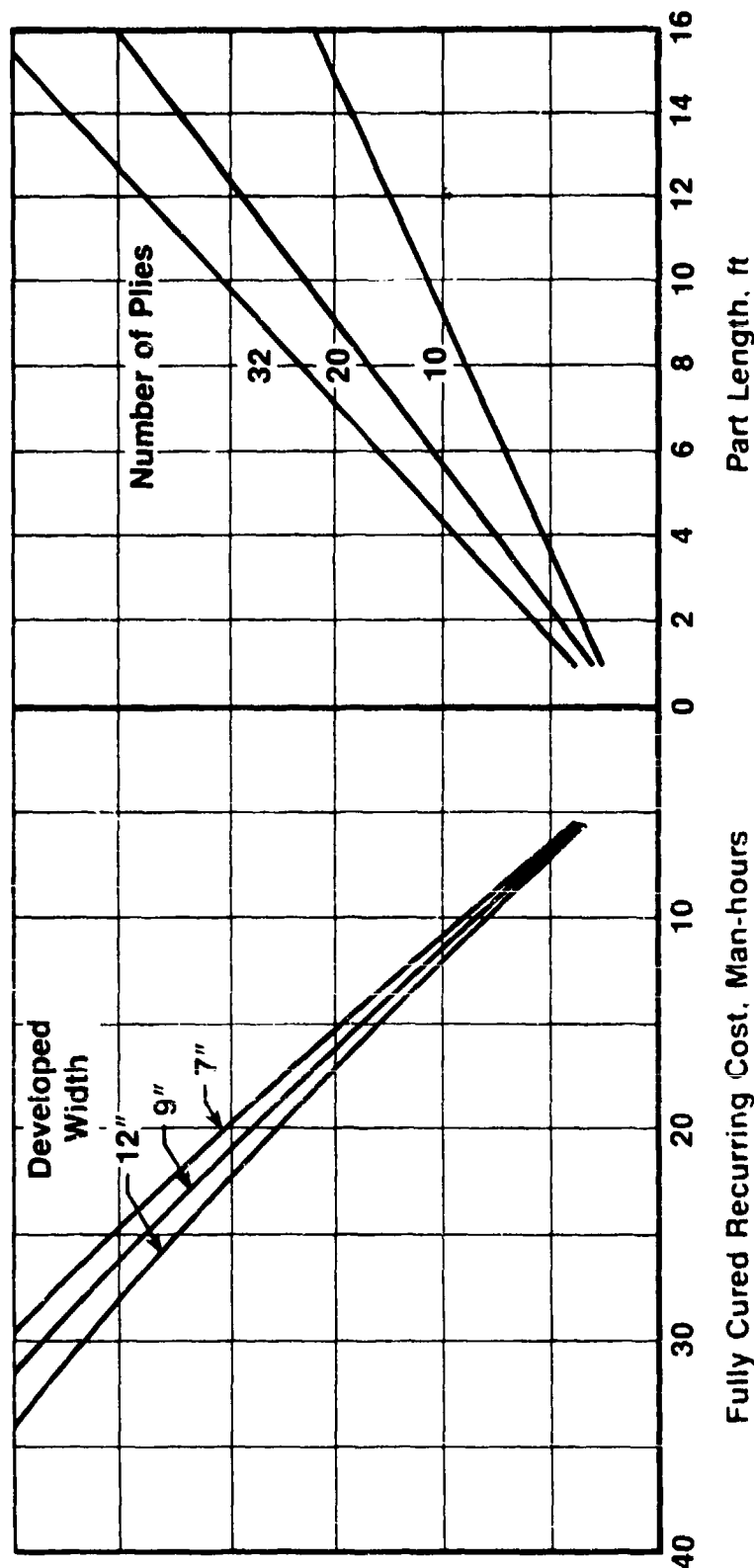
See ground rules for limitations and considerations.

COMPOSITE SINE-WAVE WEB WITH UNSYMMETRICAL FLANGES; RECURRING COST/PART

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



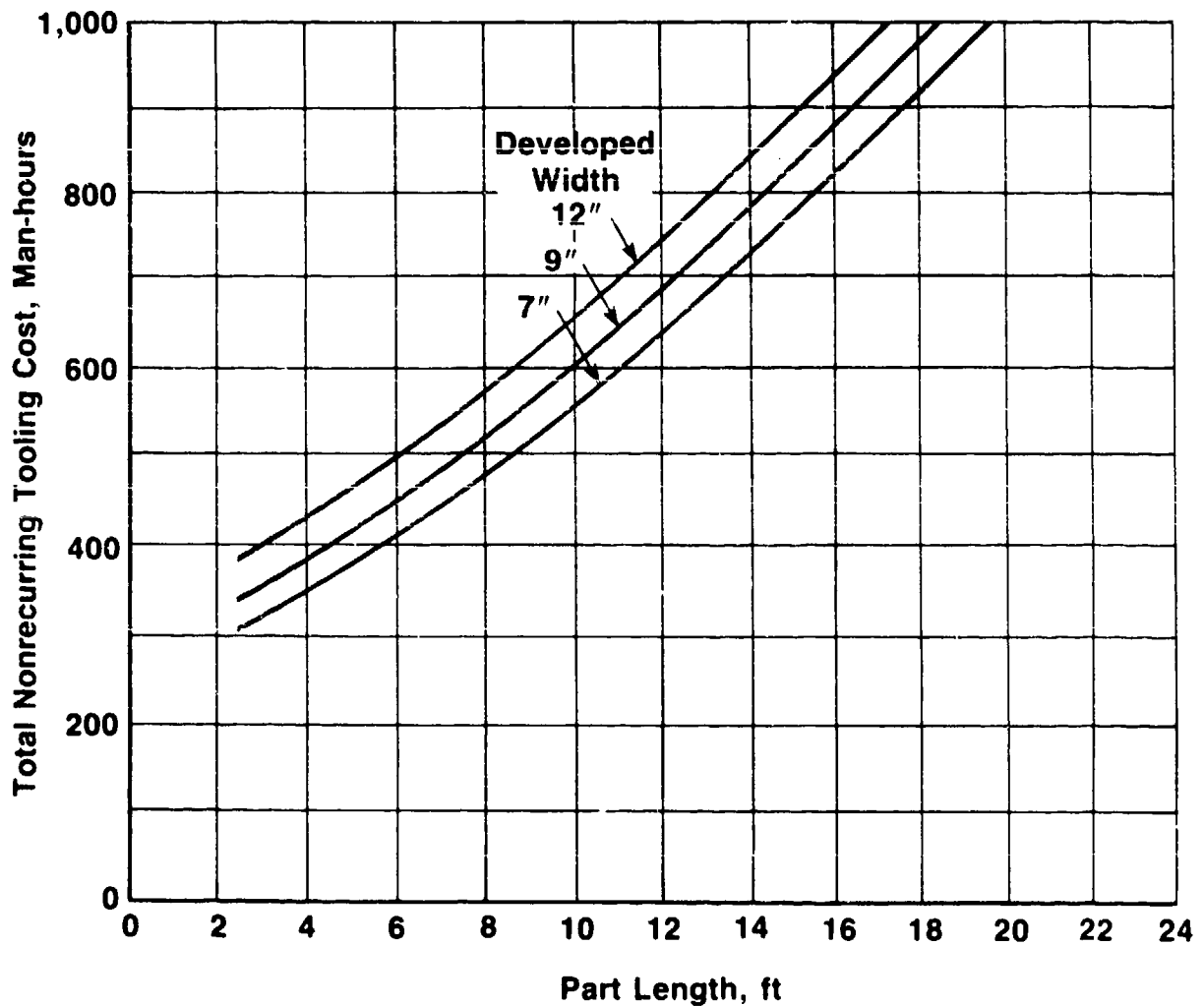
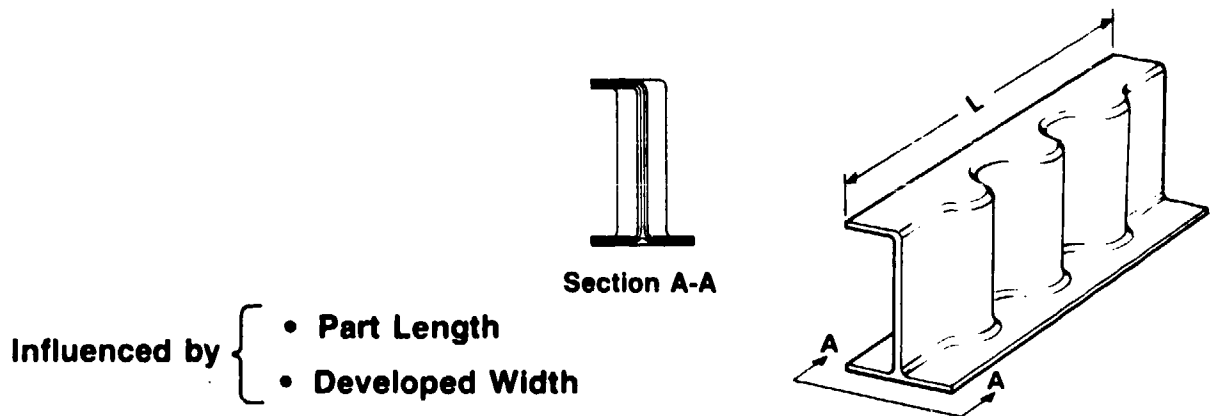
Section A-A



Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

See ground rules for limitations and considerations.

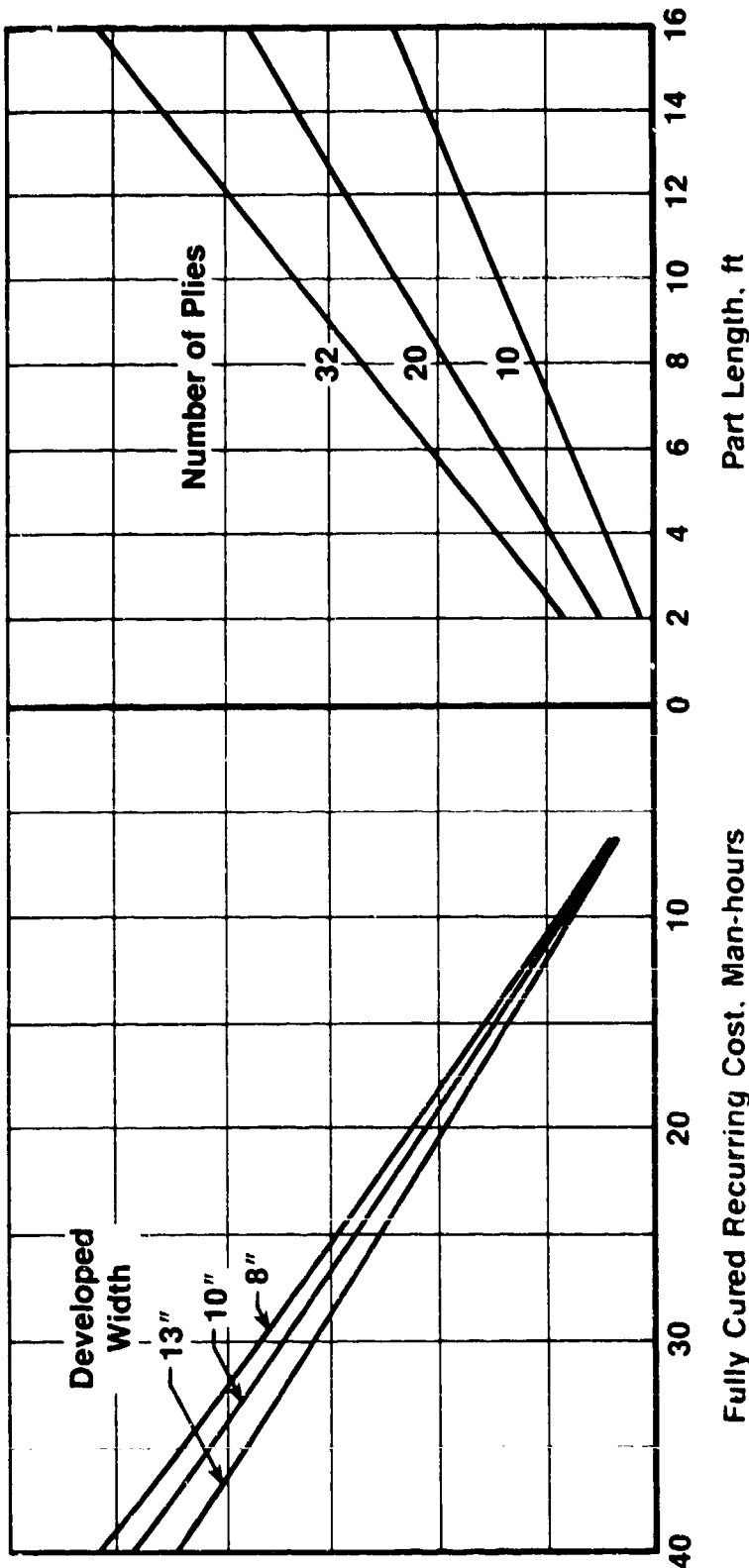
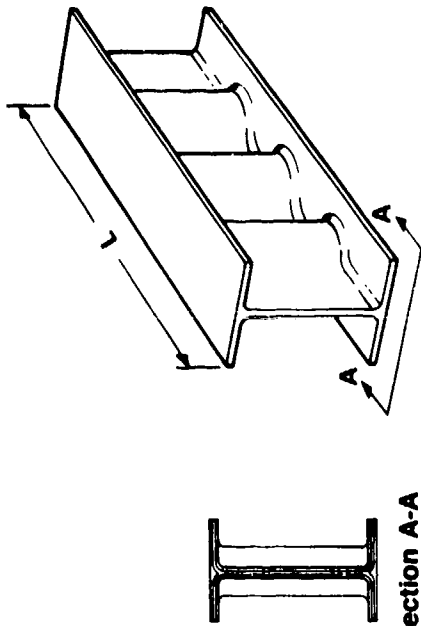
COMPOSITE SINE-WAVE WEB WITH UNSYMMETRICAL FLANGES; TOTAL NONRECURRING TOOLING COST



See ground rules for limitations and considerations.

COMPOSITE "I" SECTION WITH SINE-WAVE WEB; RECURRING COST/PART

- Influenced by {
- Part Length
 - Number of Plies
 - Developed Flat Pattern Width
 - Cure Stage



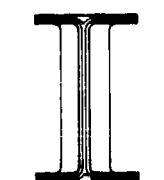
Fully Cured Recurring Cost, Man-hours
(For "B" Stage Recurring Cost, Multiply by 0.84)

See ground rules for limitations and considerations.

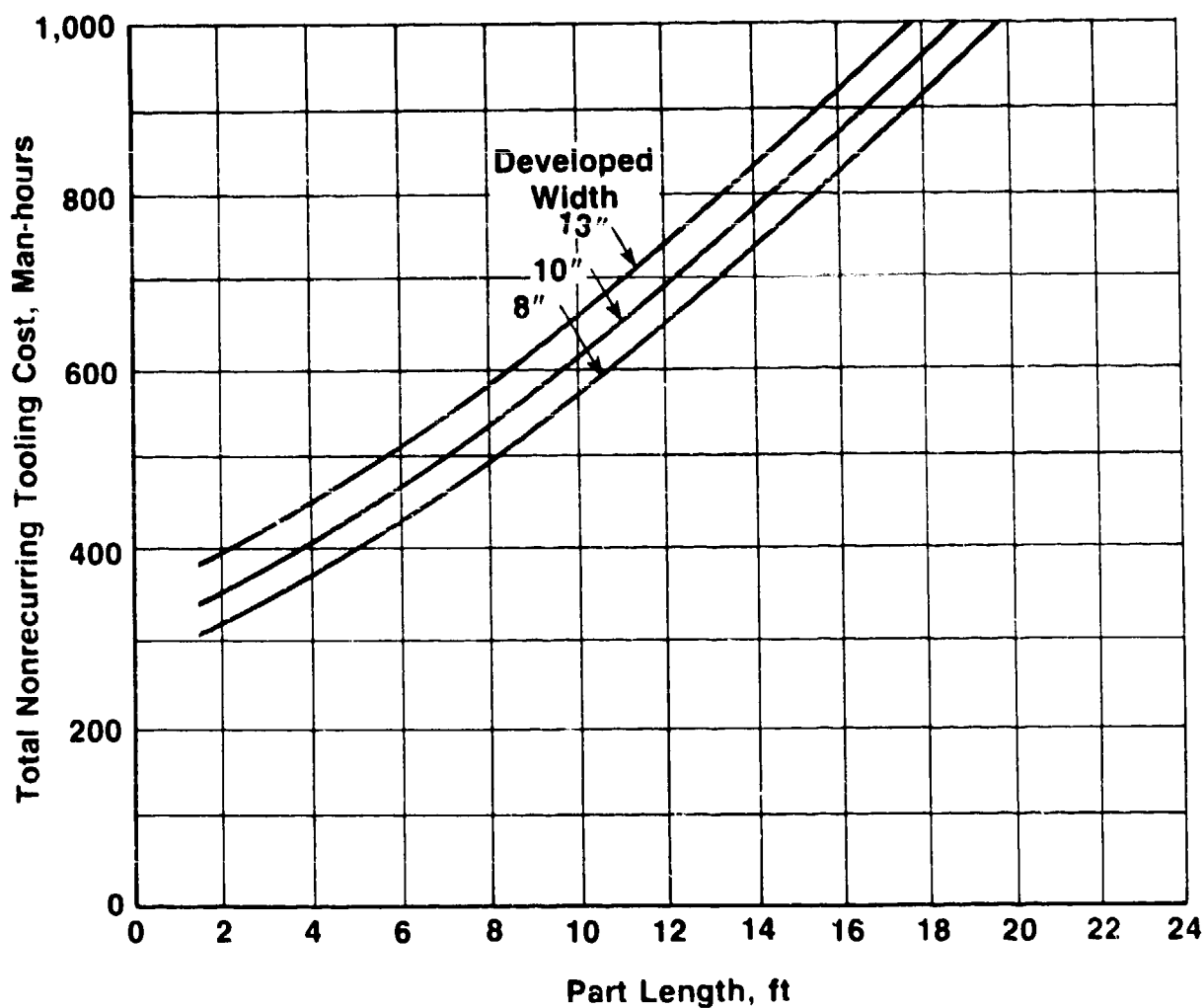
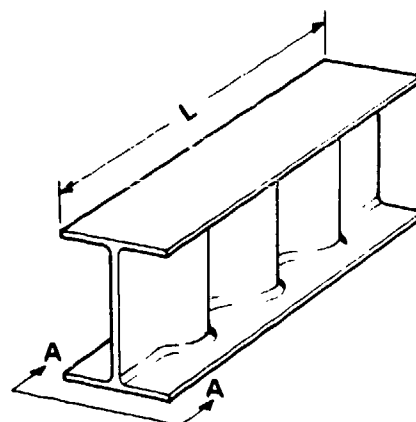
COMPOSITE "I" SECTION WITH SINE-WAVE WEB; TOTAL NONRECURRING TOOLING COST

Influenced by {

- Part Length
- Developed Width

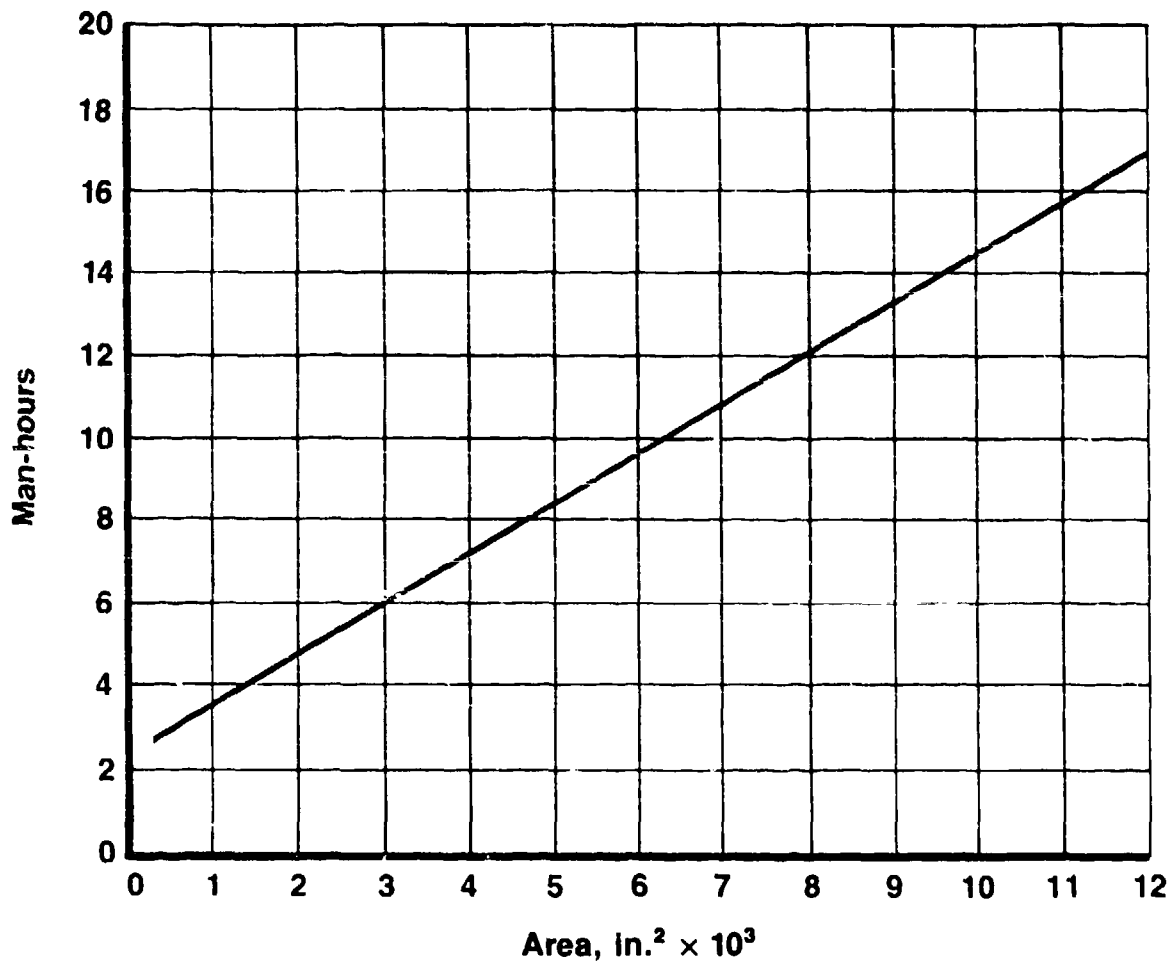
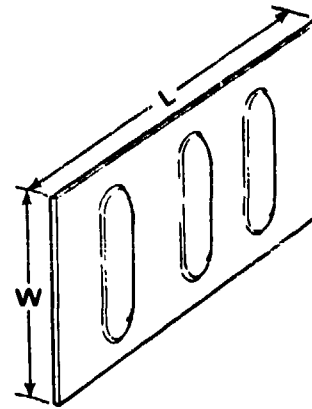


Section A-A



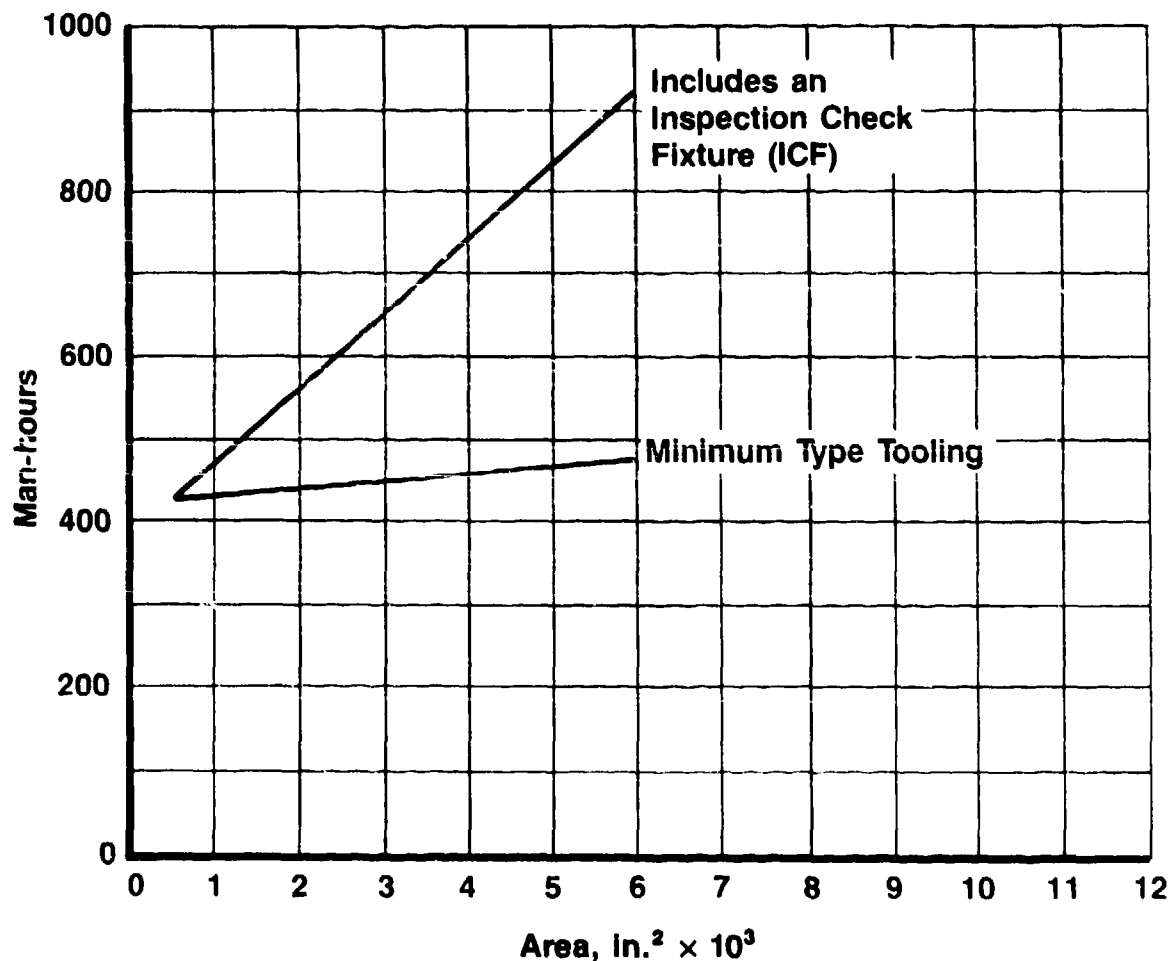
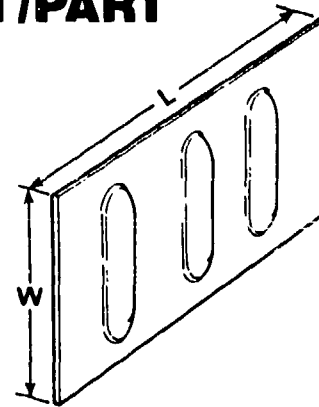
See ground rules for limitations and considerations.

**TEST, INSPECTION AND EVALUATION (TI&E)
COMPOSITE FLAT BEADED PANEL OR WEB
WOVEN MATERIAL;
RECURRING COST/PART**



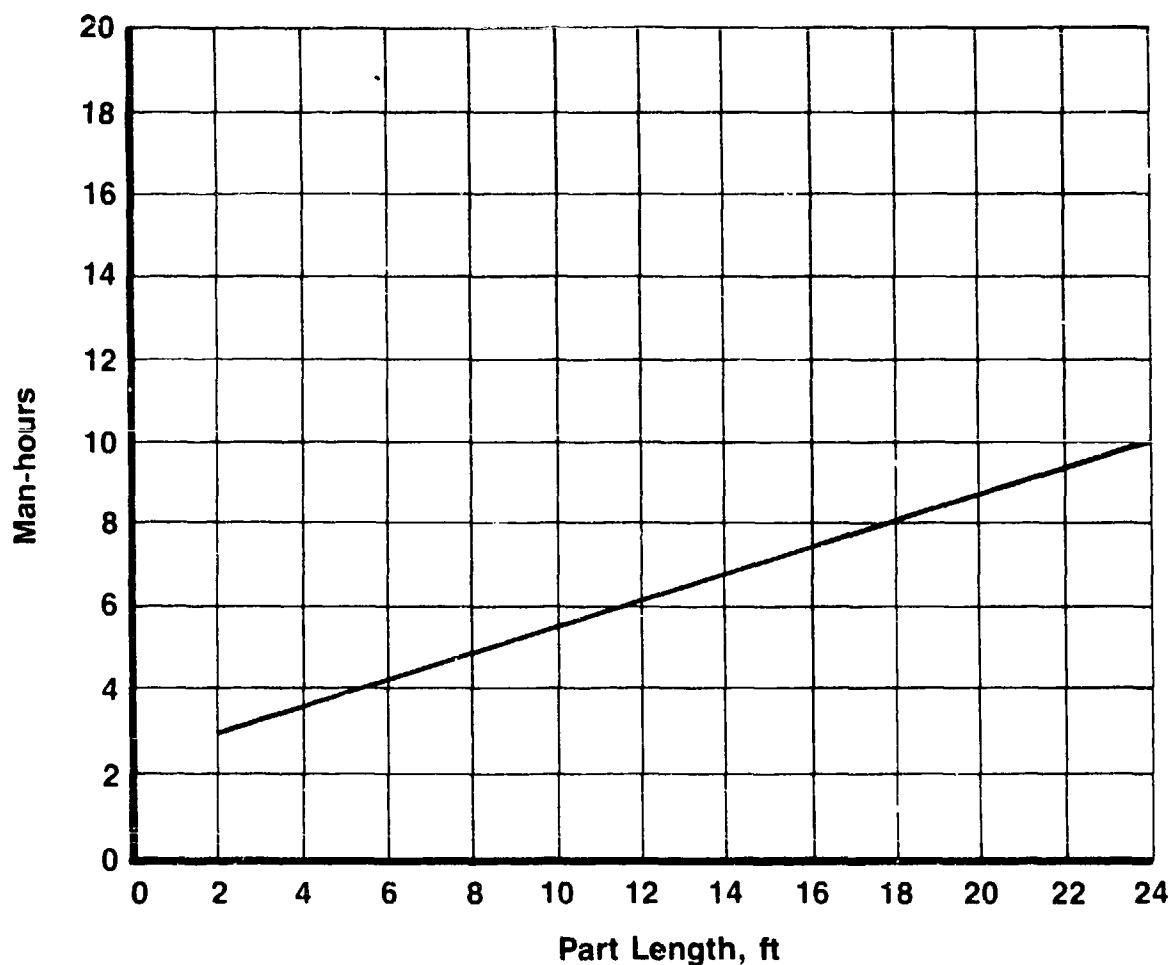
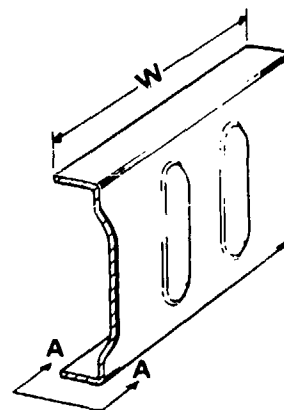
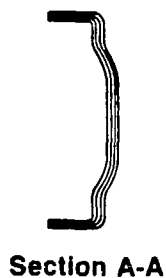
- Applies to laminates up to 24 plies.
- See ground rules for limitations and considerations.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE FLAT BEADED PANEL OR WEB; NONRECURRING TOOLING COST/PART



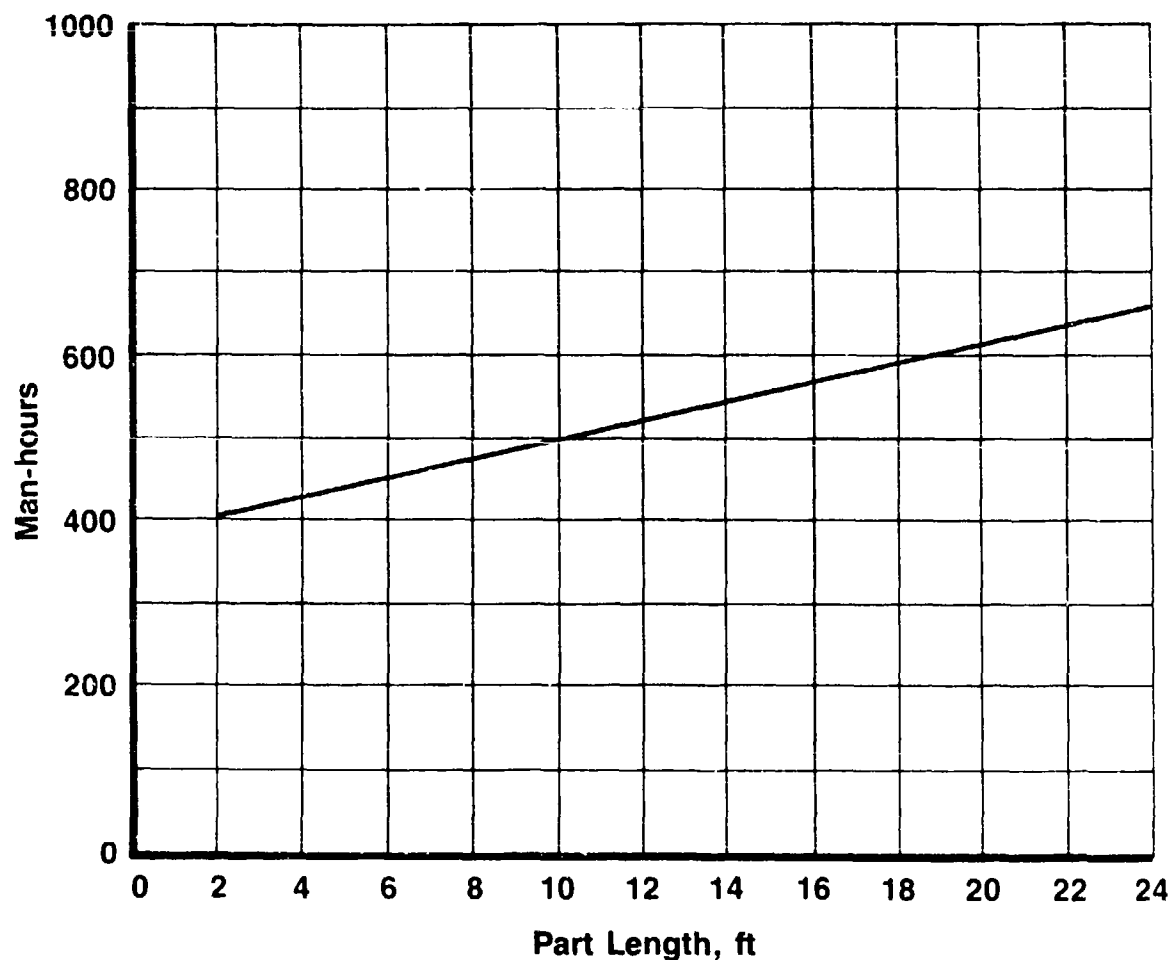
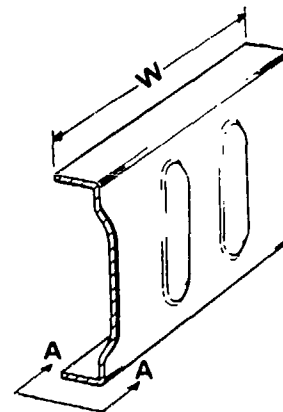
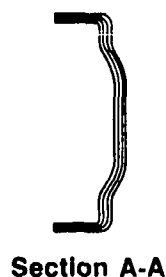
- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- See ground rules for limitations and considerations.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE CHANNEL SECTION WITH BEADED WEB; RECURRING COST/PART



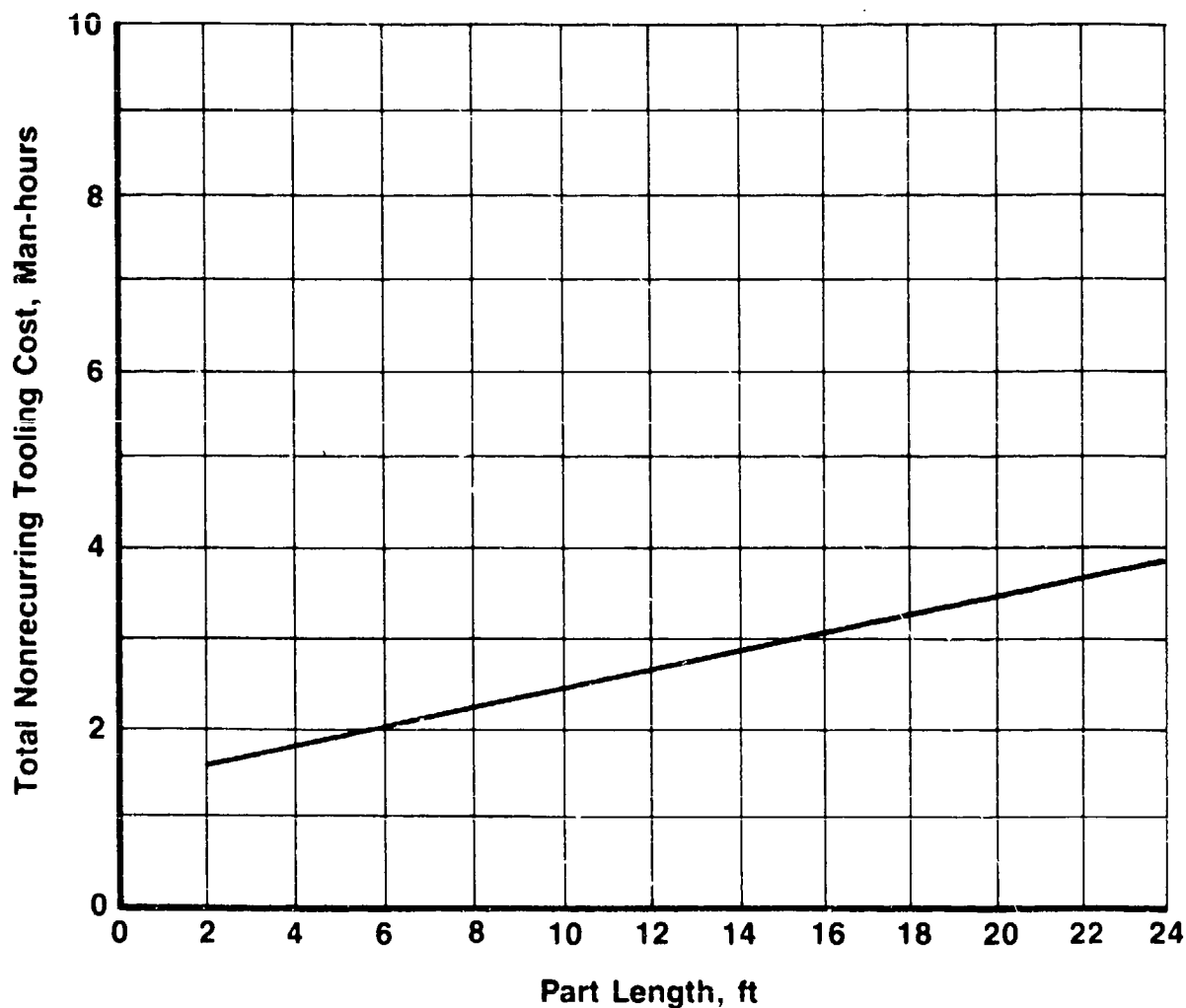
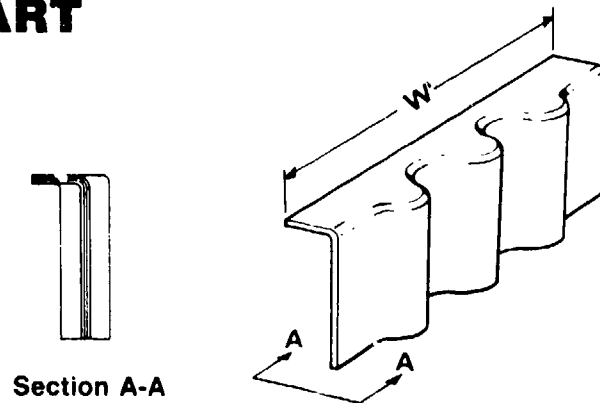
- Applies to laminates up to 32 plies.
- See ground rules for limitations and considerations.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE CHANNEL SECTION WITH BEADED WEB; NONRECURRING COST/PART



- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- See ground rules for limitations and considerations.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE SINE-WAVE SECTION WITH ONE FLANGE ONLY; RECURRING COST/PART



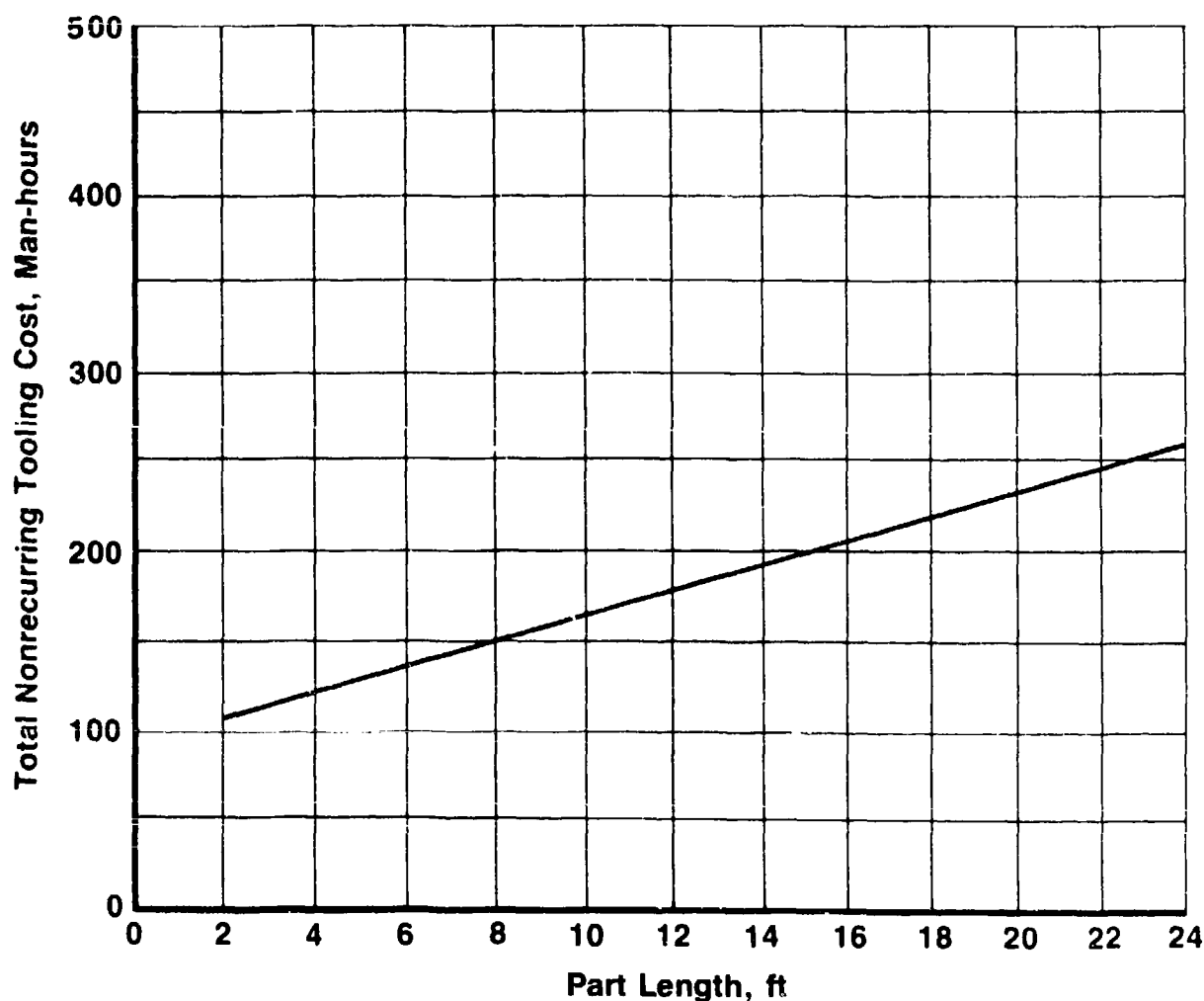
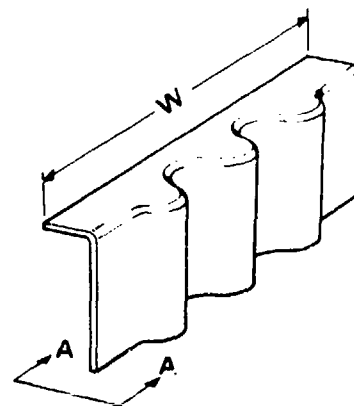
- Applies to laminates up to 32 plies
- See ground rules for limitations and considerations.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE SINE-WAVE SECTION WITH ONE FLANGE ONLY; NONRECURRING COST/PART

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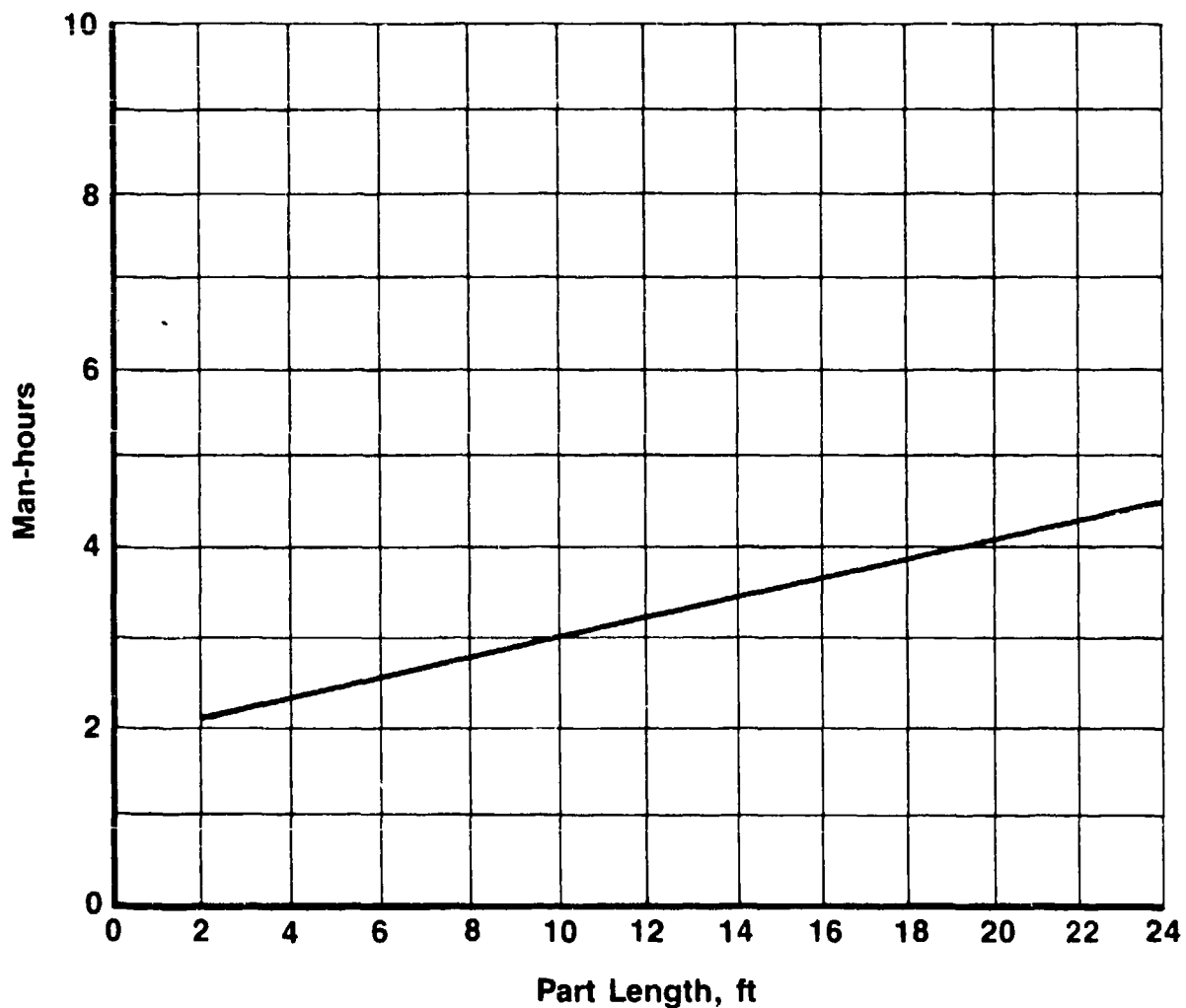
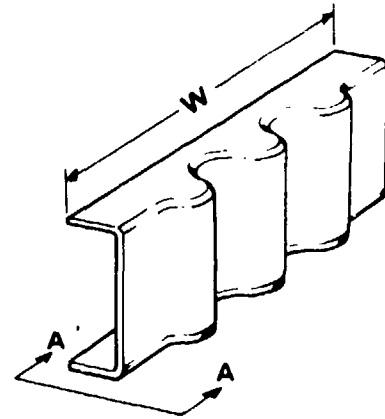
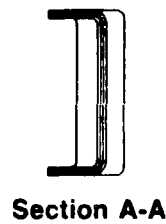
- Part Length
- Developed Width

Section A-A



- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE SINE-WAVE SECTION WITH TWO FLANGES; RECURRING COST/PART

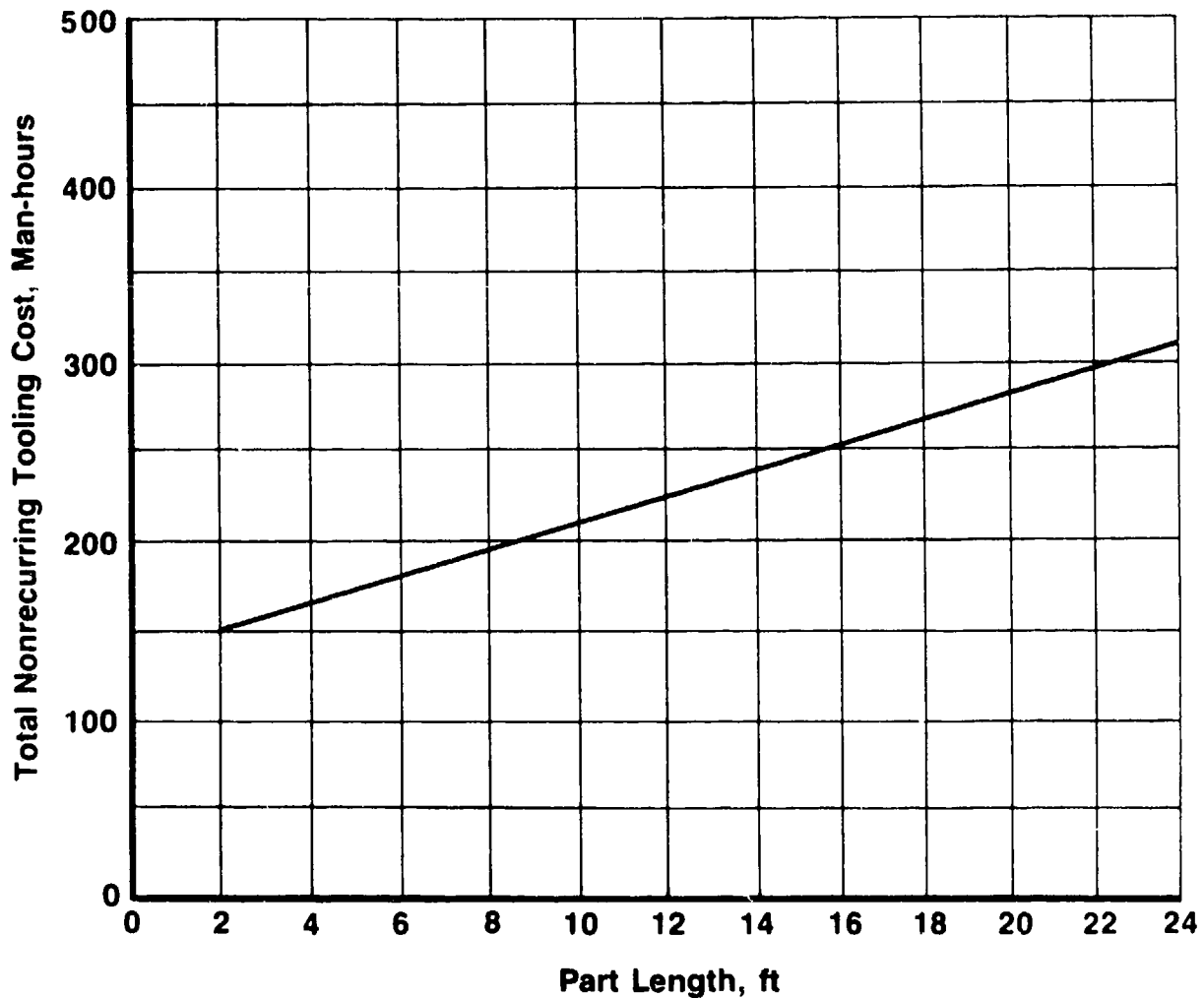
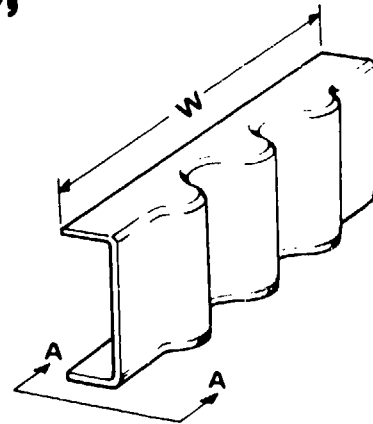
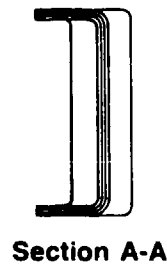


- Applies to laminates up to 32 plies
- See ground rules for limitations and considerations.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE SINE-WAVE SECTION WITH TWO FLANGES; NONRECURRING COST/PART

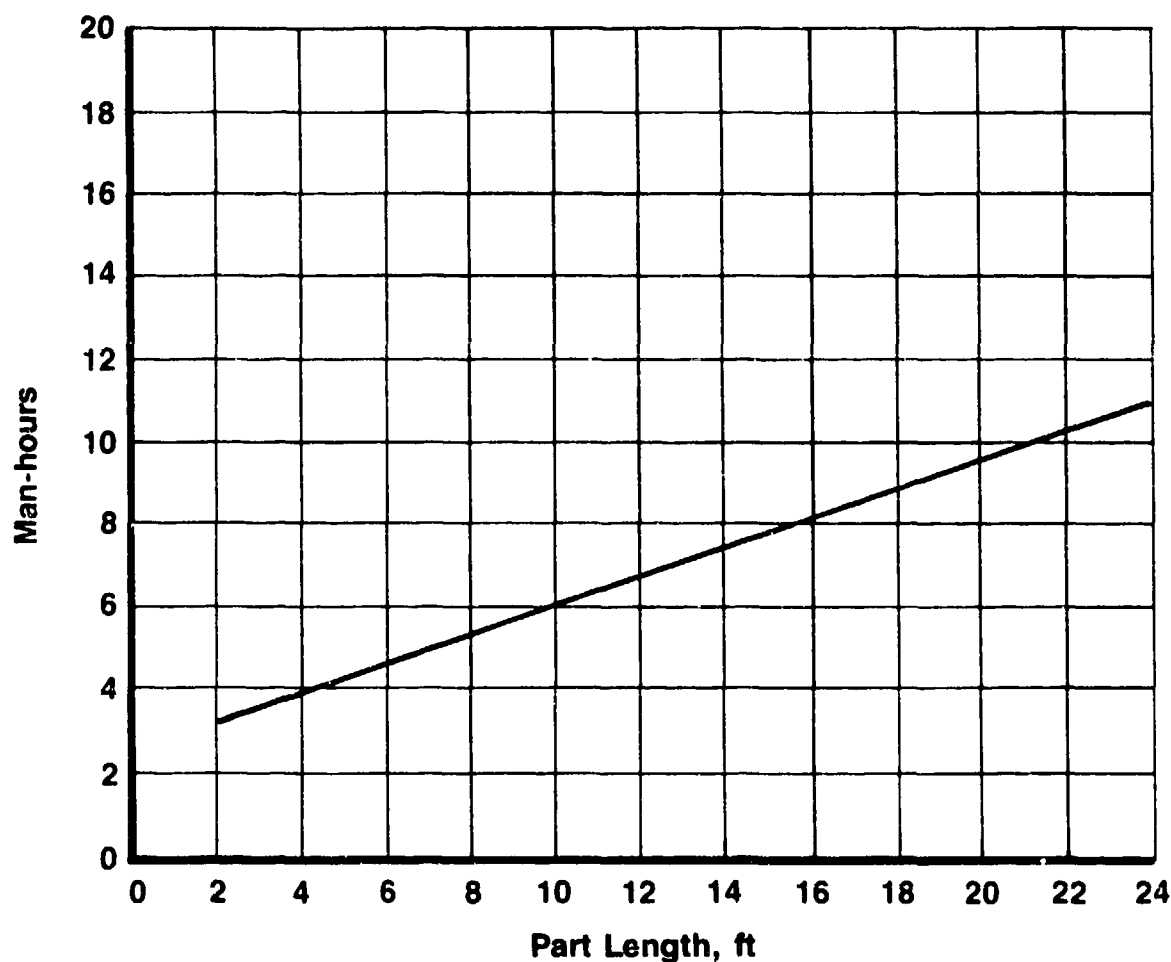
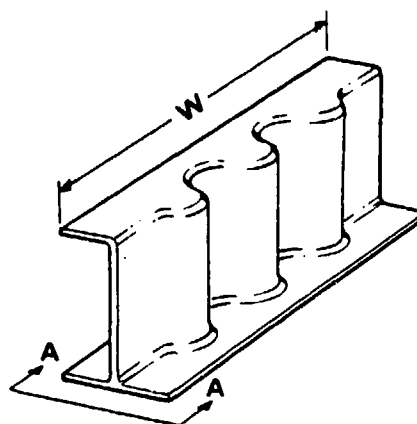
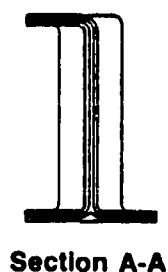
Influenced by {

- Part Length
- Developed Width



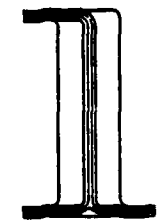
- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE "U" SECTION SINE-WAVE WEB; RECURRING COST/PART

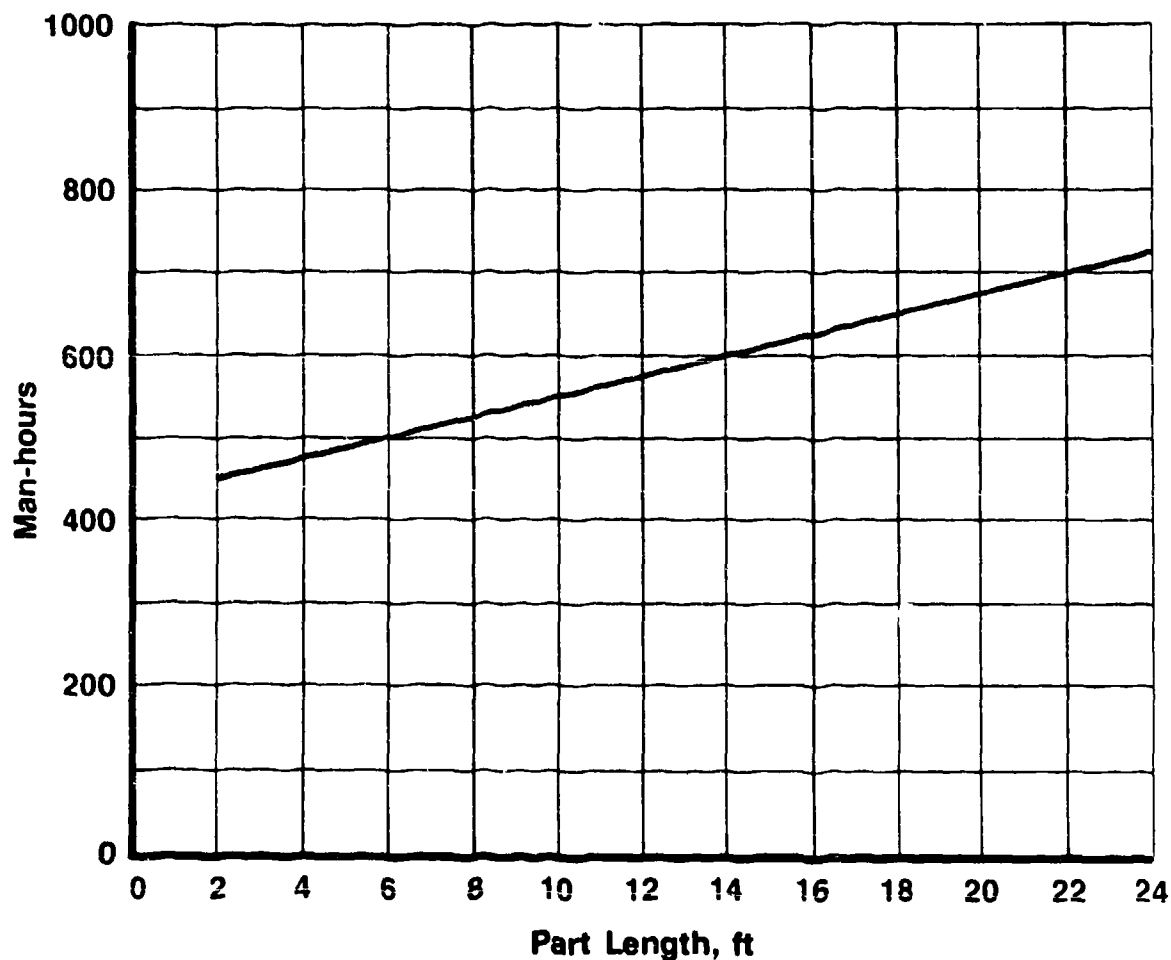
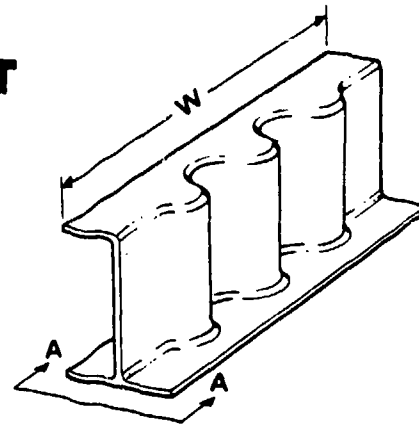


- Applies to laminates up to 32 plies.
- See ground rules for limitations and considerations.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE "U" SECTION SINE-WAVE WEB; NONRECURRING COST/PART

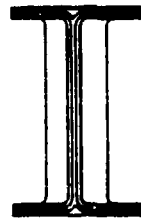


Section A-A

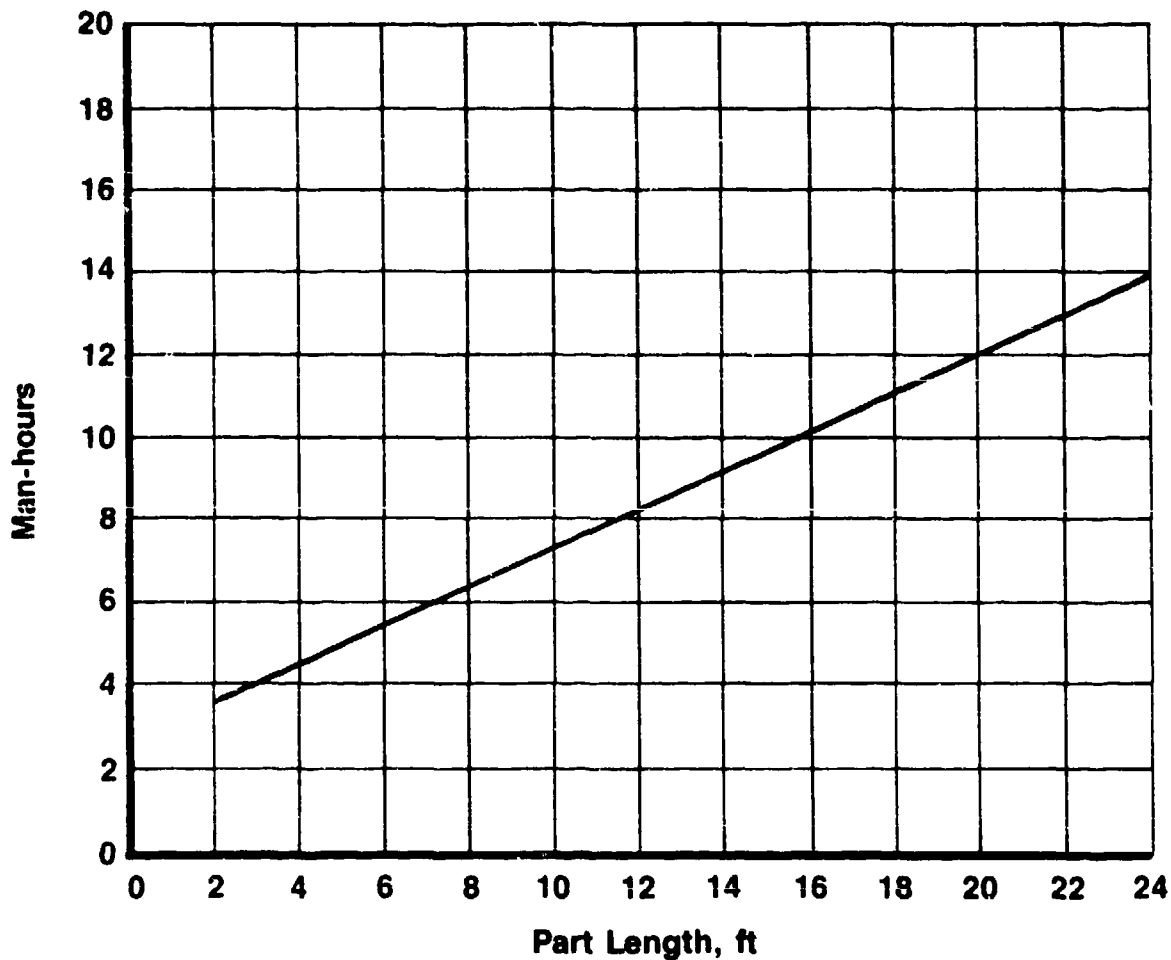
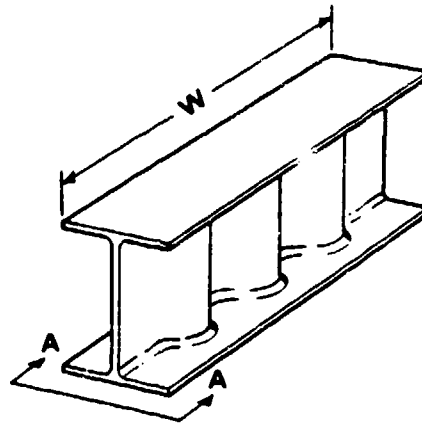


- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- See ground rules for limitations and considerations.

TEST, INSPECTION AND EVALUATION (TI&E) COMPOSITE "I" SECTION SINE-WAVE WEB; RECURRING COST/PART

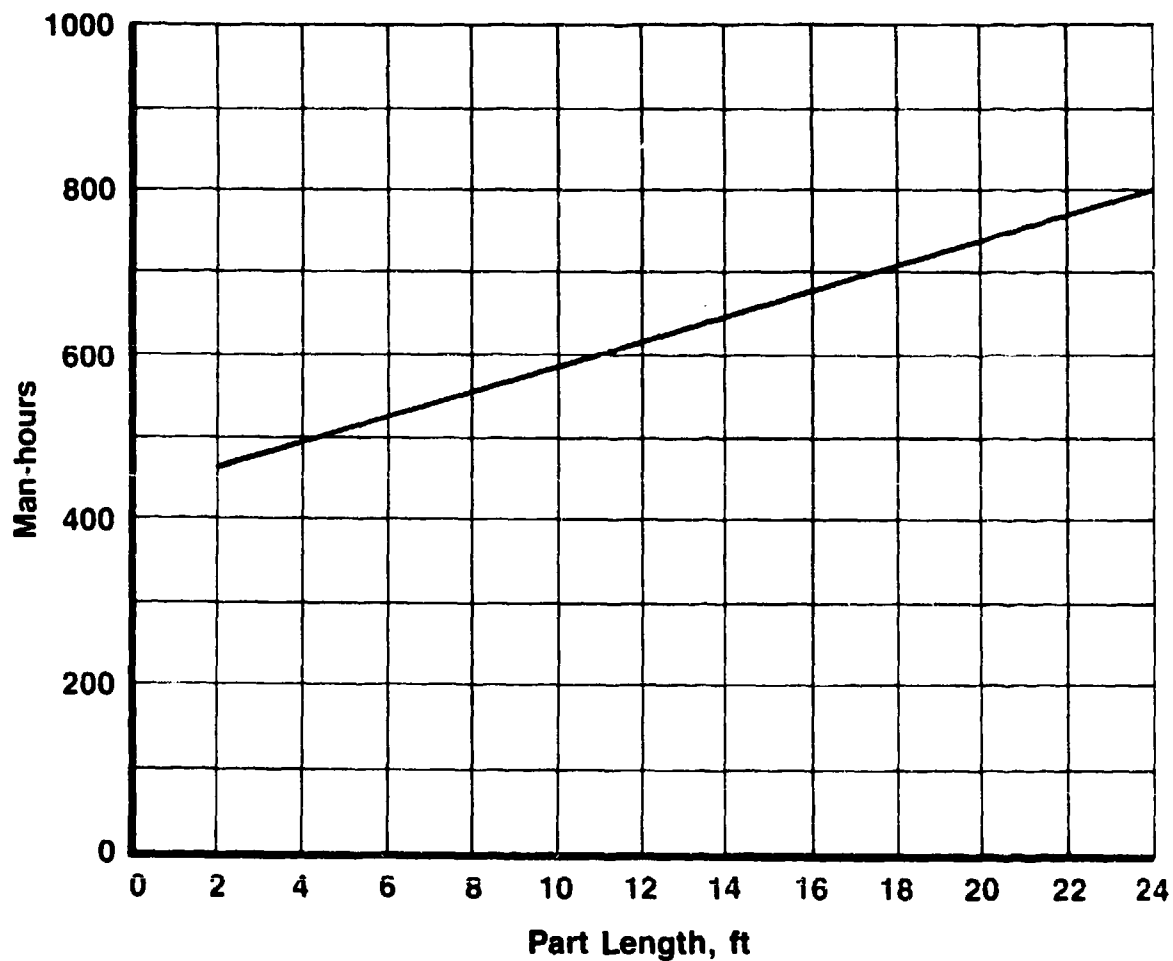
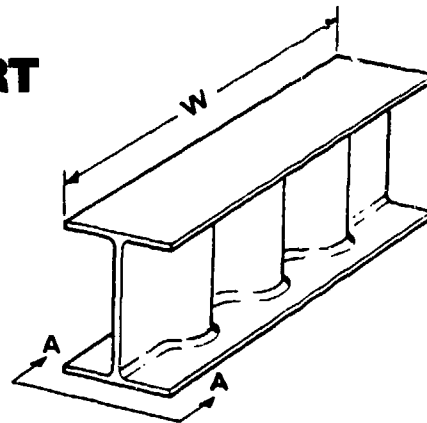
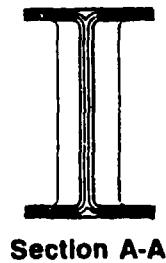


Section A-A



- Applies to laminates up to 32 plies.
- See ground rules for limitations and considerations.

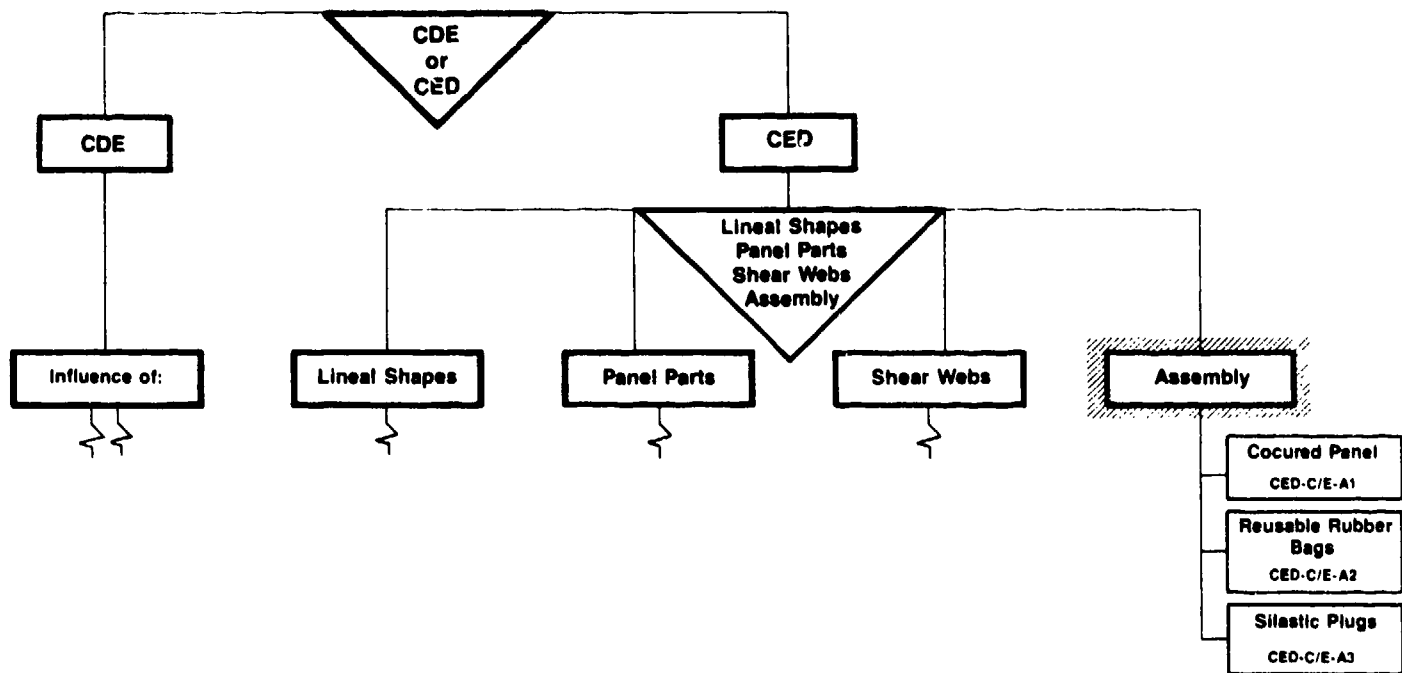
**TEST, INSPECTION AND EVALUATION (TI&E)
COMPOSITE "I" SECTION
SINE-WAVE WEB;
NONRECURRING COST/PART**



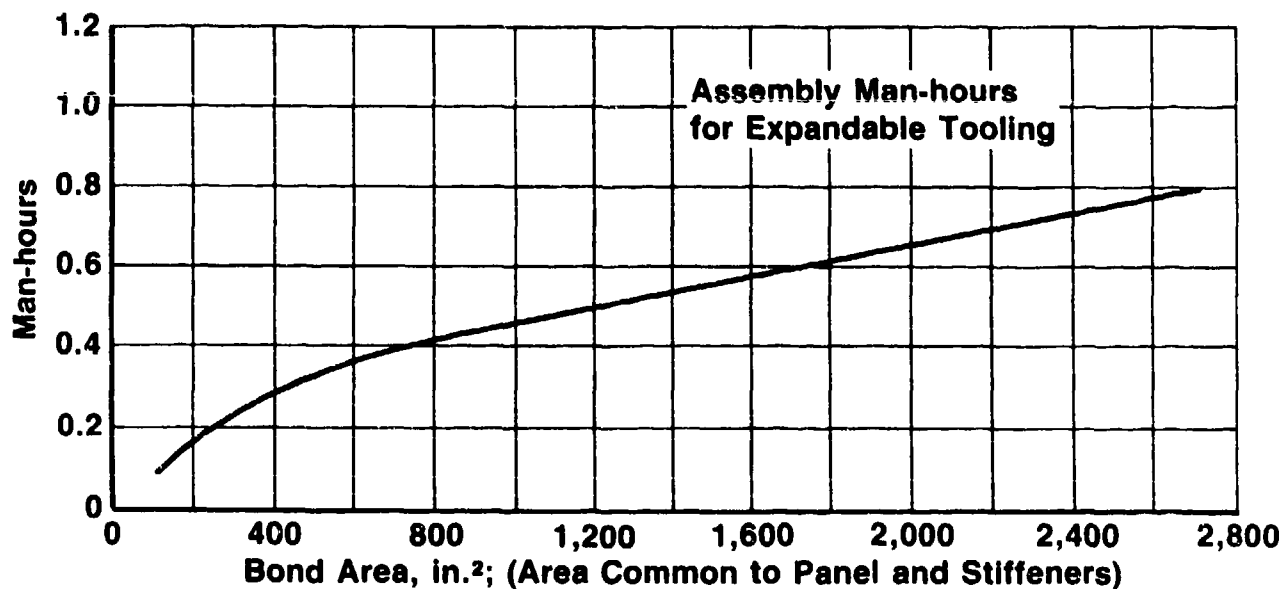
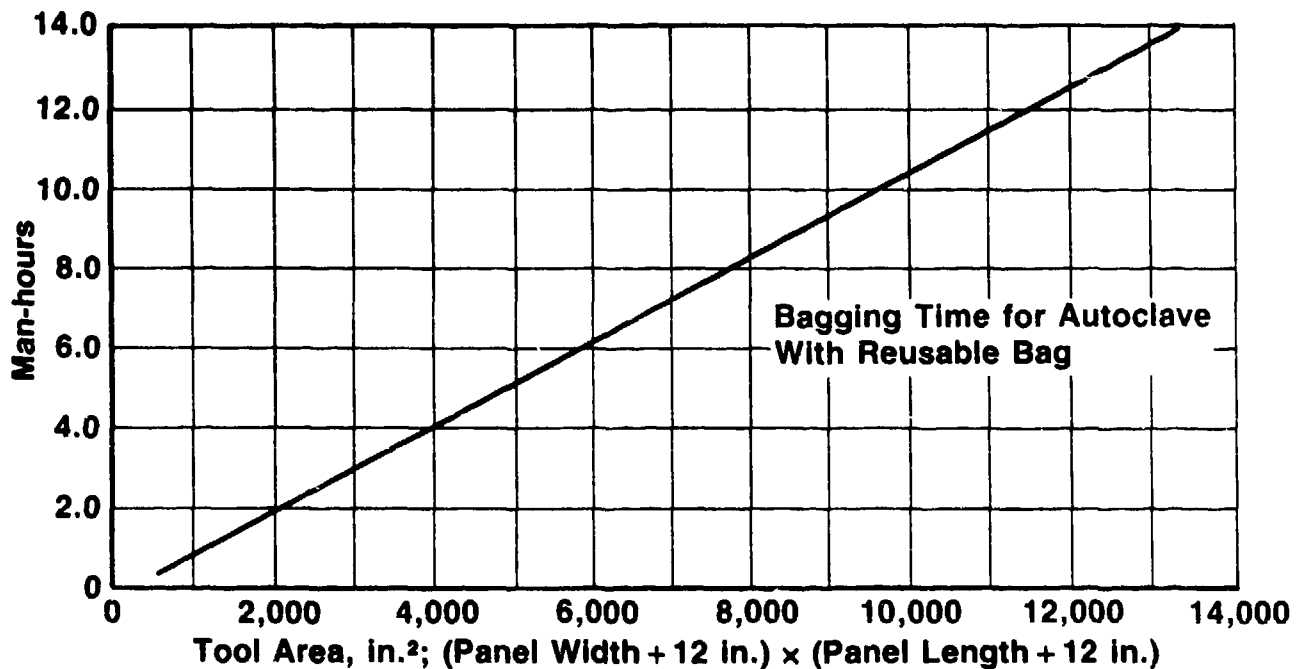
- Includes tooling, first article acceptance, ultrasonic reference standard (URS), and tool proof.
- See ground rules for limitations and considerations.

FORMAT SELECTION AID

Advanced Composite Fabrication



ASSEMBLY MAN-HOURS FOR COCURED PANEL

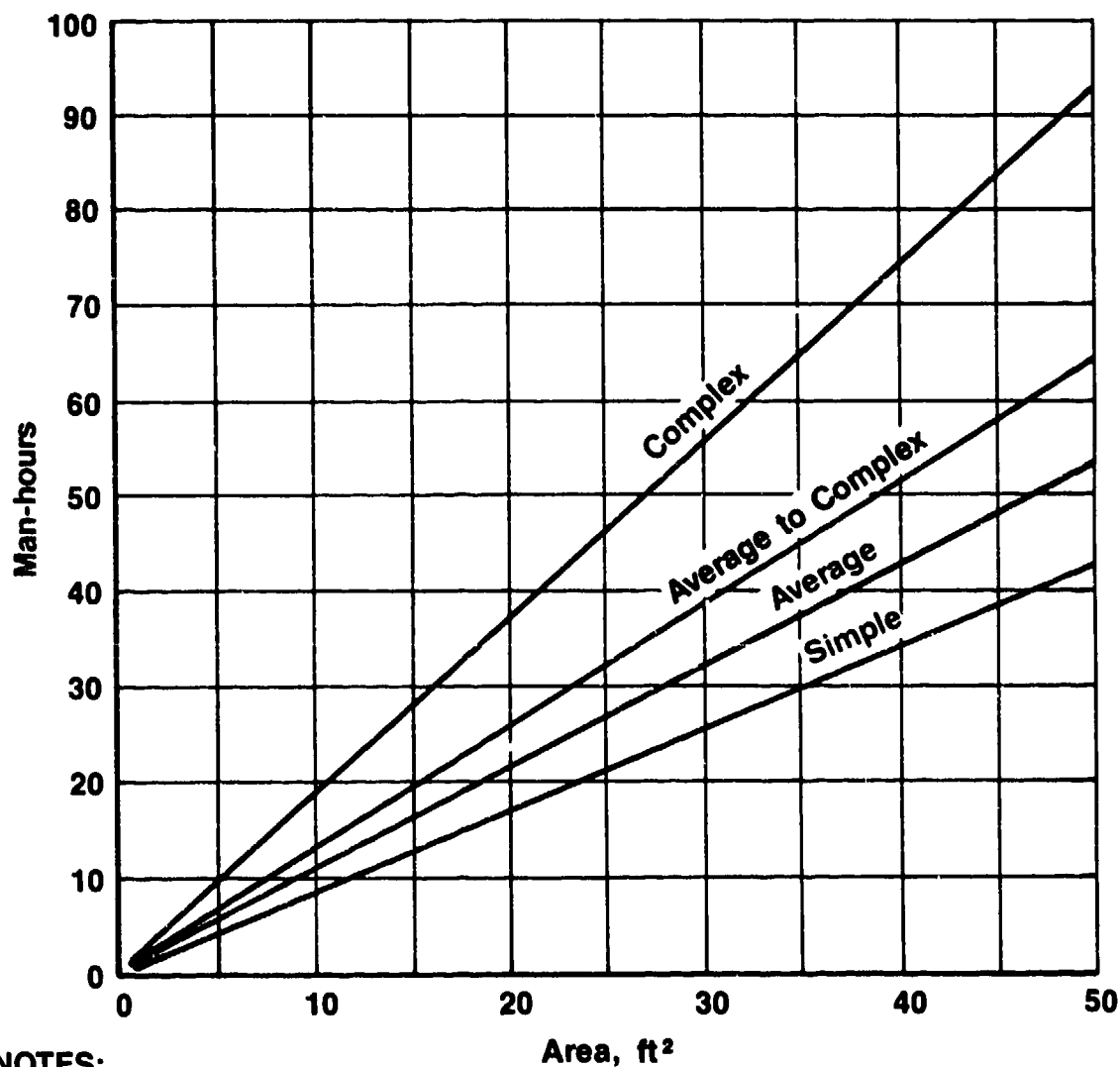


Notes: (1) To determine recurring cost of assembly and bond of fully cured skin and stiffener details, use both CED-G/E-10 and CED-G/E-9 formats.

(2) Tool made for panel (CED-G/E-8) also used for these operations.

CED-C/E-A1

REUSABLE RUBBER BAGS; NONRECURRING TOOLING COST



NOTES:

Simple—flat, low contour

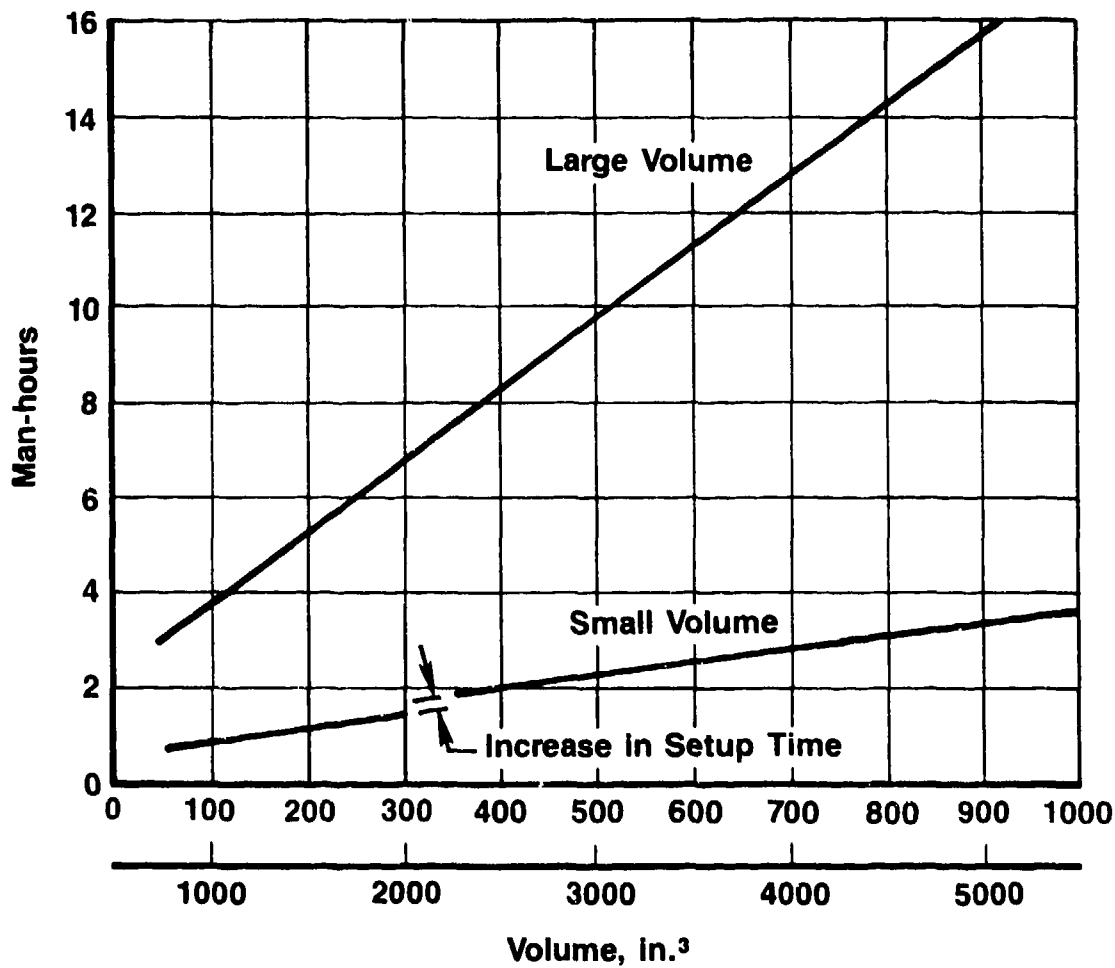
Average—low contour, edge buildup

Average to Complex—deep contours and flanges

Complex—compound contours, reverse internal bends, sharp radii.

Multiply values by 4 for 200 parts.

SILASTIC PLUGS; NONRECURRING TOOLING COST



SECTION 6.0 SUPERPLASTIC FORMING

This section contains format selection aids, identification of the types of parts analyzed for data to determine the manufacturing man-hour data, examples of how the data are utilized in airframe design and a set of formats for superplastic forming. Relative and quantitative data for two categories of superplastic forming, i.e. drape and diaphragm, are presented. Definitions of these two categories are:

(a) Drape

A forming process where a blank is placed over a tool and formed to the tool configuration by driving a SPF diaphragm over the blank. Drape forming is an SPF method allowing the blank to draw around the tool with minimum elongation and thinning. The SPF diaphragm is expendable in the drape forming process.

(b) Diaphragm

A forming process where a "superplastic sheet" is placed over a tool and formed to the tool configuration by relatively low gas pressure under superplastic conditions (temperature, strain rate).

Note

As diffusion bonding and superplastic forming/diffusion bonding (SPF/DB) are emerging technologies, it was not possible to develop more than a small number of formats for these technologies. These formats include CDE, CED, and DICE. Furthermore, considerable variation existed in the data developed. The data should therefore be used for design guidance to avoid cost drivers. As SPF and SPF/DB technologies are still in the emerging category, the facilities and tooling used in aerospace plants vary significantly. For these reasons, the MC/DG user is recommended to verify that the data and trends are representative of the equipment and practices in his or her plant.

6.1 Format Selection Aids

Format selection aids are presented to provide the user with a building-block approach to determine manufacturing cost data for alternative designs or processes. The designer can review the format selection trees and identify those areas that have an impact on his design. The formats provide CDE for qualitative guidance to lowest cost and CED in man-hours for conducting trade-off studies.

MC/DG FORMAT SELECTION AID FOR SPF & SPF/DB FABRICATION

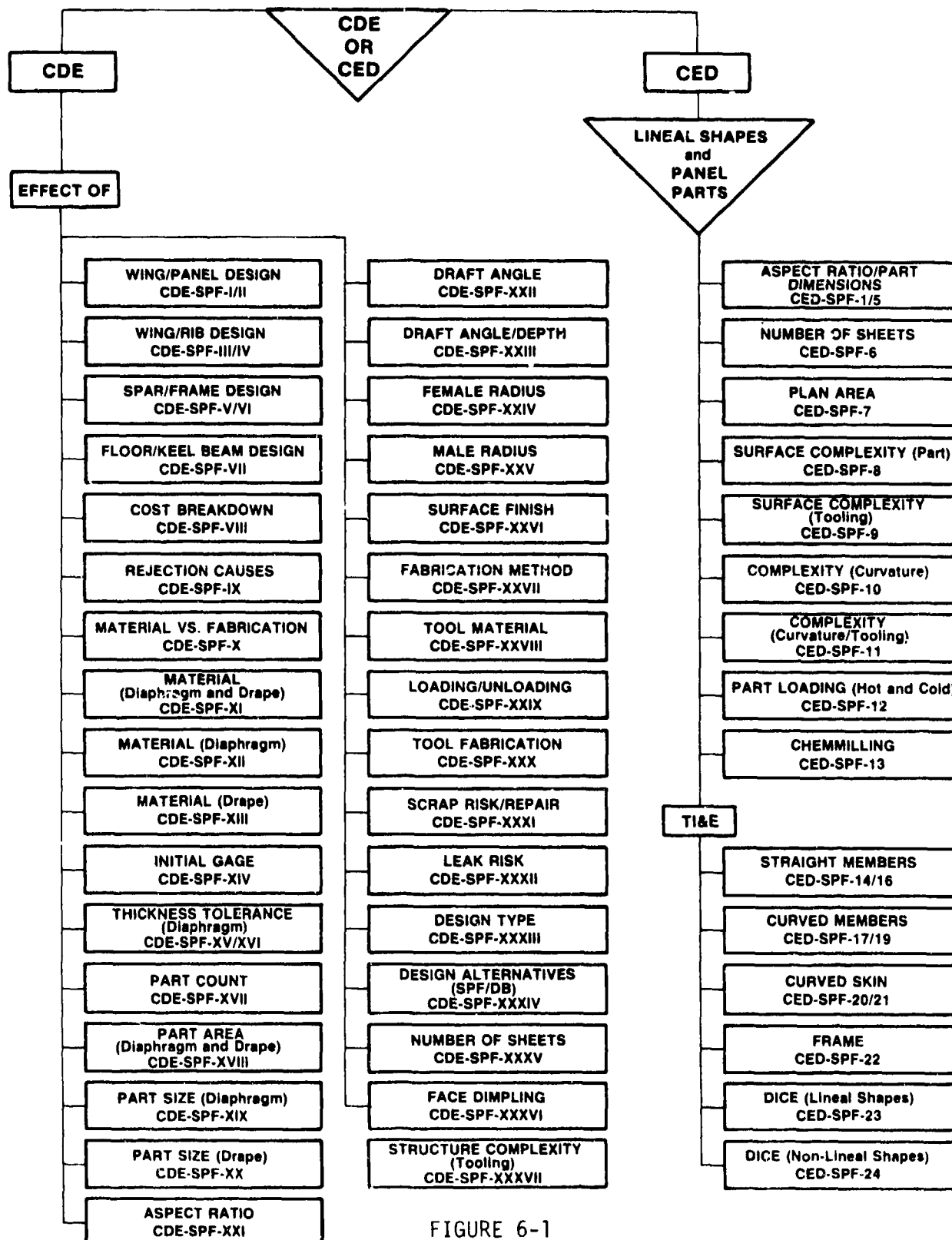


FIGURE 6-1

6.2 Example of Utilization

This example demonstrates to the designer how the data for superplastic forming is utilized on a specific design problem. The example shows how to identify applicable formats, how to extract data from the formats, and provides a discussion on how the data are used to determine the part cost in man-hours or dollars. The MC/DG cost worksheet can be used to record the cost data for easy reference and to determine the total program cost. The MC/DG worksheet appears as Table 4-3.

6.2.1 Problem Statement

The example is a stringer common to aircraft construction such as shown in Figure 6-2. The analysis of other configurations would follow the same steps in the MC/DG.

Procedure

1. Material: SPF and SPF/DB under present state of the art, requires the material to be either Ti 6-4 or Ti 6-2-4-2 sheet.
2. Design Concept: Determine the part requirements and conceptualize a configuration which can be manufactured in a single sheet of titanium. Develop a concept which has the least number of detail parts, i.e. minimize part count. To achieve design guidance, review the CDE formats relative to size, sheet thickness, bend radii, etc., employing as many of the lower cost design parameters as possible.
3. Design: For the purposes of this example, consider a stringer as presented in Figure 6-2. Once the preliminary configuration has been established, the SPF designer must evaluate the details to find the lowest cost method. Some companies will provide manufacturing specialists to aid the designer in going through the following logic.
 - (a) Sheet Gage Tolerance: From the CDE formats, we learned that larger tolerances on sheet thickness yields lower cost. The 0.40-inch callout on Figure 6-2 normally means 0.030-inch to 0.050-inch thickness. It is desirable for SPF designs to give only a minimum gage, e.g. 0.030-inch minimum. After a few more decisions an approximate thickness map of the part can be established and reiterated to the final design. However, it should be noted that due to thickness variance resulting from process or required by design, the final

A DISCRETE PART READY FOR ASSEMBLY

Titanium "Z" Section on U.S.A.F. B-1B

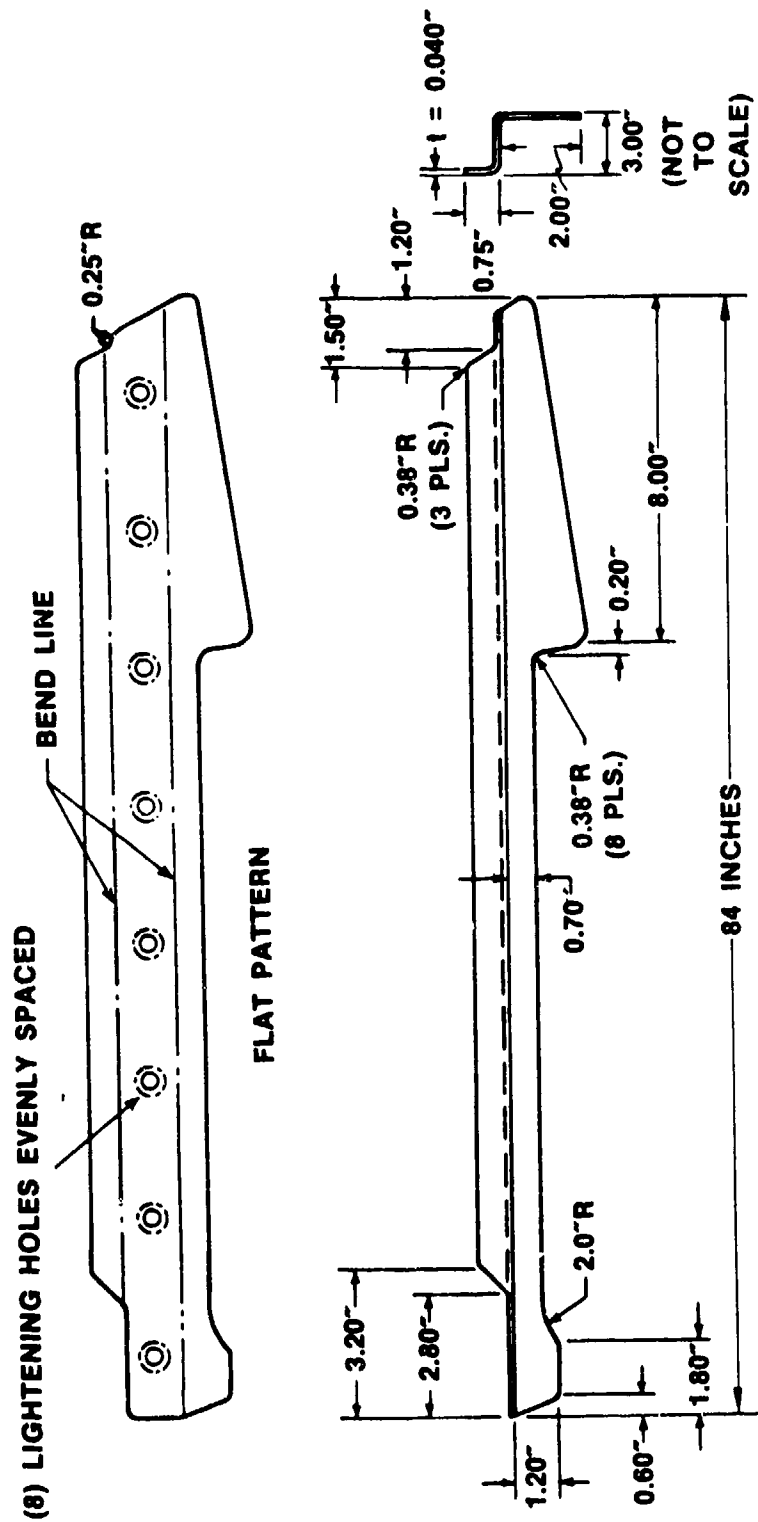


FIGURE 6-2. A DISCRETE PART READY FOR ASSEMBLY

thickness for different areas of the part are reached by selective chem-milling based on actual measurements versus requirements.

- (b) Facility Capability: The preliminary design in Figure 6-2 indicates that the part is 84 inches long. With this information, it is possible to select the sheet size and facility in which the part can be manufactured by superplastic forming. Normally this part length will require an SPF press capable of forming a 3 foot by 8 foot sheet.

If the part had been much longer the available SPF facilities may have been prohibitive. The designer should become aware of the sizes that can be manufactured by SPF and, hence, the facilities available. Some of the CDE formats included in this MC/DG section address this issue.

- (c) Diaphragm or Drap SPF: As the CDE and CED formats suggest, there are two SPF procedures that can be used to make the part. Diaphragm SPF produces variations in the sheet thickness because of the relatively large elongations associated with the deformation. Drap SPF uses a blank which is formed over the tool using a diaphragm driver sheet. The driver sheet is expendable in the drap process. The blank experiences less thinning because it is allowed to draw, much like conventional forming. The decision to diaphragm or drap SPF depends largely upon the thickness tolerance allowed by the designer. Figure 6-2B shows the basic diaphragm and drap concepts.

The major factor in the selection between drap and diaphragm procedures is the complexity of the part. Even a relatively simple part as the one shown on figure 6-6 (the part with integral flange) may require a diaphragm procedure, since the drap procedure can result in material folding at the corners. Stretching ensures smooth corners.

The drap procedure is adequate for forming when flanges are bent without corners and in this case simpler, conventional methods are already available.

Figure 6-2A shows the approximate gages resulting from both diaphragm and drap SPF. Before examining these figures closely, an additional decision is required.

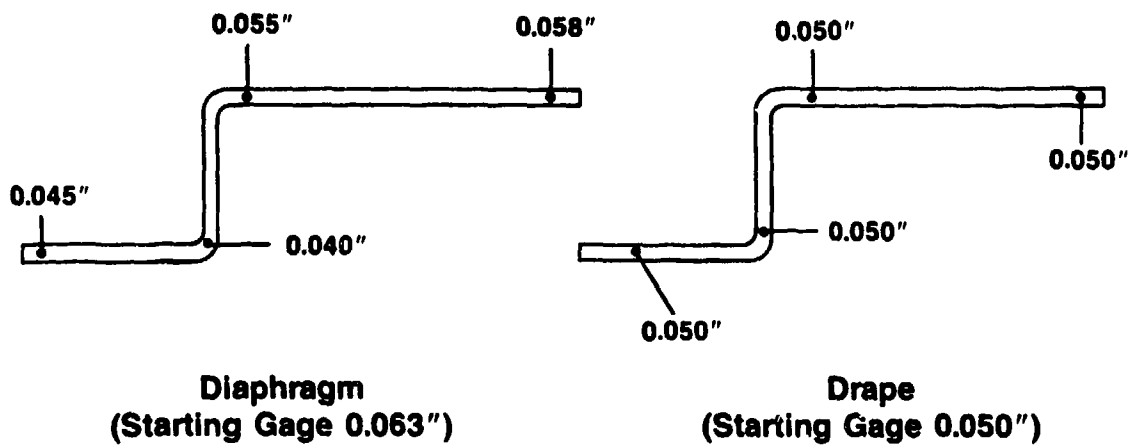


FIGURE 6-2A. APPROXIMATE THICKNESS AFTER SPF

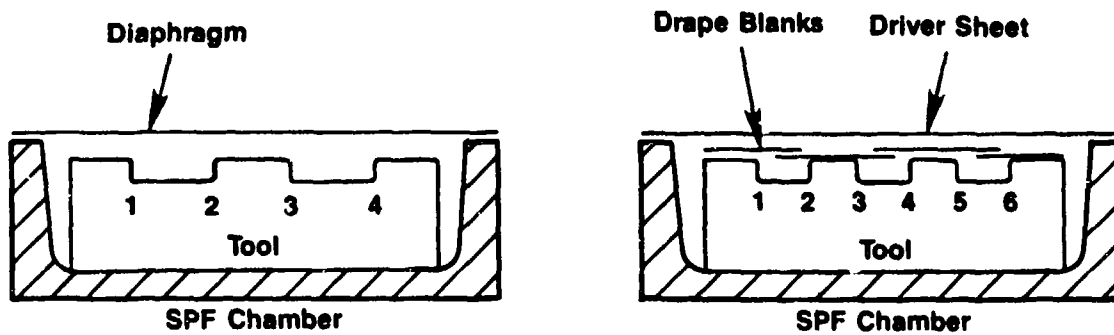


FIGURE 6-2B. TOOLING ARRANGEMENTS

- (d) Tool Nesting: Although in some companies, the designer does not have options to require the method of SPF (drape or diaphragm) or nesting of the tool package, it is, nevertheless, instructive to understand how these features effect the design and cost.

Diaphragm forming must take into account the thinning that occurs. In most cases more parts can be nested in a drape SPF over the diaphragm, because drape SPF has insignificant thinning. Eight of the example parts can be drape formed in one cycle while four would be common practice for diaphragm SPF. Also the drape SPF starting blank would be only slightly above the nominal part thickness to account for alpha case removal. The starting sheet for diaphragm SPF would be over 0.060 inch to meet a 0.030-inch minimum. Usually an even higher gage is selected for diaphragm SPF where thickness can be controlled by chem-milling during alpha case removal.

4. Lowest Cost Design: By observing the guideline presented in the CDE formats, a design can be made not only functional, but with consideration of the least costly manufacturing method. The opportunity exists to evaluate several iterative designs for trade-off studies.

To determine the cost of producing the designed part, it is necessary to refer to the Cost Estimating Data (CED) formats. These formats provide the designer with an approximate value of the man-hours involved to fabricate the part.

- (a) Tooling: As noted on the CED formats there are three options available to select the tooling method. Steel tools are machined to the proper configuration to compensate for the difference between the thermal expansion coefficients of steel and titanium.

The steel tools are machined to the proper configuration compensated by the difference in thermal expansion between the steel and titanium. Such tools will be made approximately 10 inches wide for drape forming and about 15 inches wide for diaphragm SPF and be attached to a base filler plate.

Ceramic tools are made by modeling the tooling package in plaster taking account of the thermal expansion differential between the ceramic and titanium and the shrinkage factor associated with the plaster and ceramic casting processes. The master model would then serve as the mold for the ceramic tool. Usually these tools would be relative thick and dimensioned to fit within the SPF forming chamber as one piece (for the example part).

Both have advantages and disadvantages as shown on the CDE and CED formats. Quantity of parts is the major deciding factor.

- (b) Part Fabrication: The CED formats account for not only the SPF operation but for conventional processing, trimming, chem-milling, and alpha case removal. The man-hour cost factors are approximate and are intended for trade-off studies in the design phase.

6.3 Airframe Parts

To determine the manufacturing man-hours for superplastic forming, the parts such as shown in Figures 6-3 through 6-11 were analyzed.

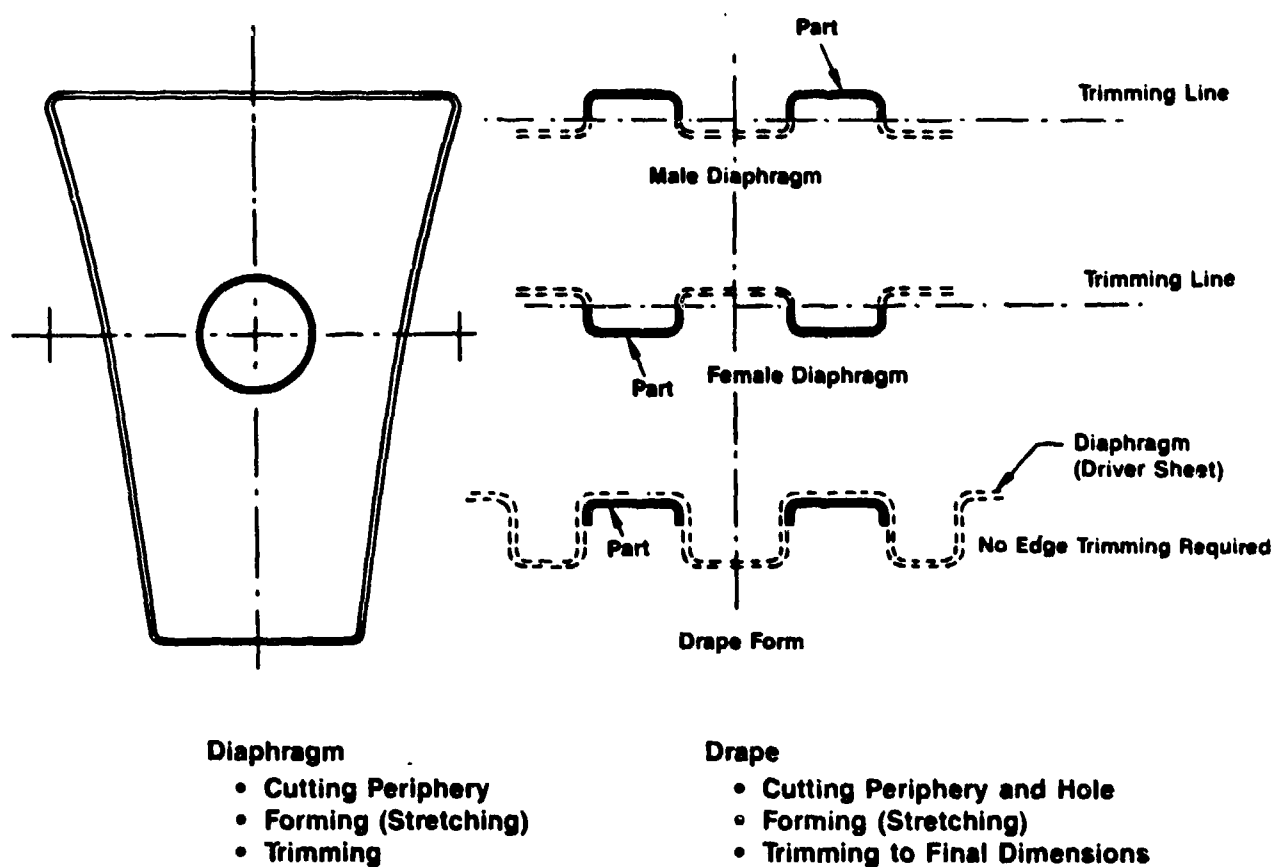


FIGURE 6-3. EXAMPLE OF DIAPHRAGM PREFERRED FABRICATION FOR SPF DESIGN GUIDANCE

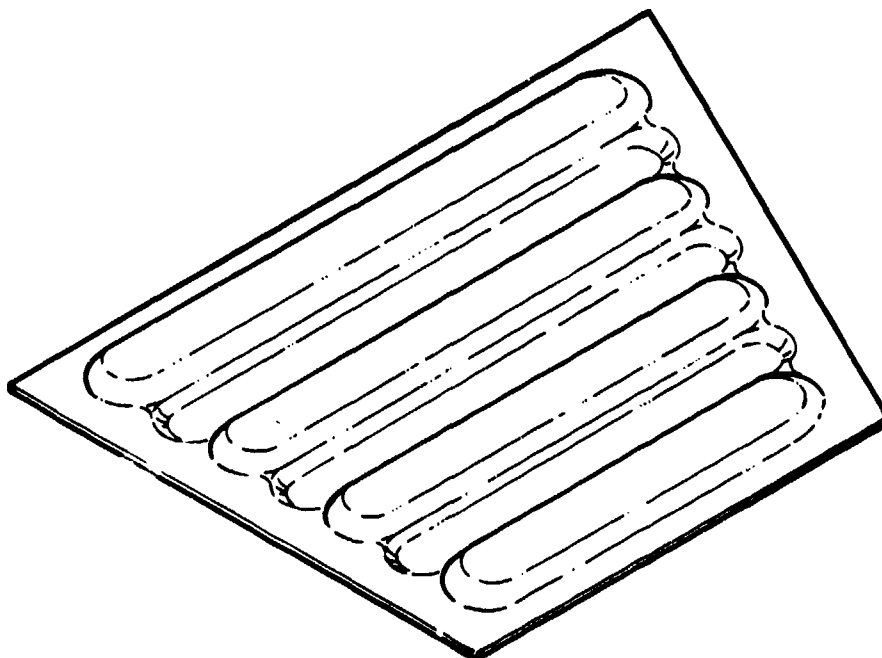


FIGURE 6-4. EXAMPLE OF SPF SINEWAVE WEB

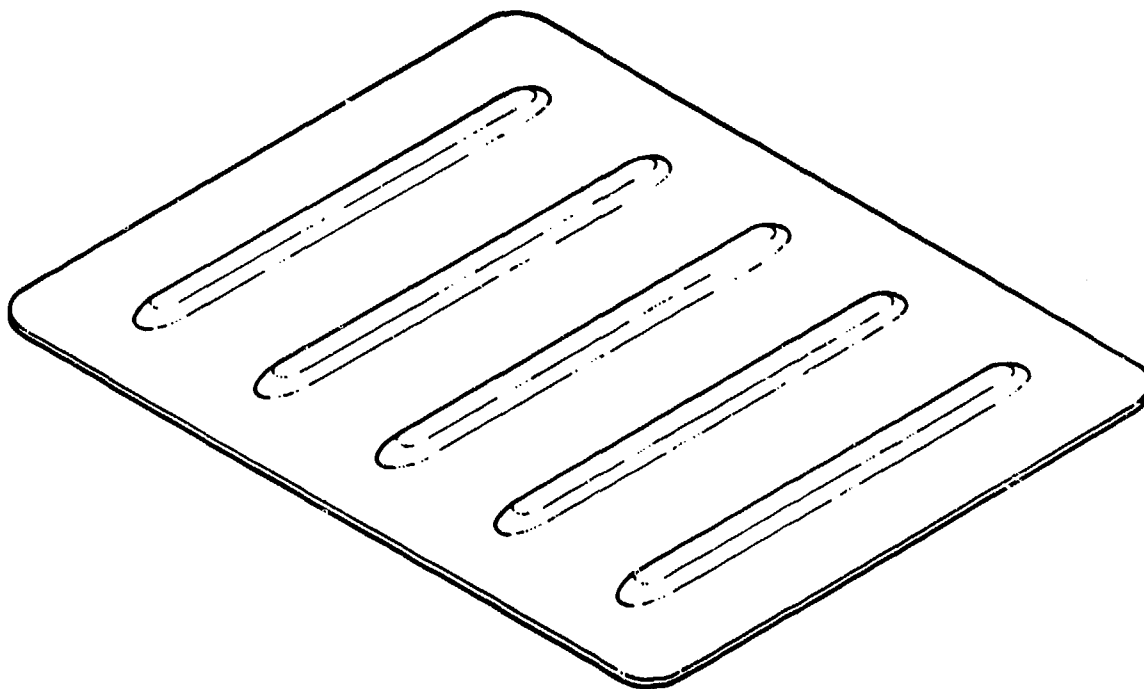


FIGURE 6-5. EXAMPLE OF SPF BEADED WEB

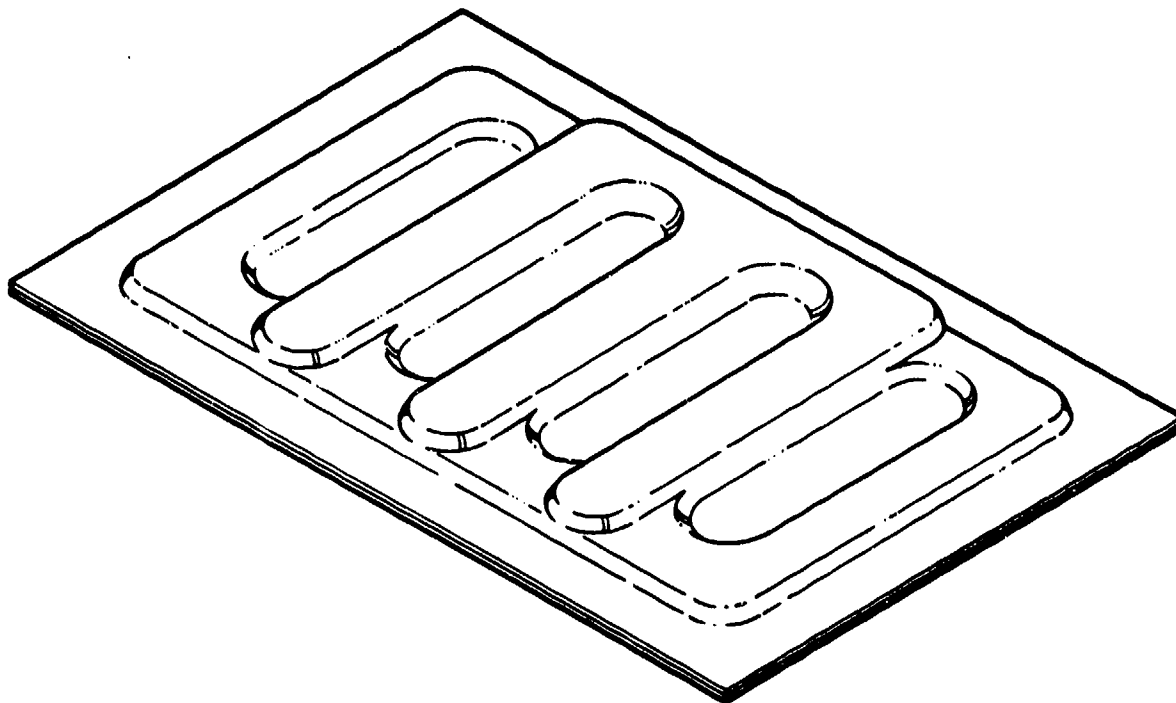


FIGURE 6-6. EXAMPLE OF SPF STIFFENED WEB

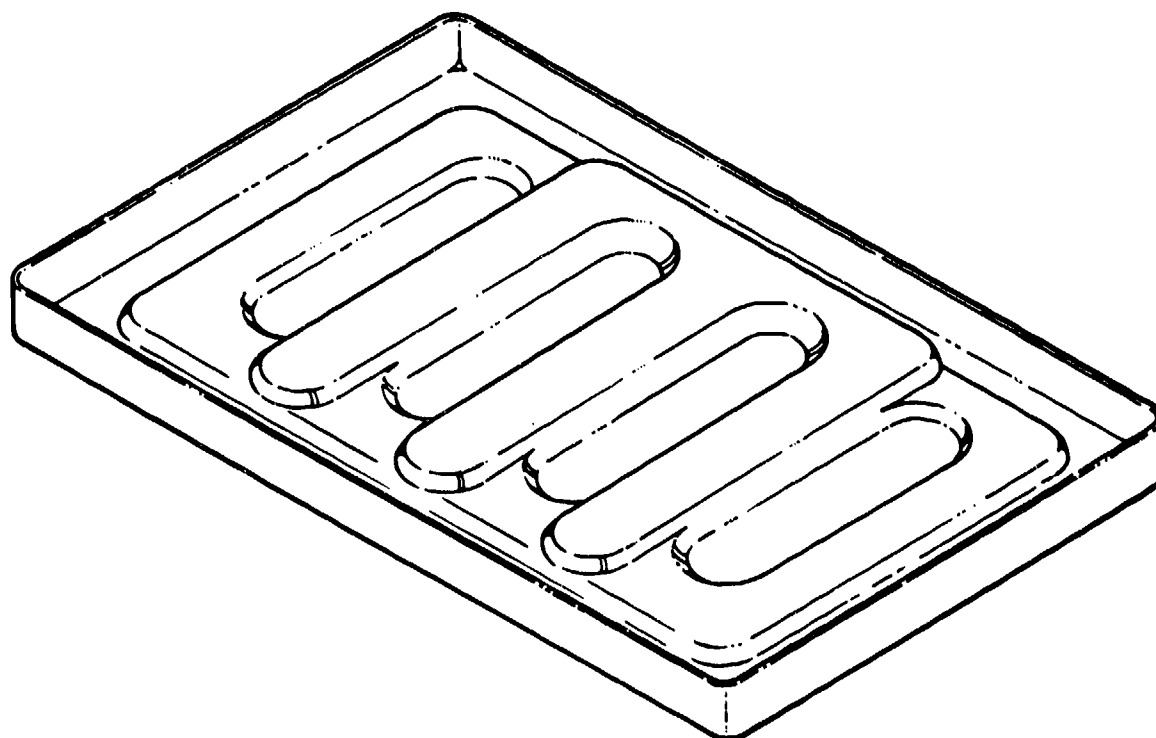


FIGURE 6-7. EXAMPLE OF SPF STIFFENED WEB WITH INTEGRAL FLANGE

FIGURE 6-8

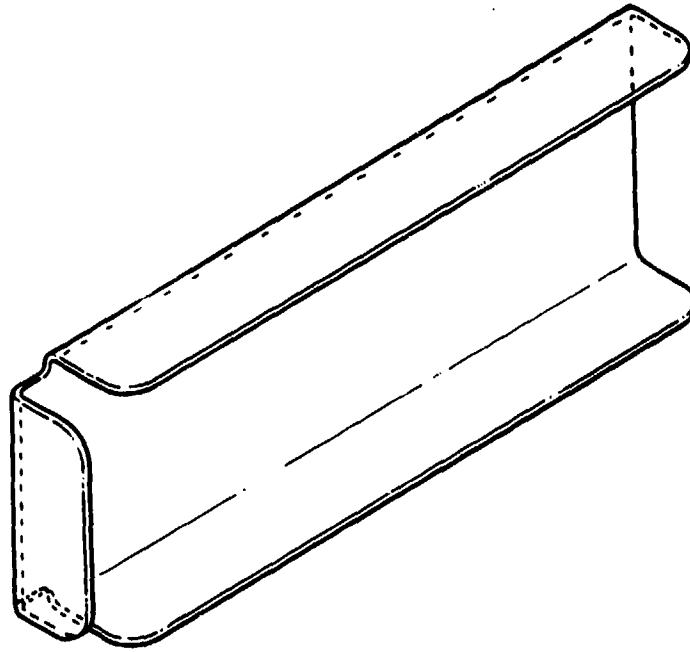


FIGURE 6-8. EXAMPLE OF SPF FORMED INTERCOSTAL STRUCTURAL MEMBER

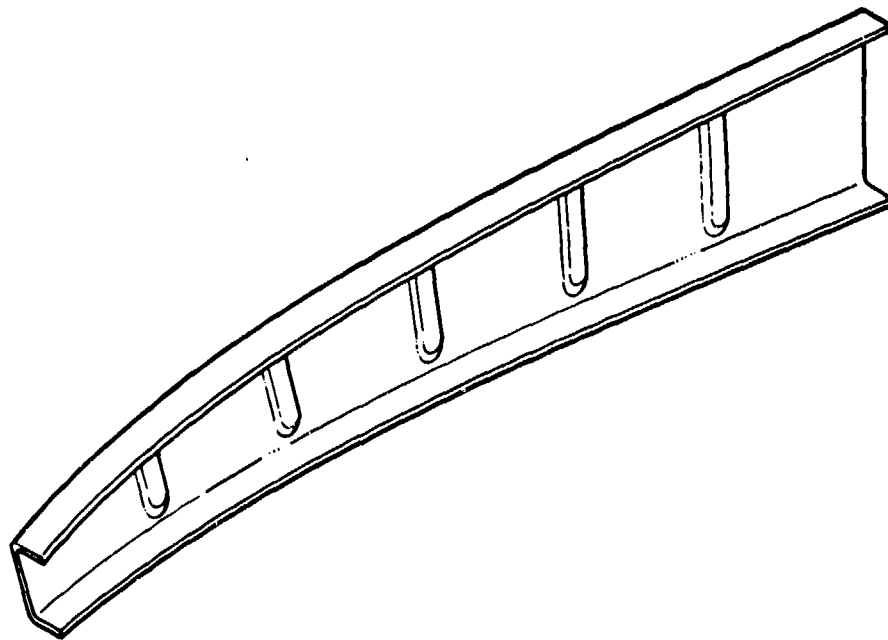
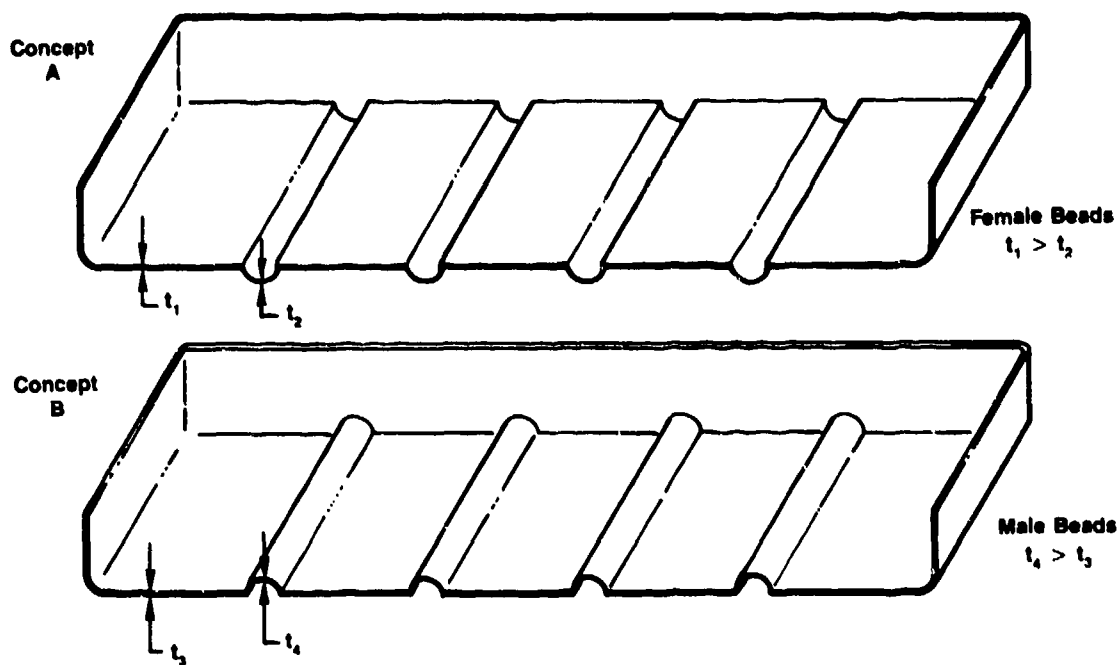


FIGURE 6-9. EXAMPLE OF SPF FORMED FRAME STIFFENED BY BEADS



For stress criteria the thicker bead is preferred. Concept B preferred over Concept A.

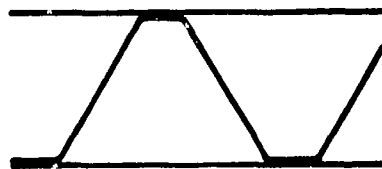
FIGURE 6-10. FEMALE VERSUS MALE BEADS FOR SPF PARTS



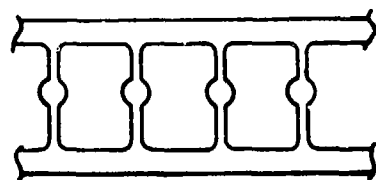
① **SPF: One Sheet**



② **SPF/DB: Two Sheets**



③ **SPF/DB: Three Sheets**



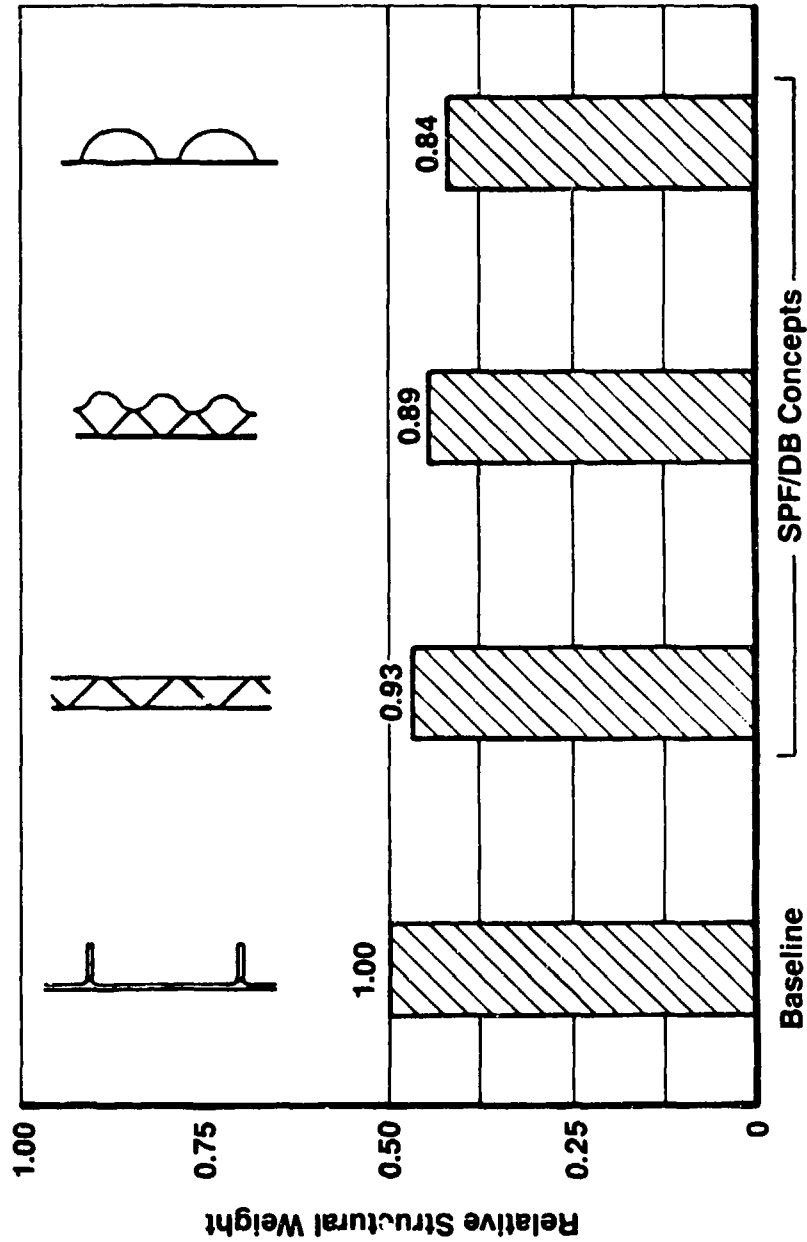
④ **SPF/DB: Four Sheets**

FIGURE 6-11. EXAMPLES OF SPF AND SPF/DB CONCEPTS

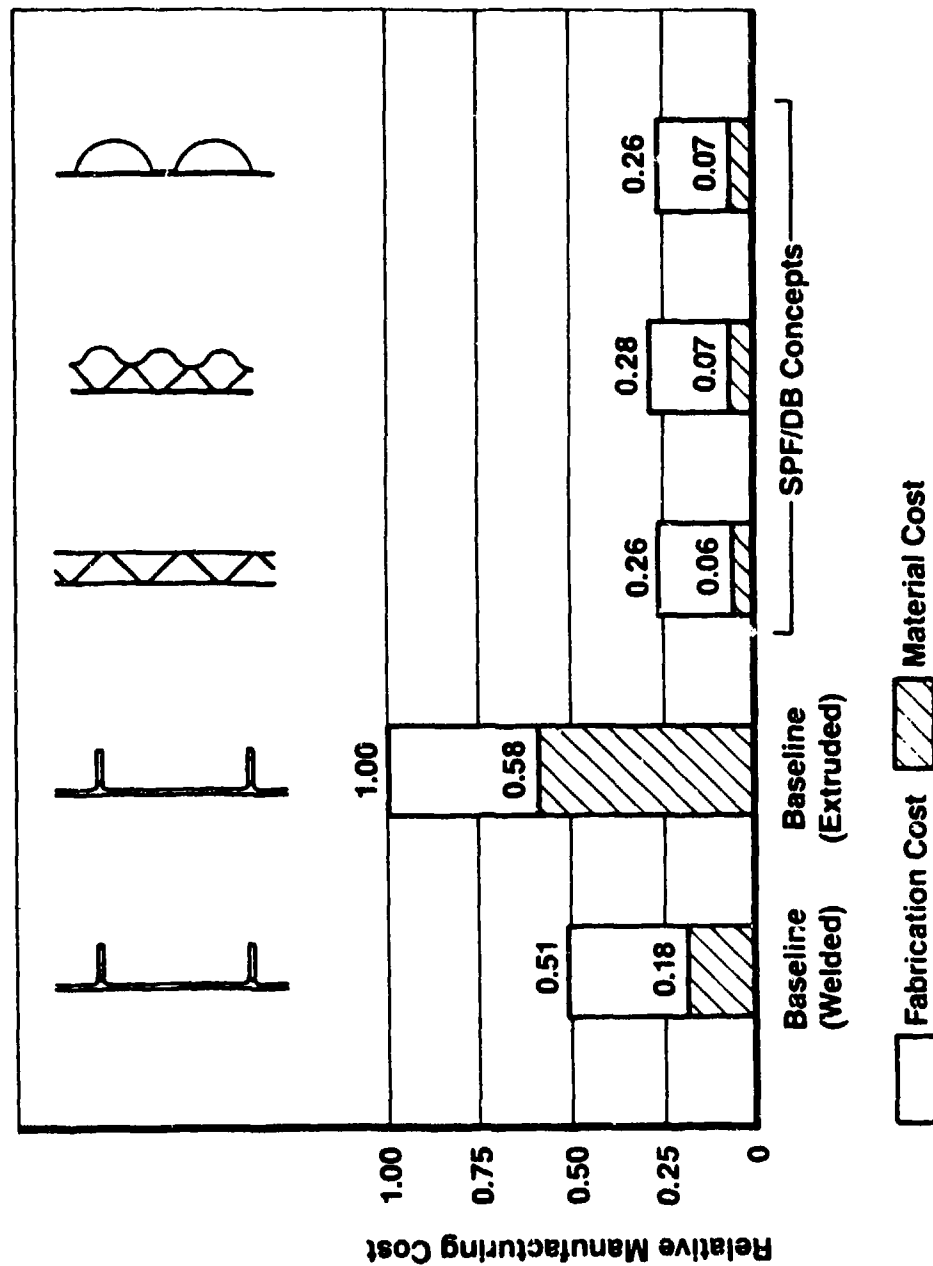
6.4 Manufacturing Data for Superplastic Forming

The following data for superplastic formed parts are presented using CED and CDE formats for conducting trade-studies.

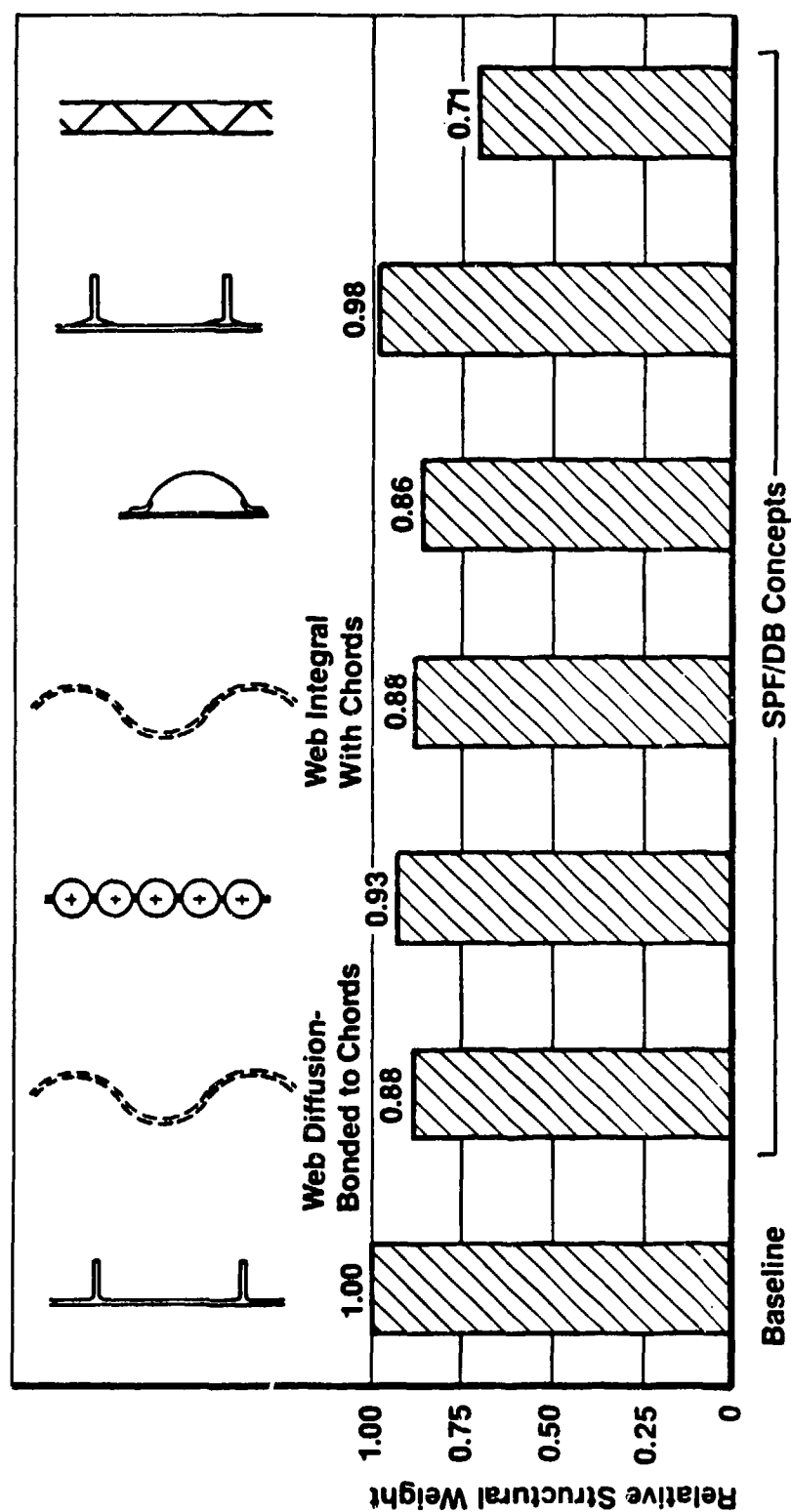
STRUCTURAL WEIGHT COMPARISON FOR VARIOUS WING PANEL CONFIGURATIONS (Ref. 8)



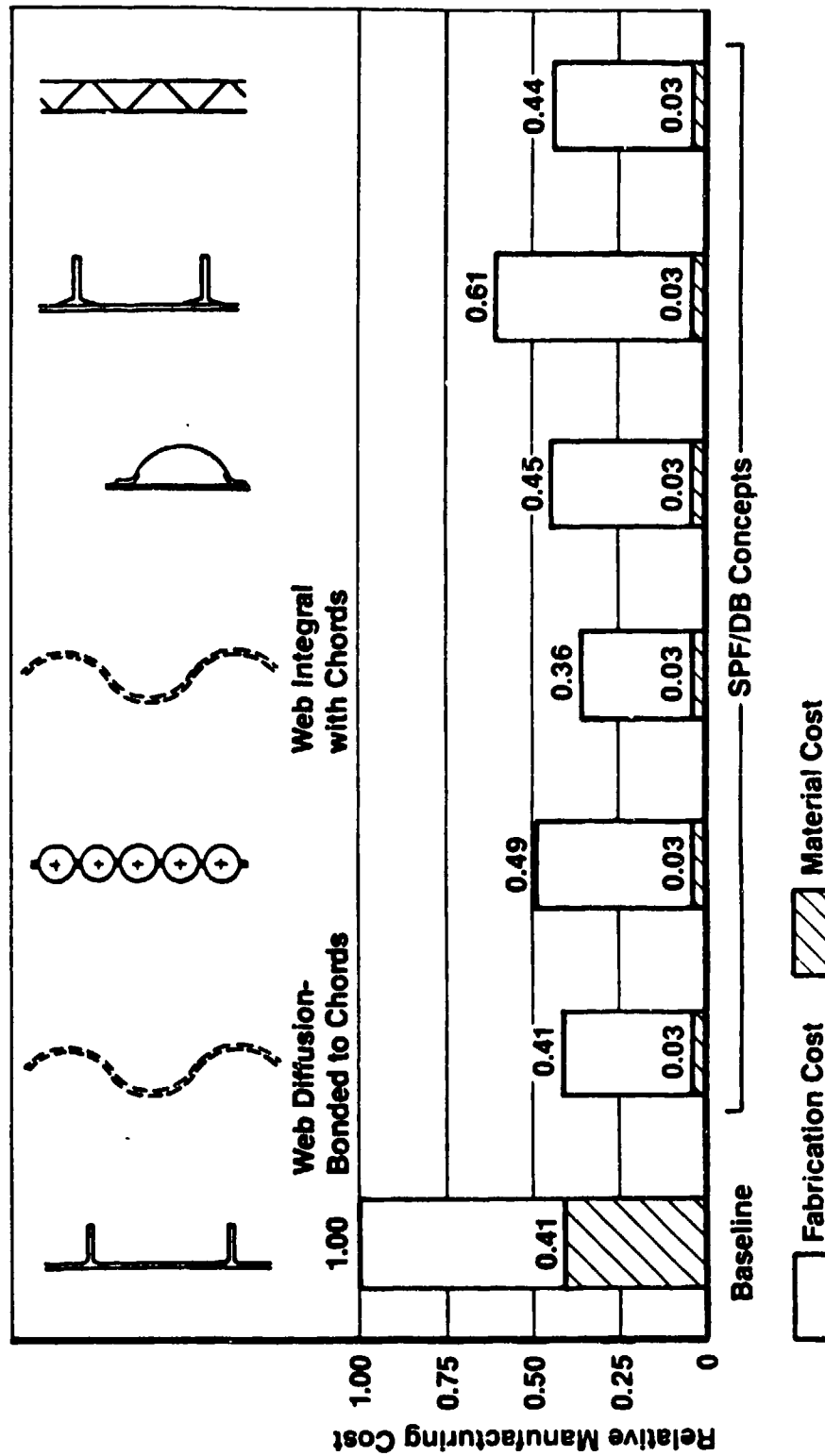
TOTAL MANUFACTURING COST COMPARISON FOR VARIOUS WING PANEL CONFIGURATIONS (Ref. 8) (500-Airplane Program)



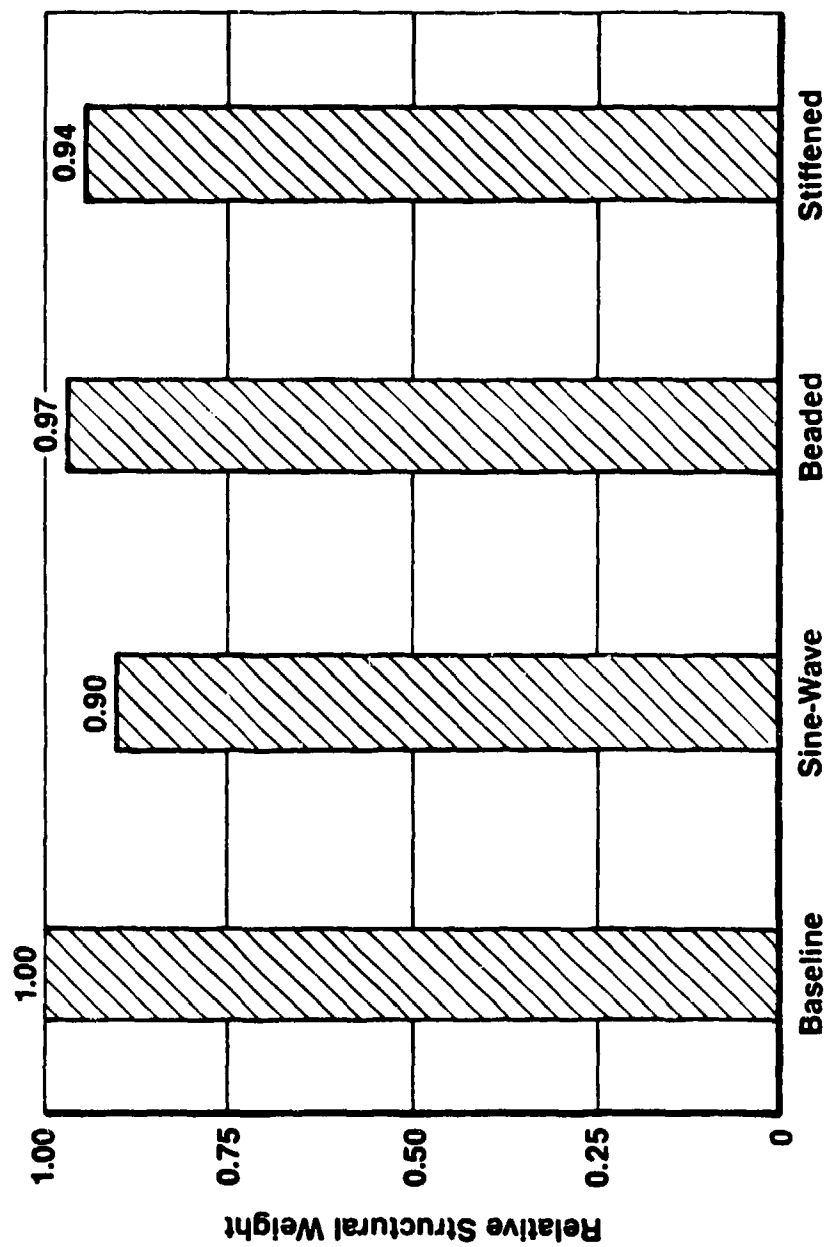
STRUCTURAL WEIGHT COMPARISON FOR VARIOUS WING/RIB CONFIGURATIONS (Ref. 8)



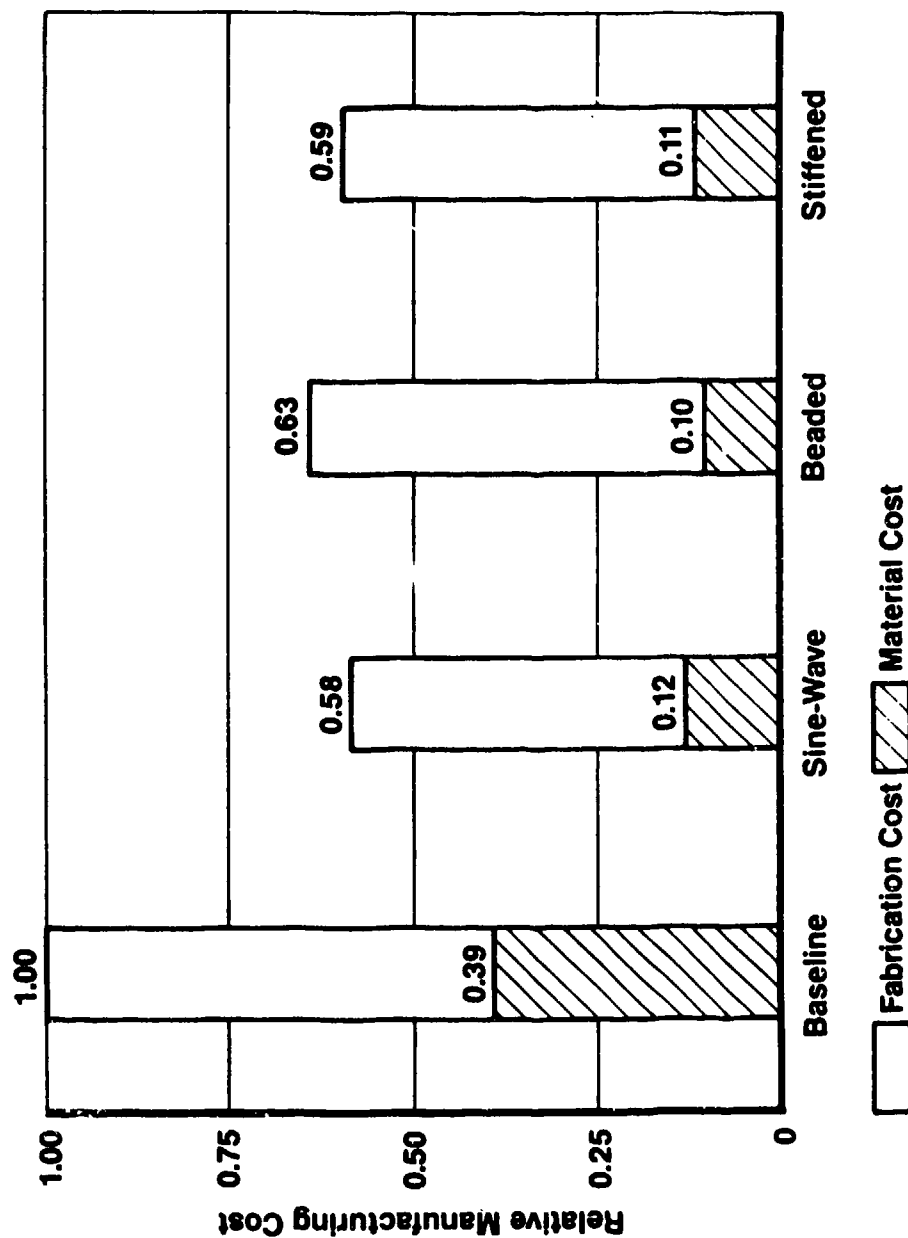
TOTAL MANUFACTURING COST COMPARISON FOR VARIOUS WING/RIB CONFIGURATIONS (500-Airplane Program) (Ref. 8)



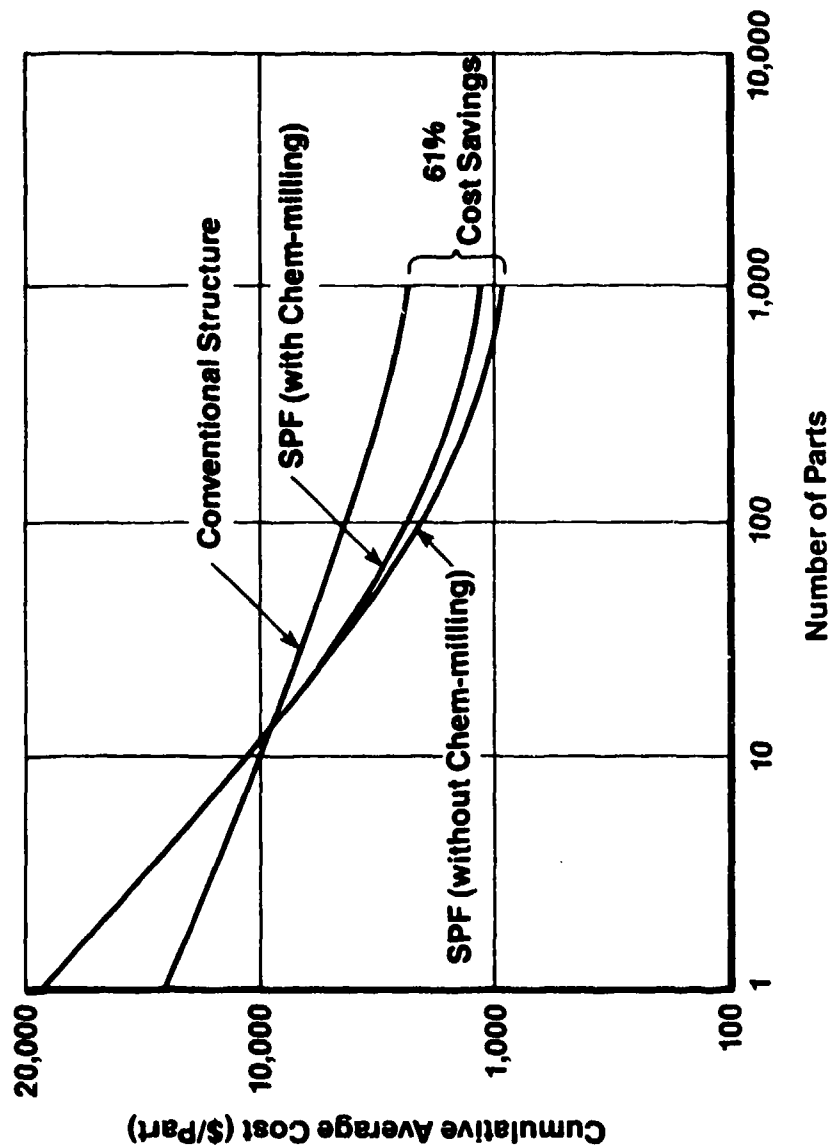
STRUCTURAL WEIGHT COMPARISON FOR VARIOUS SPAR/FRAME CONFIGURATIONS (Ref. 8)



TOTAL MANUFACTURING COST COMPARISON FOR VARIOUS SPAR/FRAME CONFIGURATIONS (Ref. 8) (50C Airplane Program)

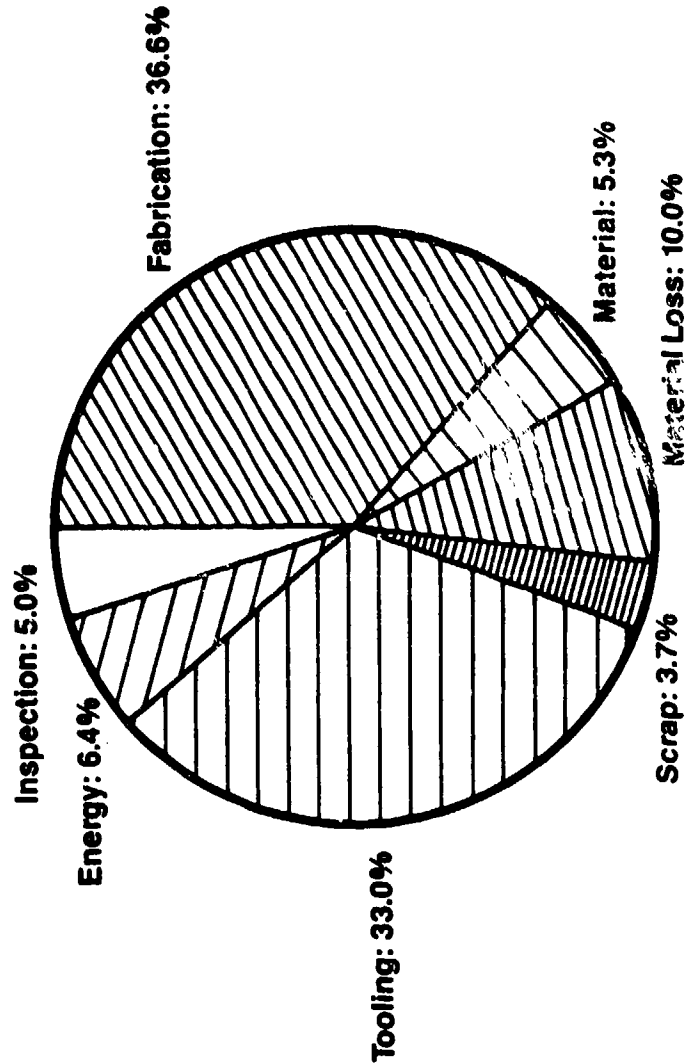


COST SAVINGS WHEN DESIGNING A HELICOPTER (AH-64A) FLOOR/KEEL BEAM (Ref. 9)

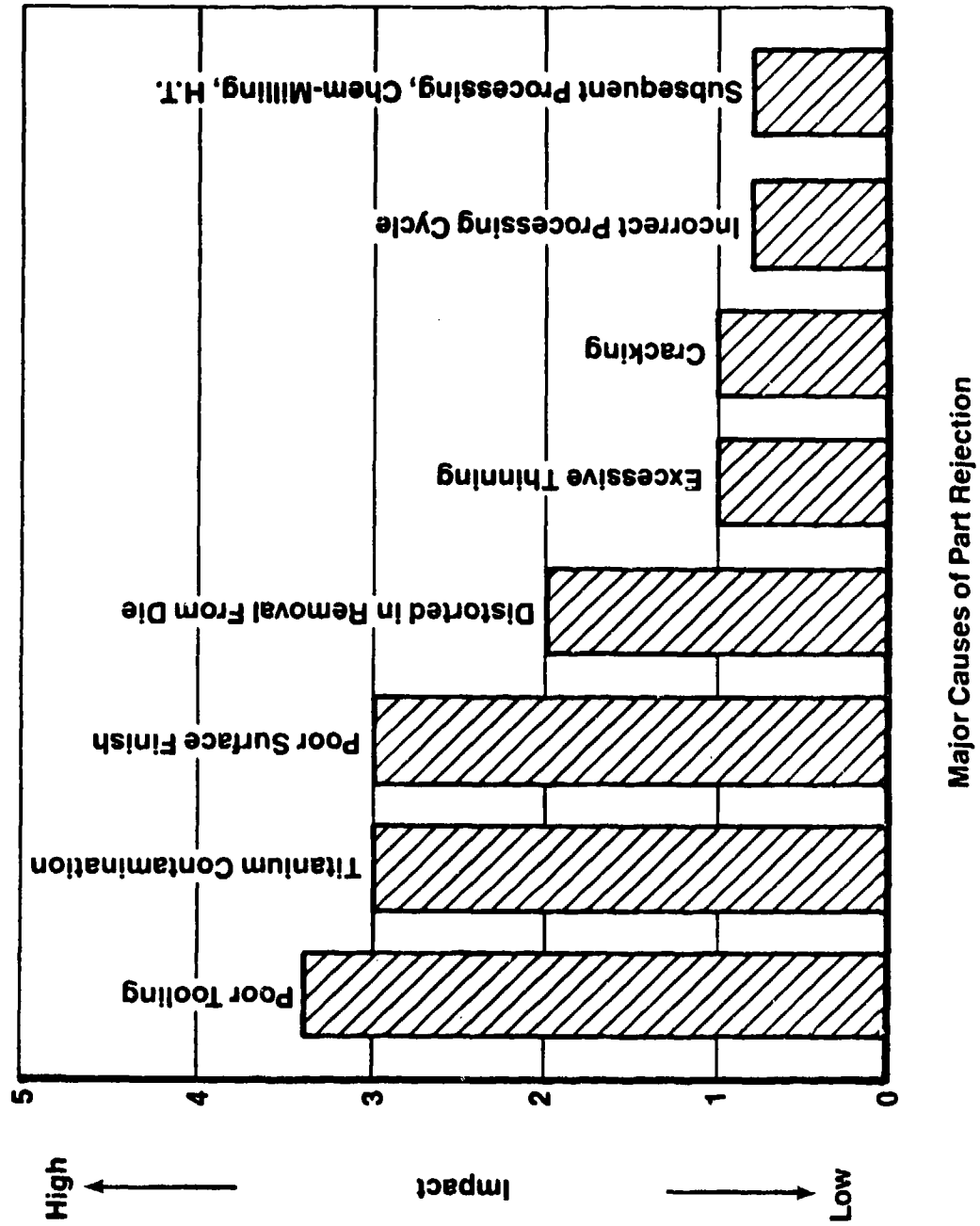


DISTRIBUTION OF COST FOR TITANIUM DEFLECTOR MANUFACTURED BY SPF

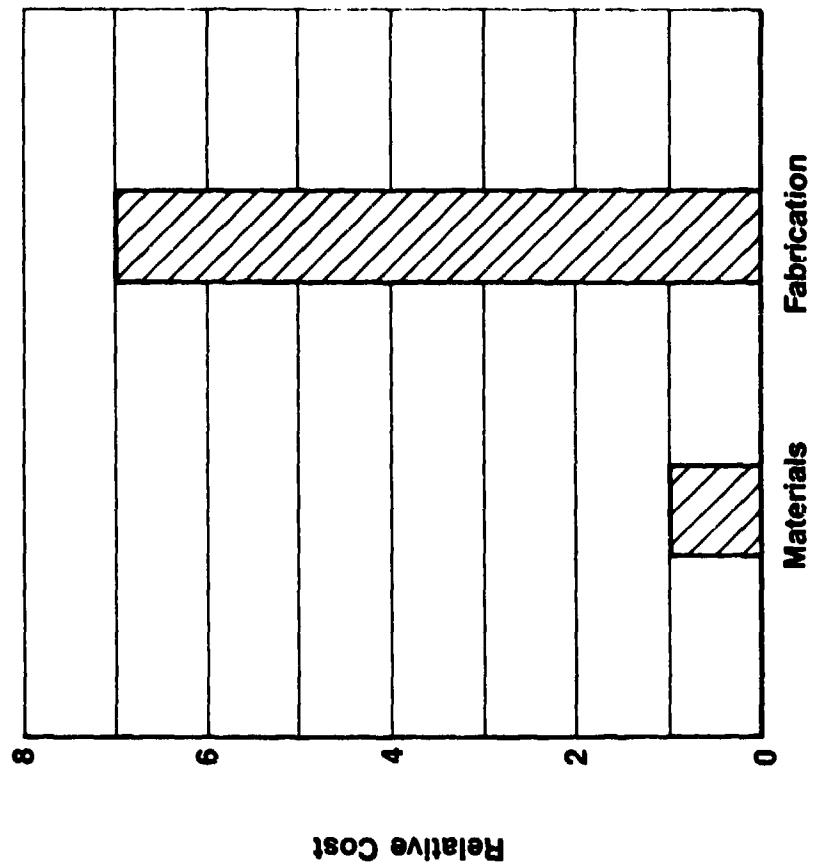
200 Cumulative Unit Average Cost per Part



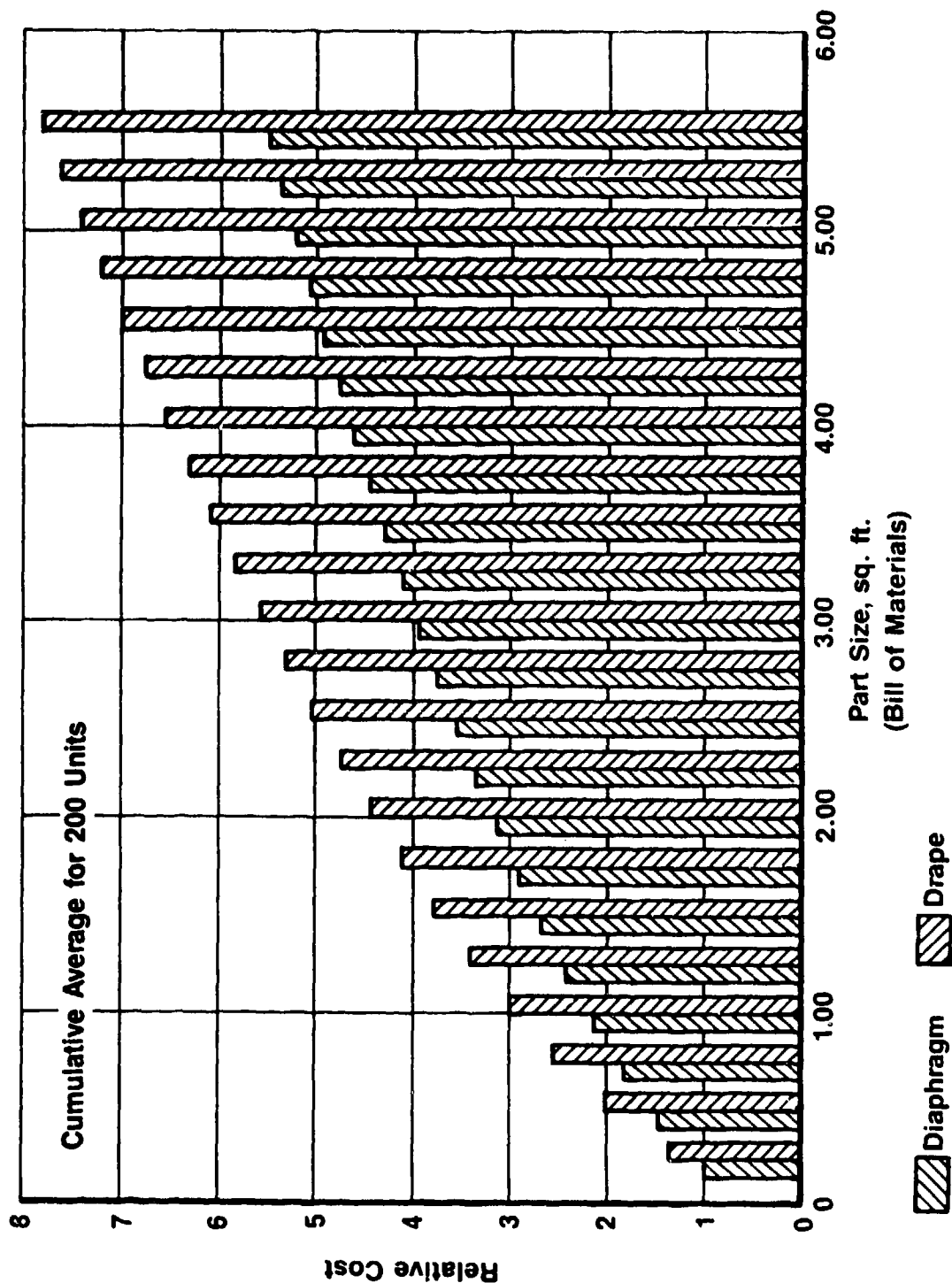
MAJOR CAUSES OF PART REJECTION



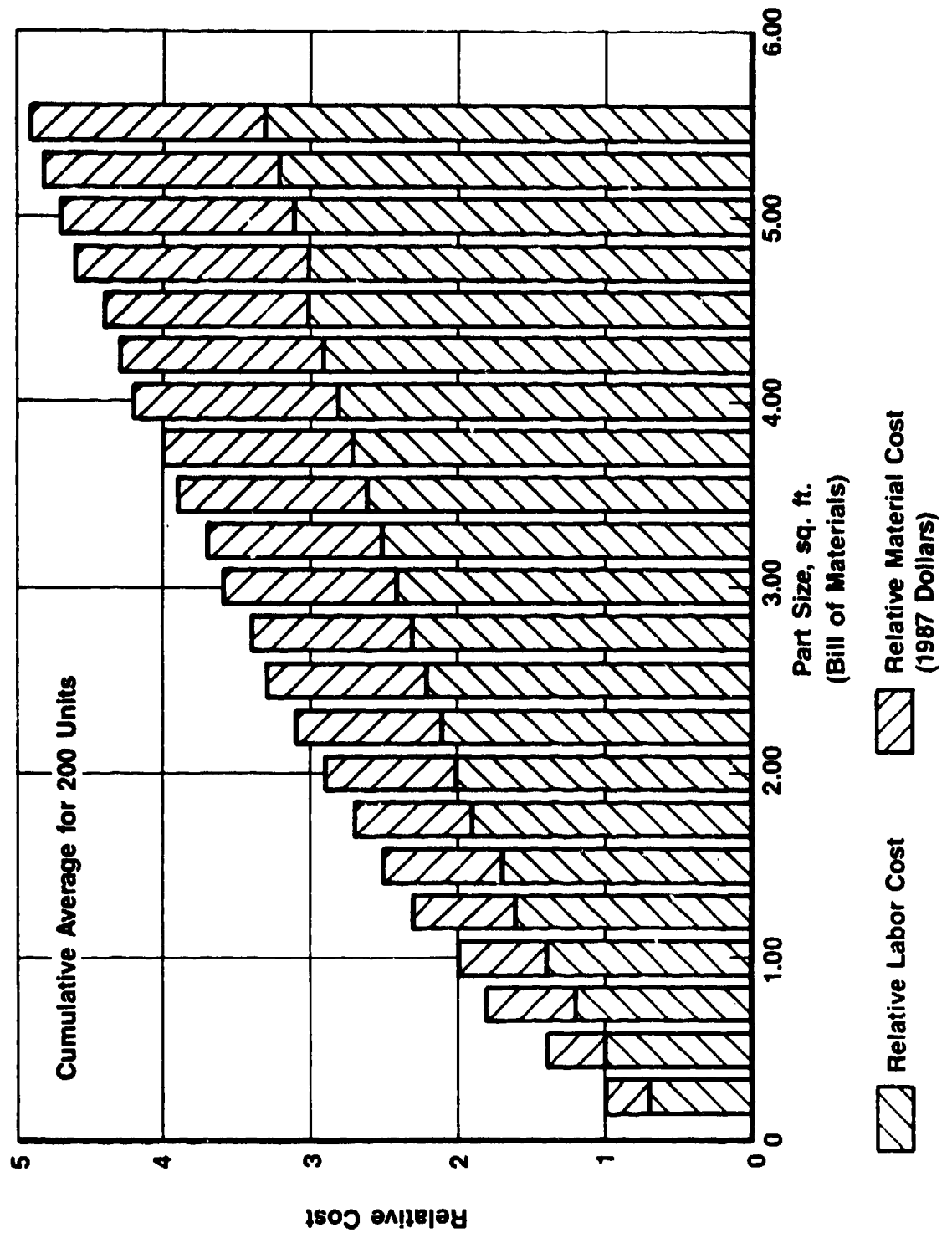
MATERIAL VERSUS FABRICATION COST FOR SPF PARTS (CDE)



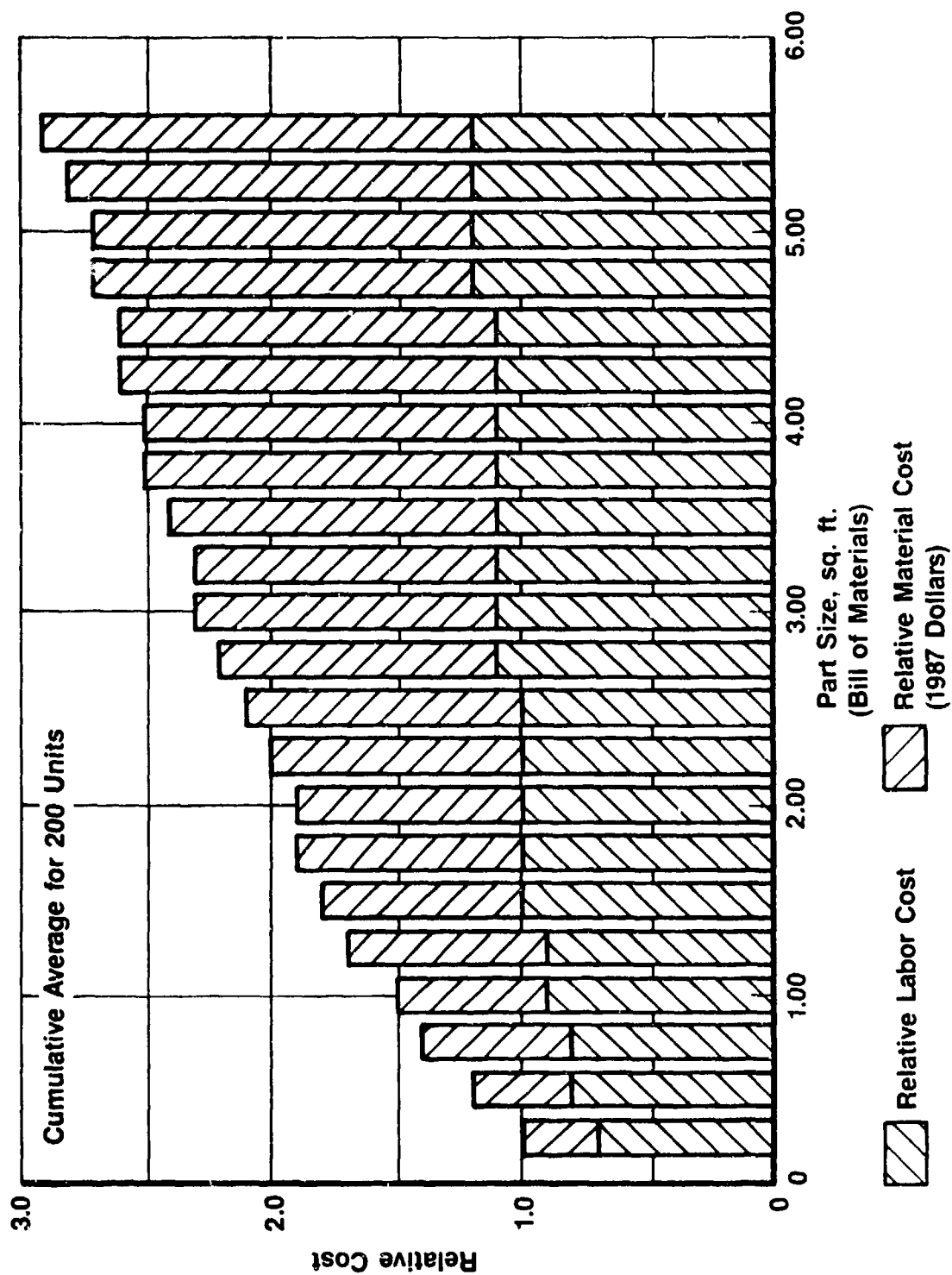
INFLUENCE OF MATERIAL COST FOR SPF (DIAPHRAGM AND DRAPE) (CDE)



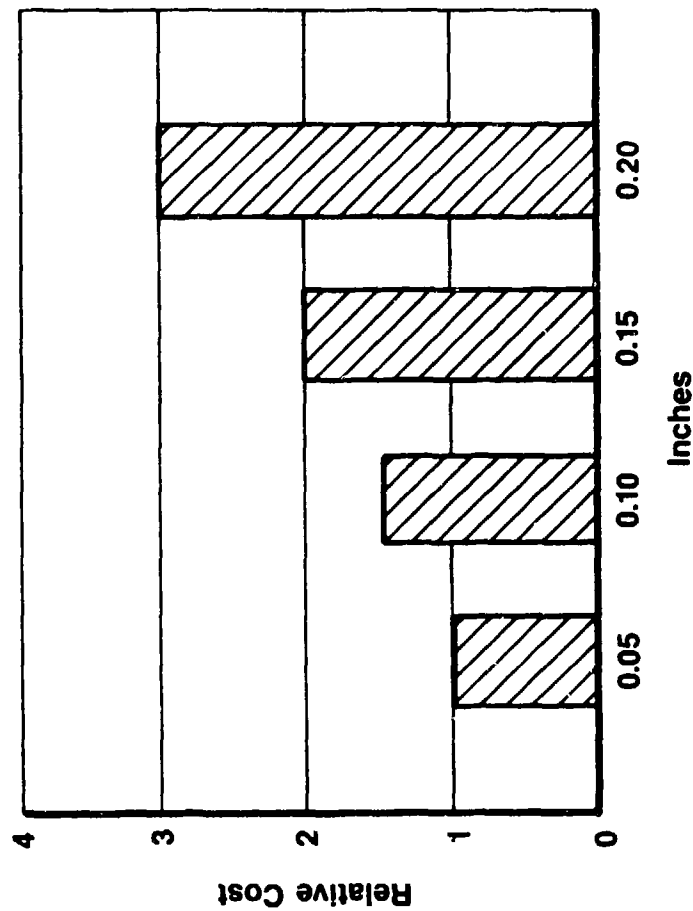
RELATIVE COST FOR MANUFACTURING AND MATERIAL FOR SPF (DIAPHRAGM) (CDE)



RELATIVE COST FOR MANUFACTURING AND MATERIAL FOR SPF (DRAPE) (CDE)



IMPACT OF INITIAL OR STARTING GAGE FOR SPF (CDE)

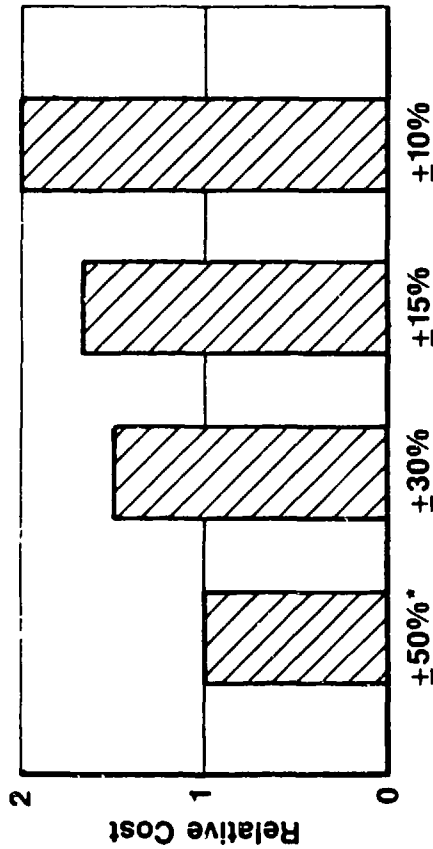


COST ELEMENTS:

- Requires higher pressure or longer time as thickness increases

CDE-SPF-XIV

IMPACT OF SPF PART THICKNESS DESIGN TOLERANCE (DIAPHRAGM SPF) (CDE)

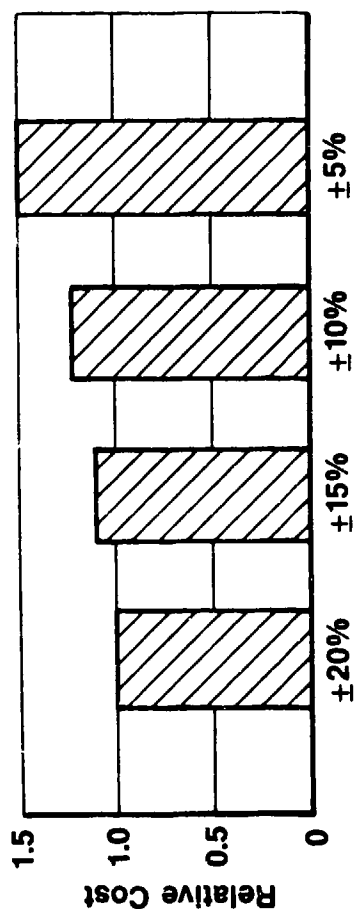


* Desired as
"Minimum Gage"
With No Maximum

COST ELEMENTS:

- Tighter gage tolerance requires selective chem-milling
- Influenced by aspect ratio
- Increased starting gage required with tighter tolerances

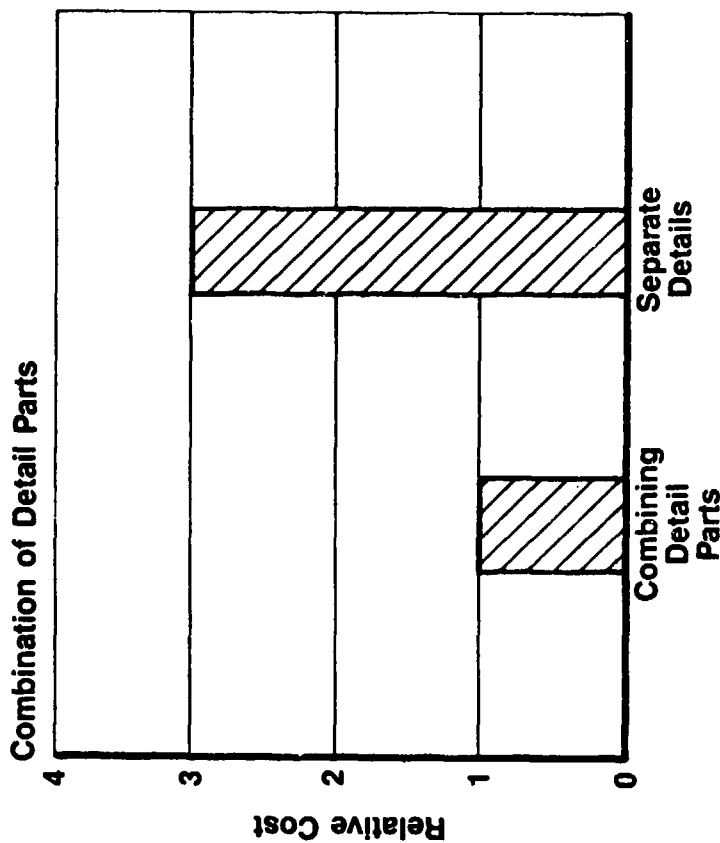
IMPACT OF SPF SHEET THICKNESS DESIGN TOLERANCE (DRAPE SPF) (CDE)



COST ELEMENT:

- Tolerances tighter than normal mill gage variations require: half tolerance sheet purchase and selective chem-milling

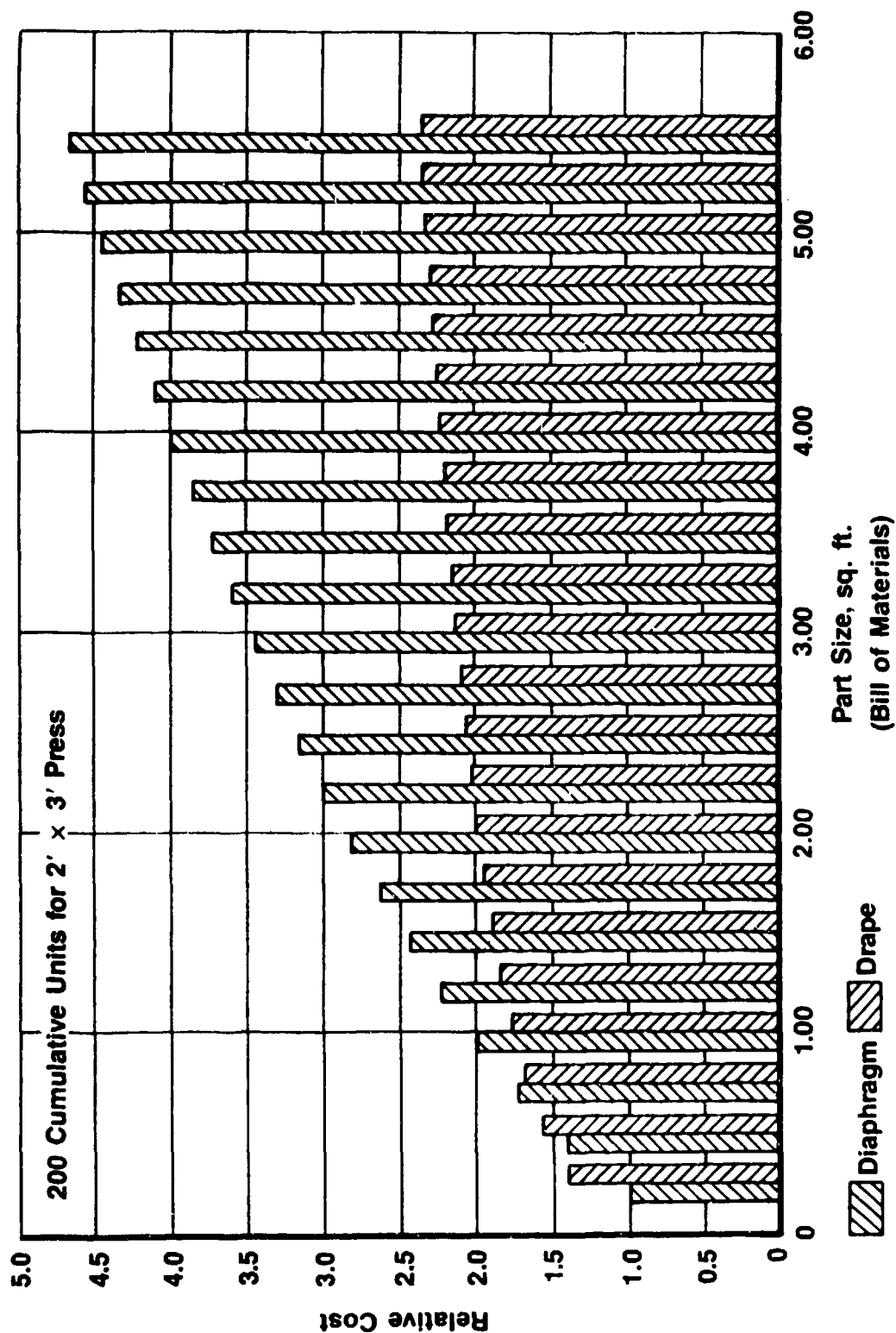
INFLUENCE OF PART COUNT ON SPF COST (CDE)



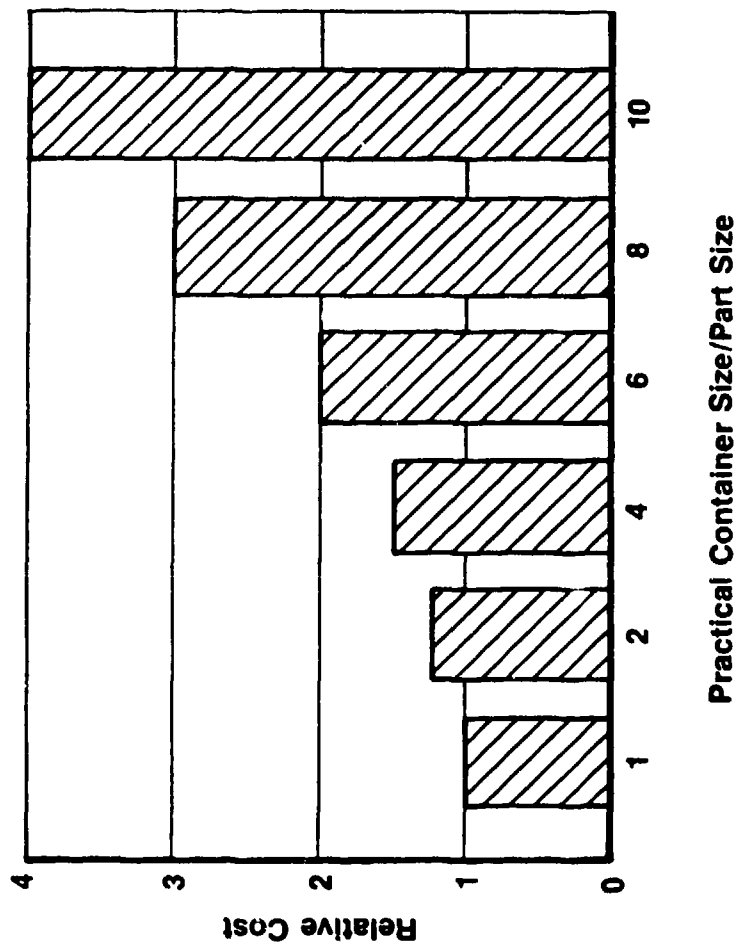
COST ELEMENTS:

- Each part number reduced by combining parts, saves cost of: design; drawing; release; planning; tool design; tool release; tool planning; tool order; checking; material plan; purchase order or tool build; production plan; crib records; inspection; inventory; etc.
- At least a 30% recurring cost savings potential with each part combination and 70% savings on non-recurring tool cost

INFLUENCE OF PART AREA FOR SPF (DIAPHRAGM AND DRAPE) (CDE)



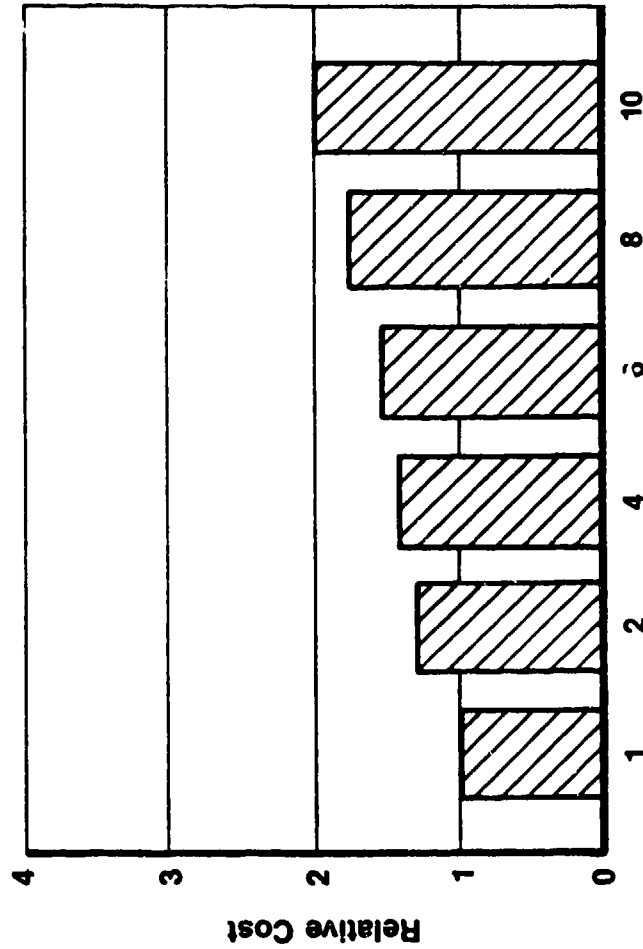
IMPACT OF PART SIZE ON SPF COST (DIAPHRAGM SPF) (CDE)



COST ELEMENTS:

- Depends upon tool nesting for least thinning variation
- Cost increase due to material utilization
- Affords opportunity for combining several parts into one
- Smaller the part reduces material utilization
- Smaller parts complicate tool nesting

IMPACT OF PART SIZE ON SPF COST (DRAPE SPF) (CDE)

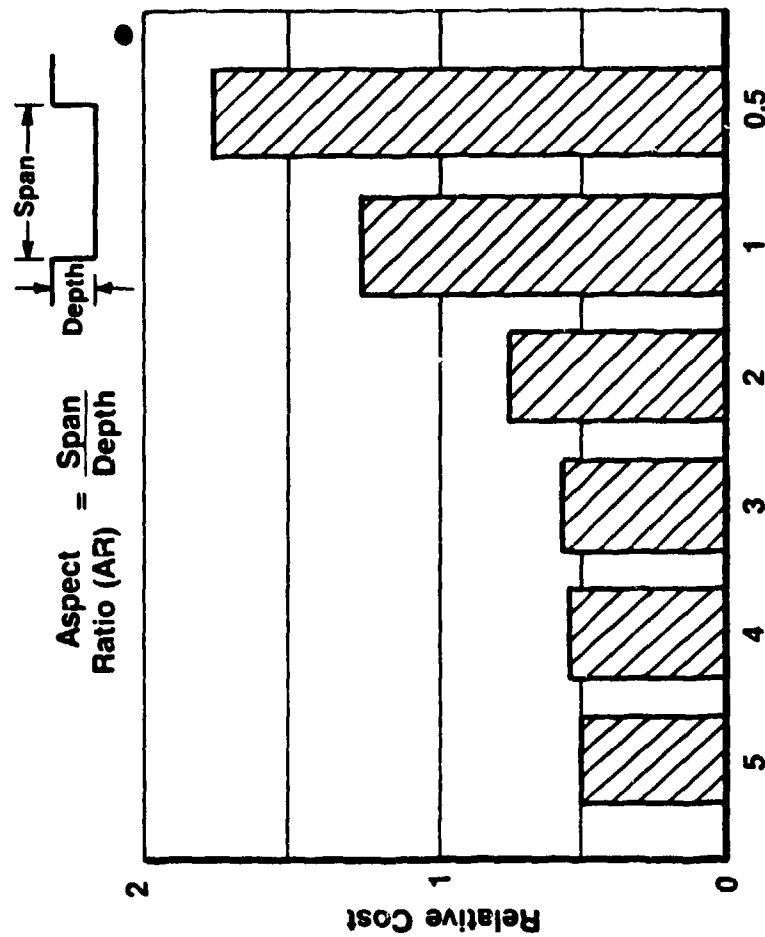


Practical Container Size/Part Size

COST ELEMENTS:

- No effect on thinning
- Depends on tool nesting and part blank size
- Increases set-up time
- More tools in nest, longer SPF loading operation
- Small parts should be examined for combining with adjacent details

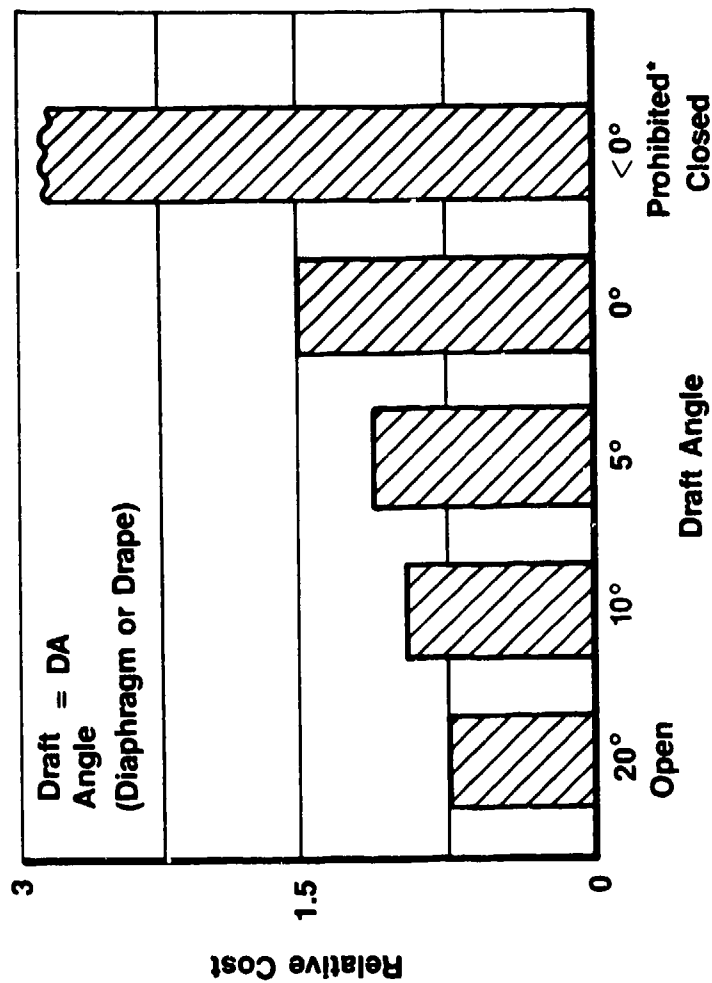
IMPACT OF ASPECT RATIO ON SPF COST (DIAPHRAGM OR DRAPE) (CDE)



COST ELEMENTS:

- Narrow spans require increased pressure and time to reach depth
- Thinning variations become more severe at smaller AR
- Smaller AR causes larger female radii
- Very small AR may not be possible because of facility limitations
- Dependent upon draft angle

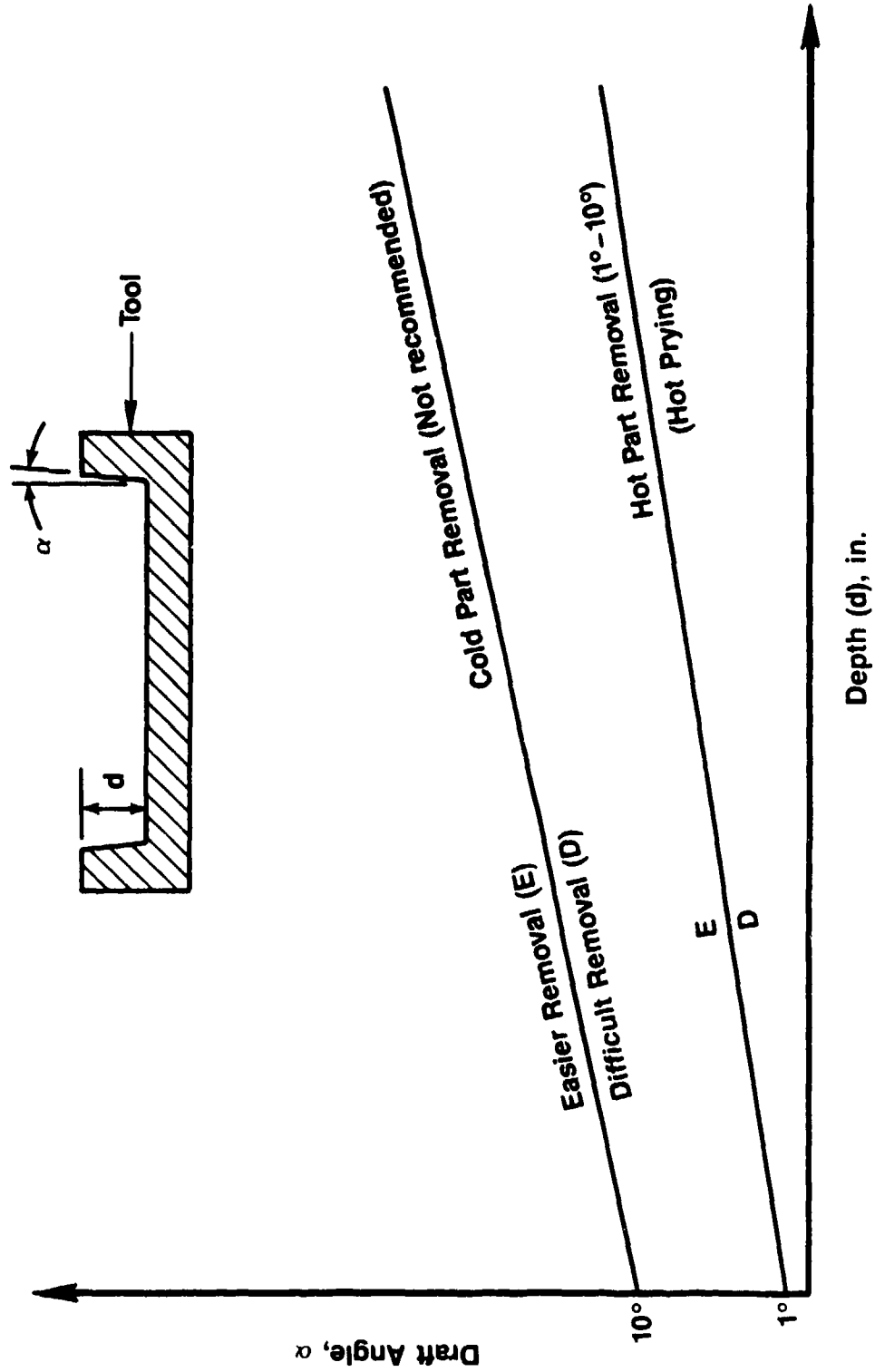
IMPACT OF DRAFT ANGLE ON SPF COST (DIAPHRAGM OR DRAPE) (CDE)



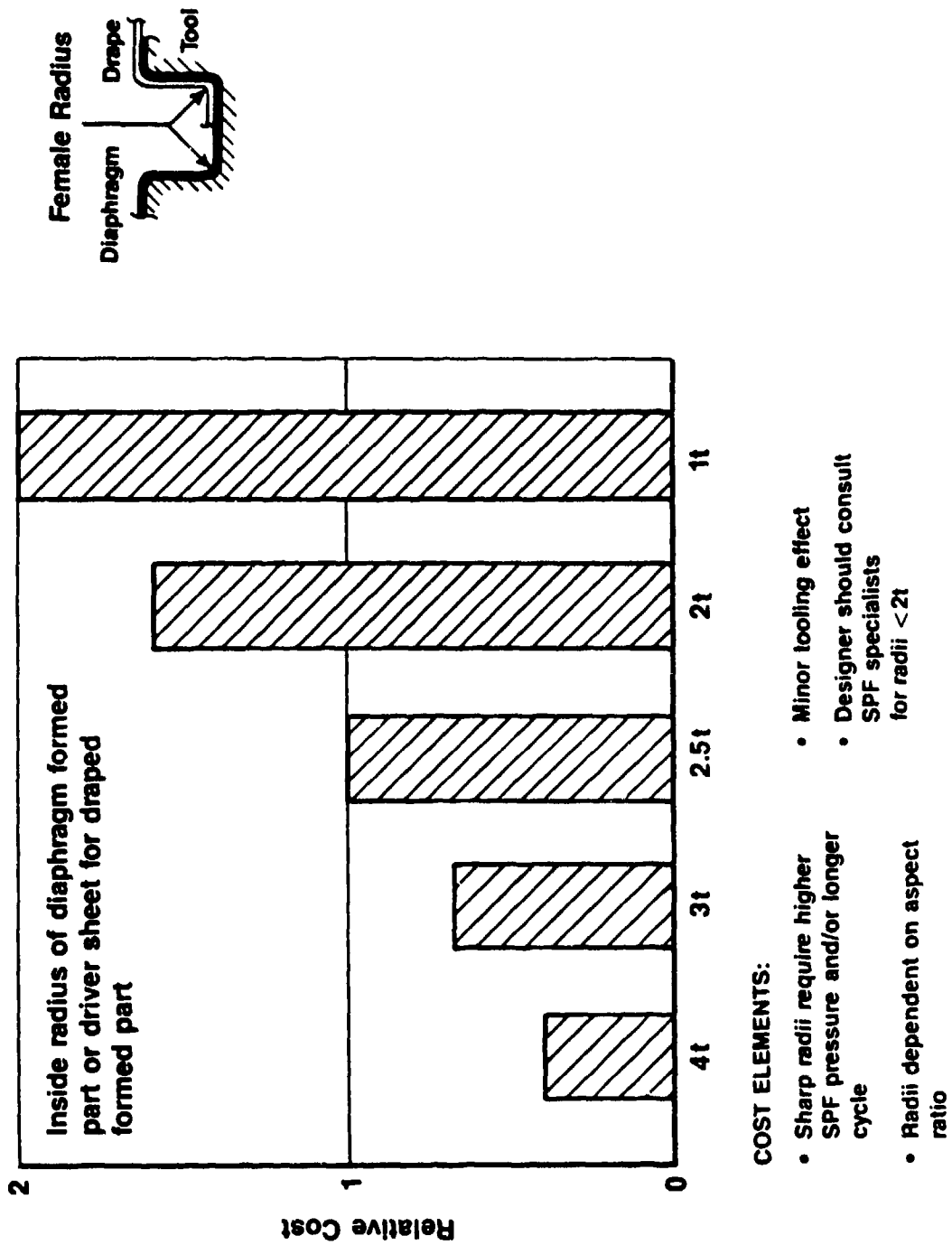
COST ELEMENTS:

- Part removal from tool not possible with closed angles; prohibited*
- 90° side walls (or 0° draft angle) cause: difficult part removal; requirement for steel tooling; increased tool maintenance
- Dependent upon aspect ratio
- Only possible with costly split tooling or breakaway tools

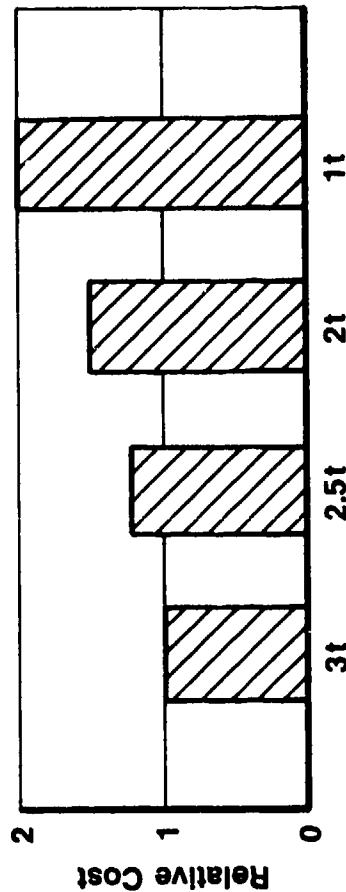
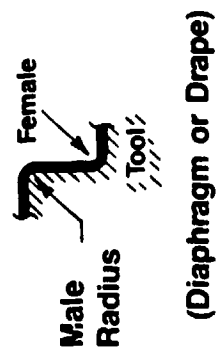
SPF DESIGN FOR PART REMOVAL (CDE) (DRAFT ANGLE VERSUS DEPTH)



IMPACT OF FEMALE RADIUS ON SPF COST (CDE)



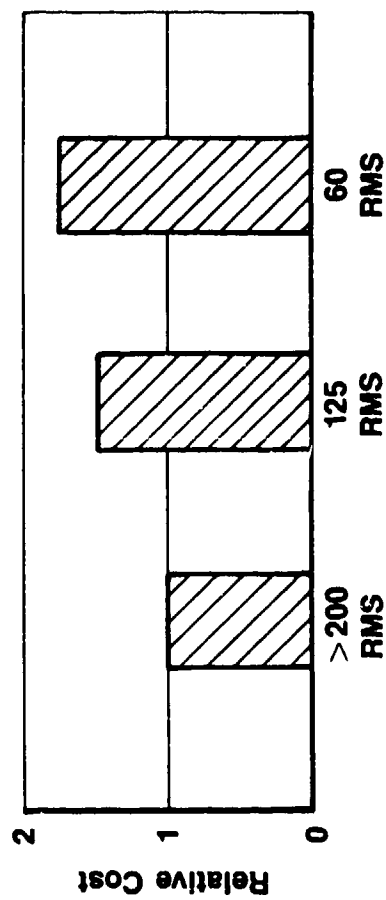
IMPACT OF MALE RADIUS ON SPF COST (CDE)



COST ELEMENTS:

- Sharper radii requires steel tooling
- Large radii allows ceramic tools
- Cost can increase also due to additional chemmilling and thicker material
- Sharp radii requires more frequent tool maintenance (particularly with ceramic tools)
- Sharp radii experience more thinning adjacent to radii

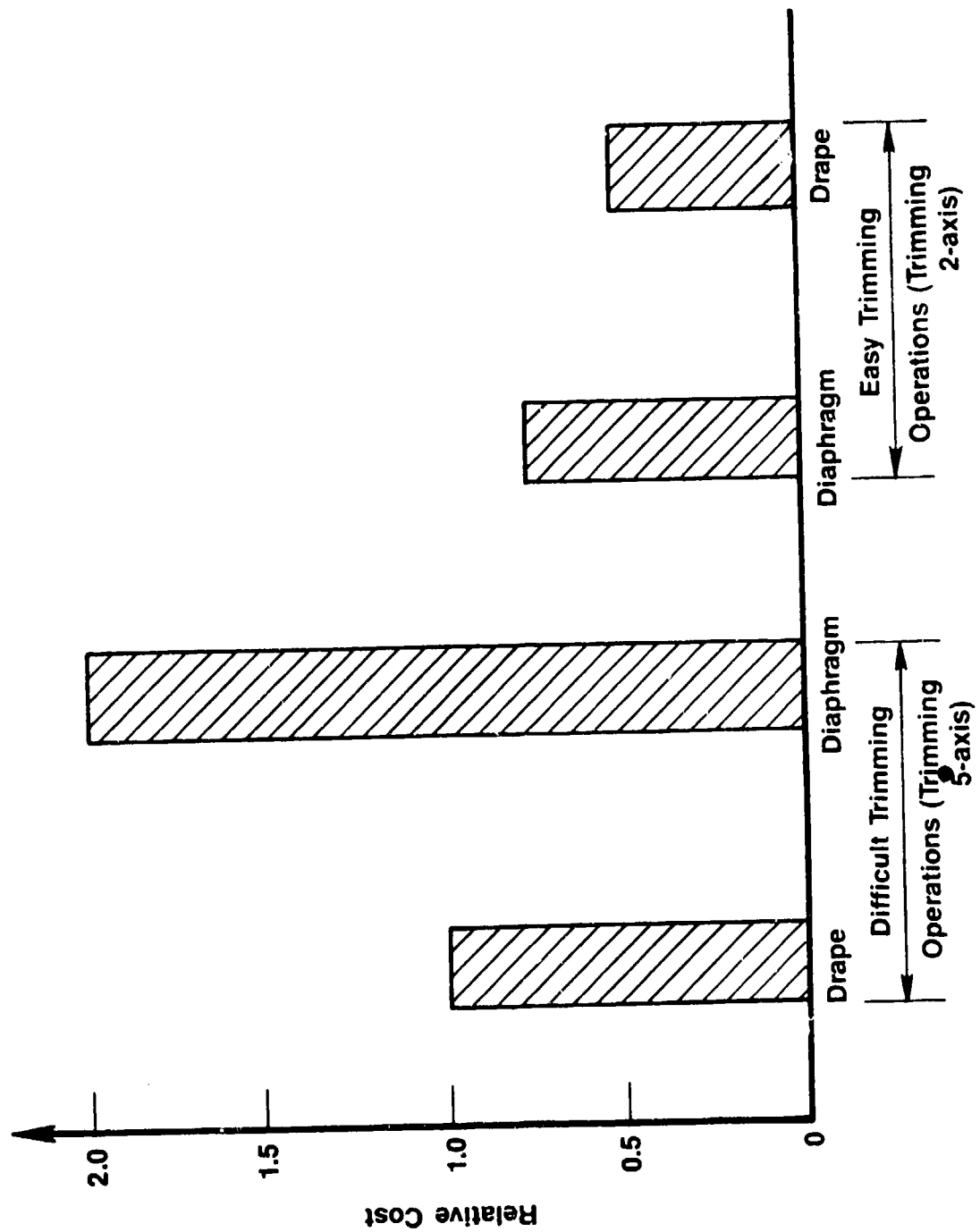
IMPACT OF SURFACE FINISH CALLOUT ON SPF COST (CDE)



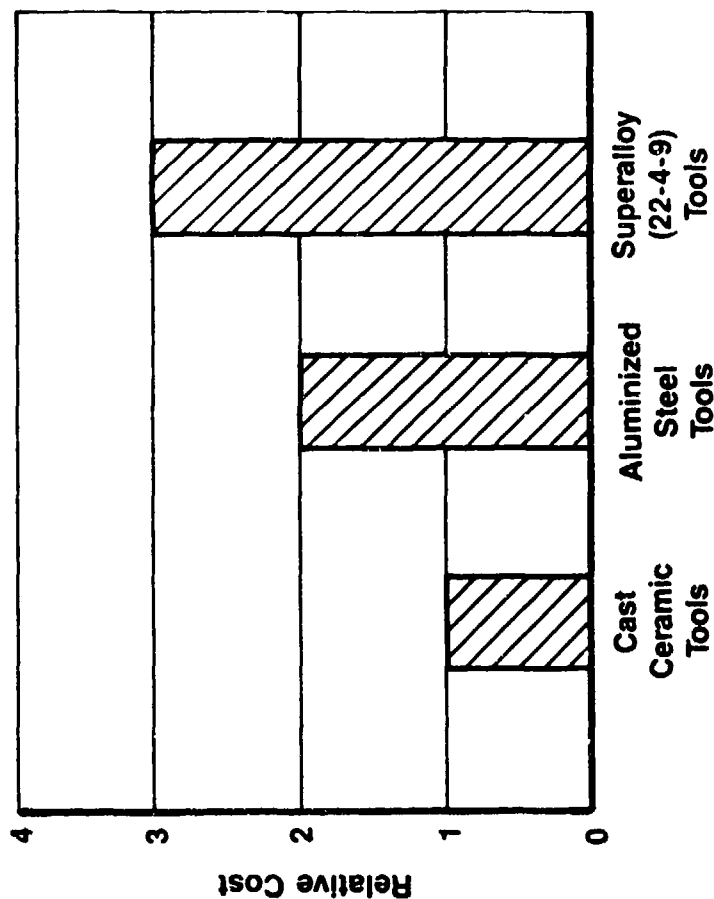
COST ELEMENTS:

- 125 RMS requires frequent tool maintenance
- 60 RMS requires part polishing plus tool maintenance

DIAPHRAGM VERSUS DRAPE FABRICATION FOR SPF PARTS (CDE)



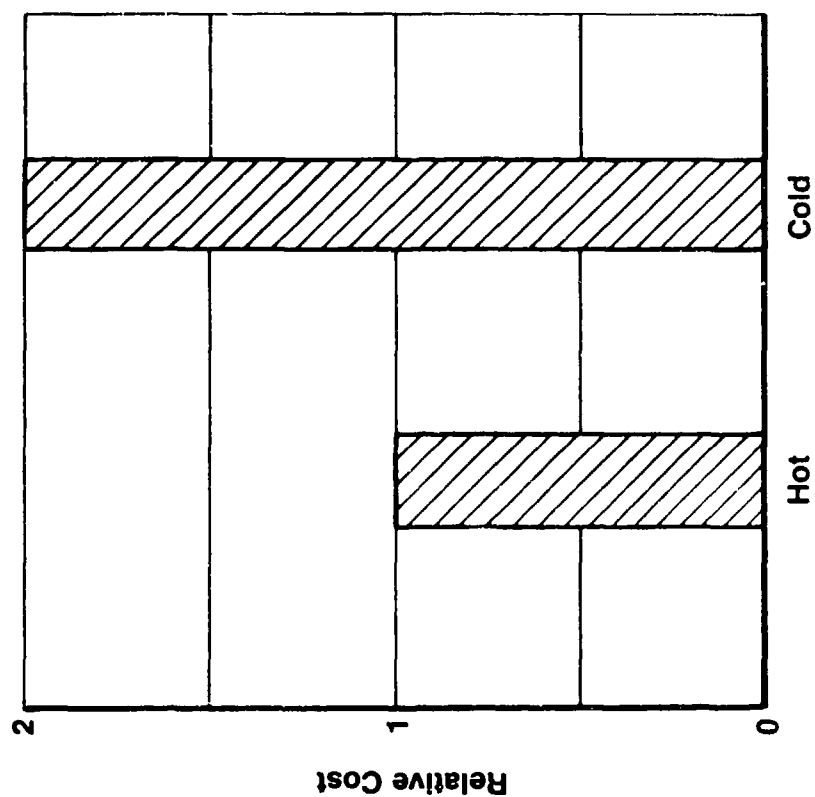
IMPACT OF SPF TOOL MATERIALS (CDE)



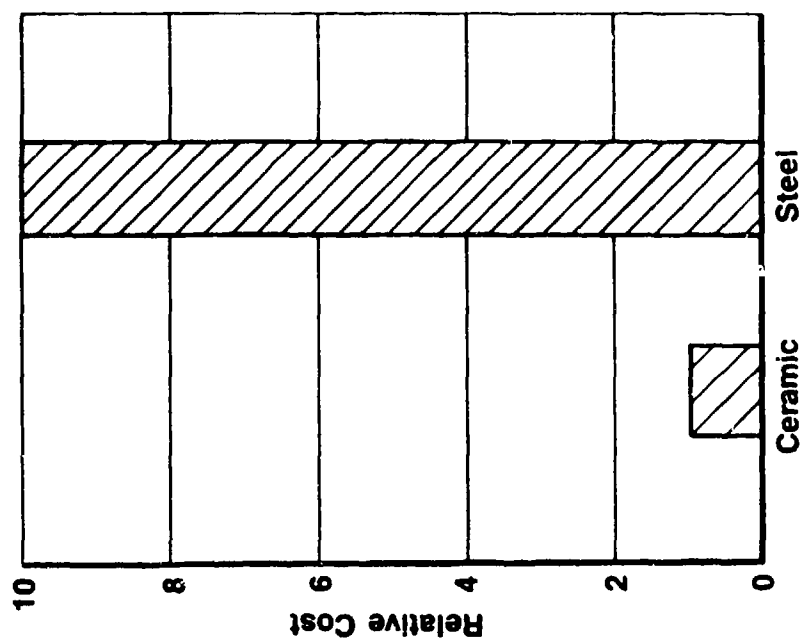
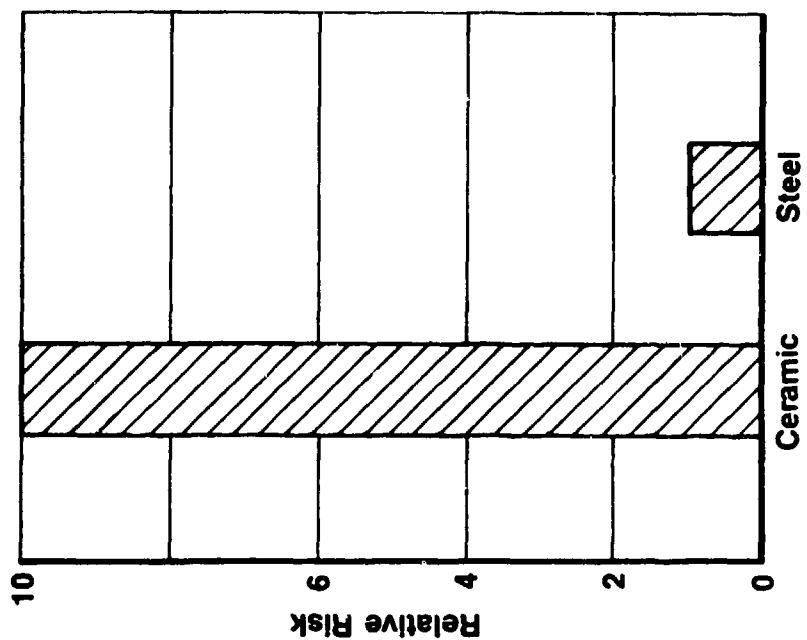
COST ELEMENTS:

- Ceramic requires model of part
- Steel tools are easily machined, but must be coated
- Superalloy tools difficult to machine (no coating required)

SPF PART LOADING/UNLOADING (CDE) (HOT VERSUS COLD)

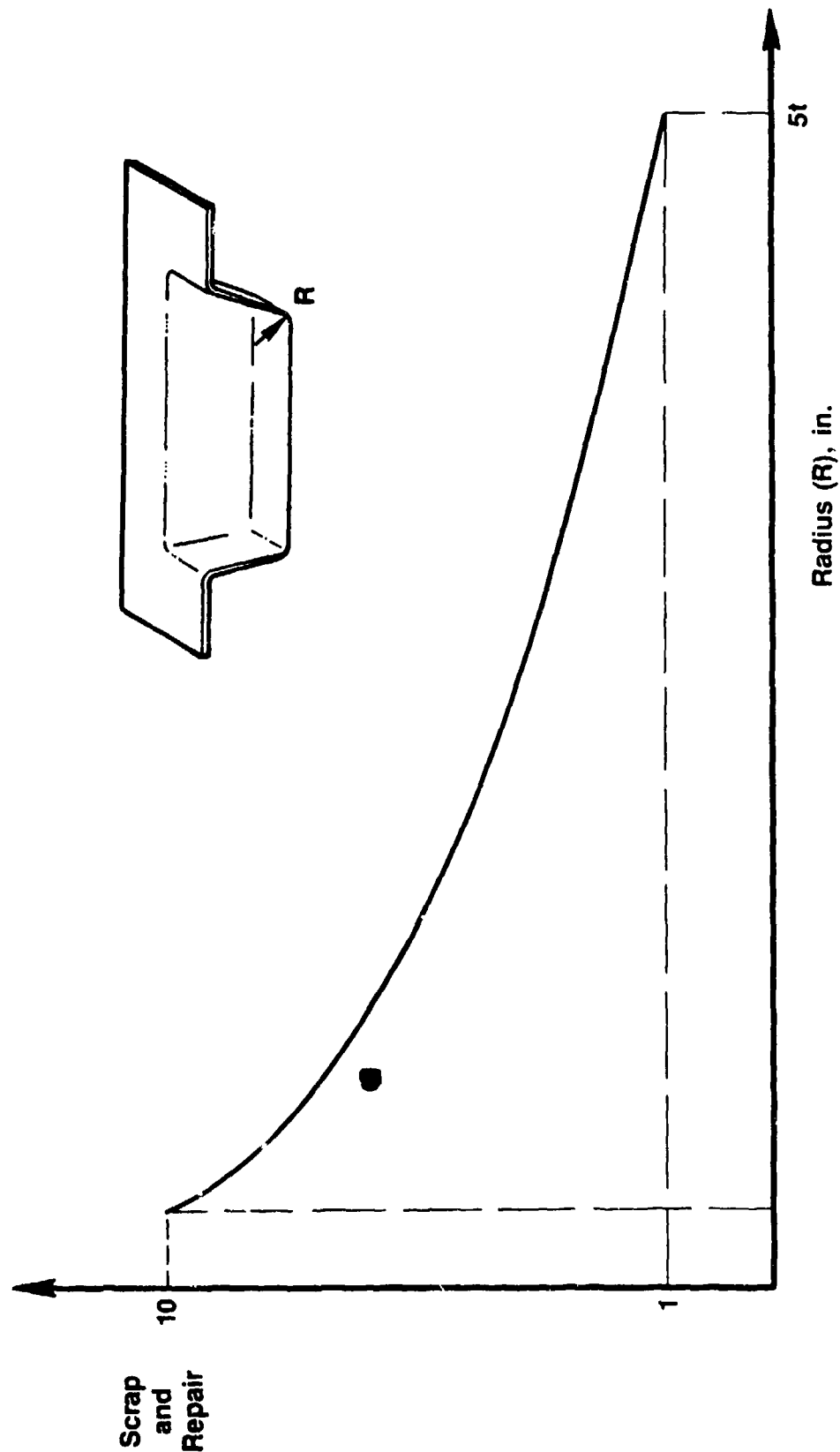


TOOL FABRICATION COST VERSUS OPERATIONAL RISK FOR SPF PARTS (CDE)

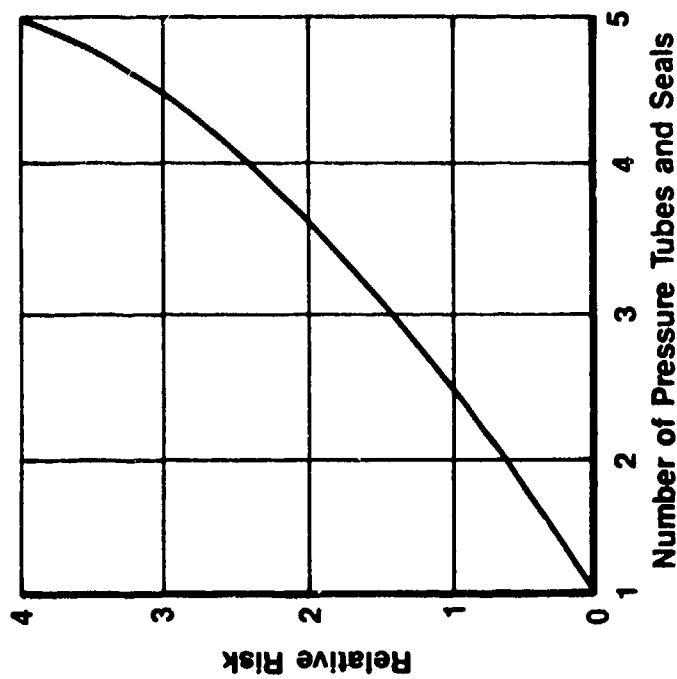


CDE-SPF-XXX

APPROXIMATION OF TREND IN SCRAP RISK AND REPAIR COSTS VERSUS RADIUS FOR SPF PARTS



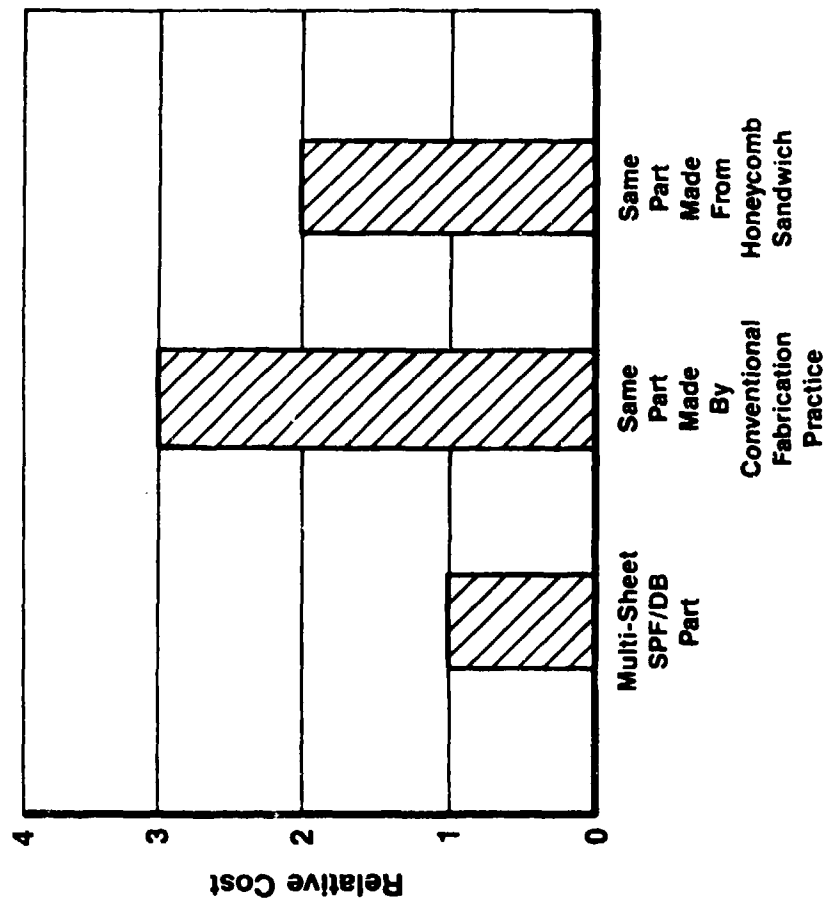
PRESSURE LEAK RISK (IMPACTING COST) IN SPF/DB OPERATION (CDE)



COST ELEMENT:

- Complex pressure management with multiple SPF/DB pressure circuits and sequences causes increased risk of leaks or pressure inlet blockages during operation

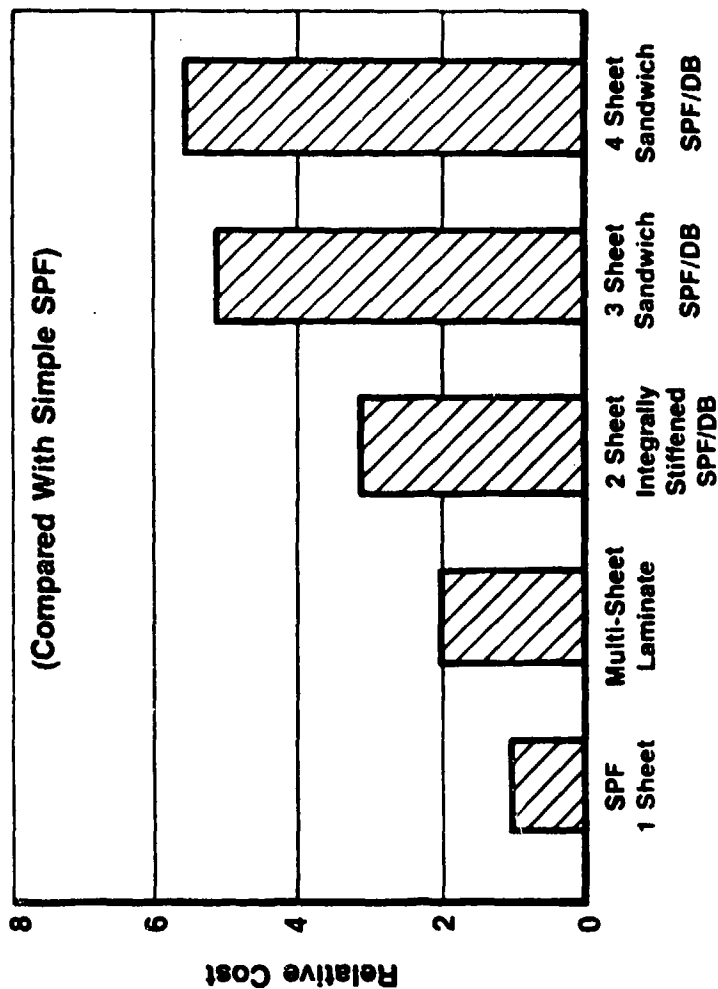
SPF/DB BENEFITS RELATIVE TO CONVENTIONAL FABRICATION AND SANDWICH CONSTRUCTION (CDE)



COST ELEMENTS:

- SPF/DB eliminates numerous conventional detail parts
- Eliminates assembly time and fasteners
- Usually lower weight structures with higher integrity
- Eliminates residual stresses caused by conventional assembly
- Eliminates cost of honeycomb core manufacture & assembly time

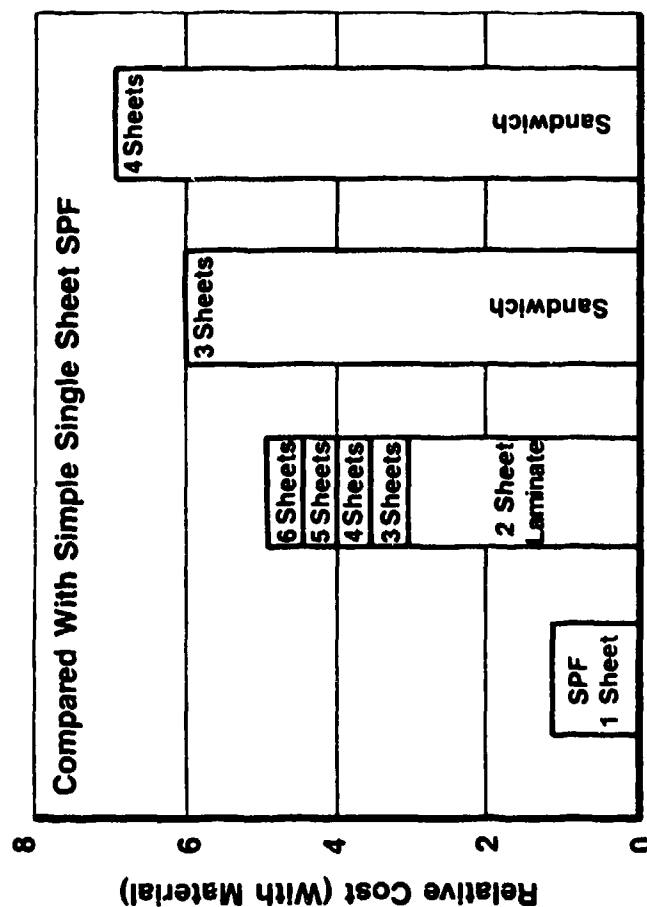
IMPACT OF SPF/DB ASSEMBLY TYPE ON COST (CDE)



COST ELEMENTS:

- 3 and 4 sheet structures requires complex assembly
 - Silk screen stop-off
 - Resistance weld pattern
 - Resistance weld edge sealing
 - TIG weld fittings (between each layer)
 - Complex plumbing
- The more assembly operations the greater the risk for
 - Leaks
 - Contamination
 - Misalignment
- Laminated SPF/DB does not require added pressure tubes or seals

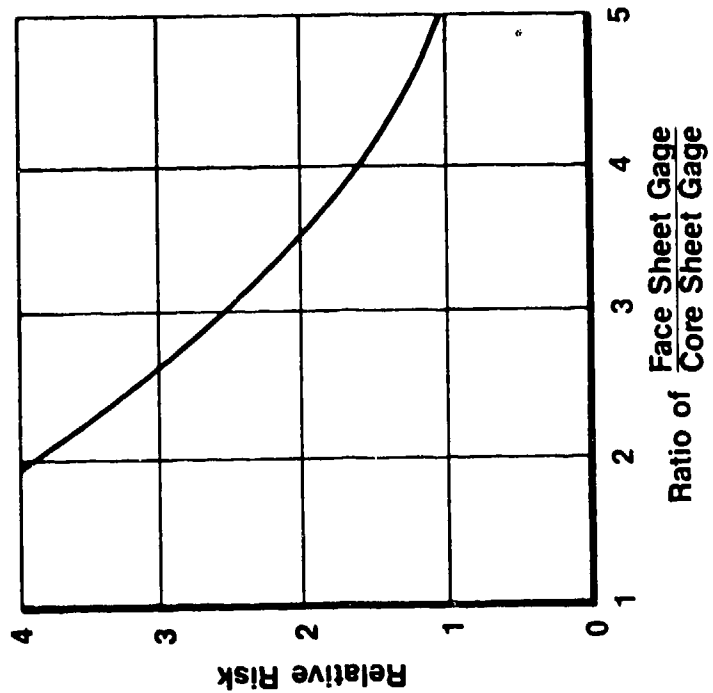
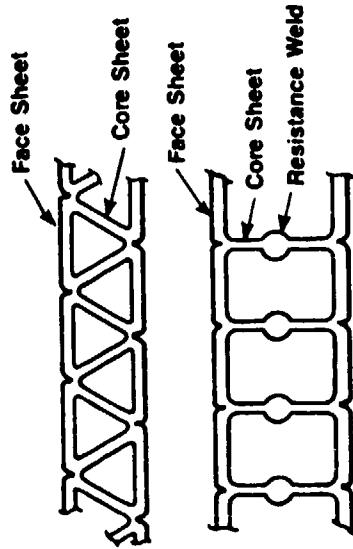
INFLUENCE OF NUMBER OF SHEETS ON SPF COST (CDE)



COST ELEMENTS:

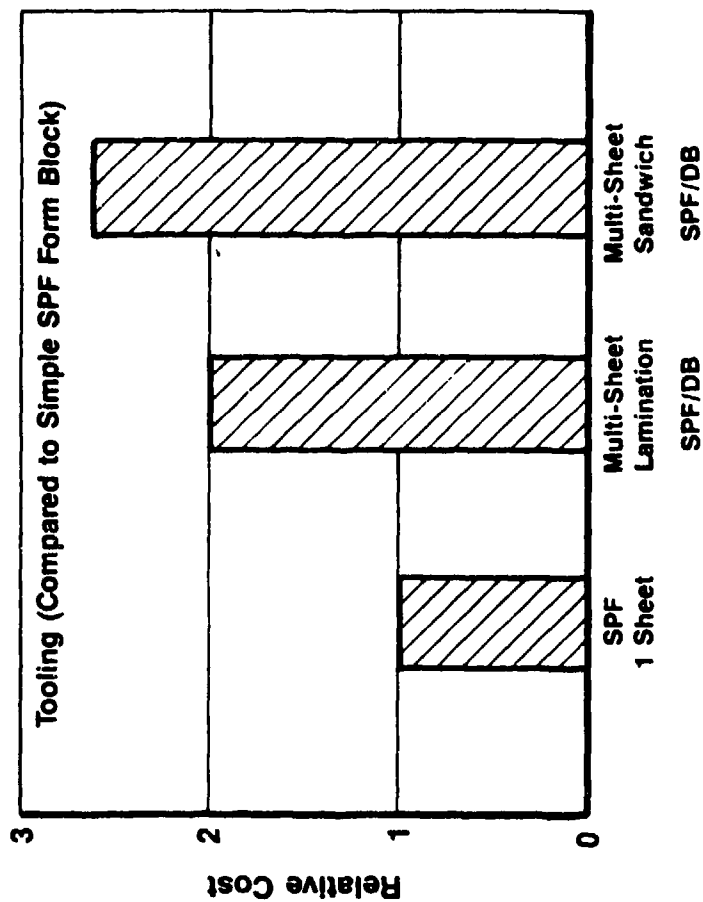
- 2 sheet (e.g., doubler or flange addition to SPF sheet) required to be SPF/DB in ultra-clean system
- 2, 3 & 4 sheets by either silk screen stop-off or resistance weld methods (sandwich)
- 2 sheet method may be extended to multiple sheets by lamination (no sandwich)
 - Used for reinforcing areas subject to extreme thinning
 - Accomplished in ultra-clean environment

RELATIVE RISK OF FACE DIMPLING OR GROOVING (IMPACTING COST) DURING SPF/DB OPERATION (CDE)



- Risk of dimpling or grooving decreases with increase in face to core thickness ratio

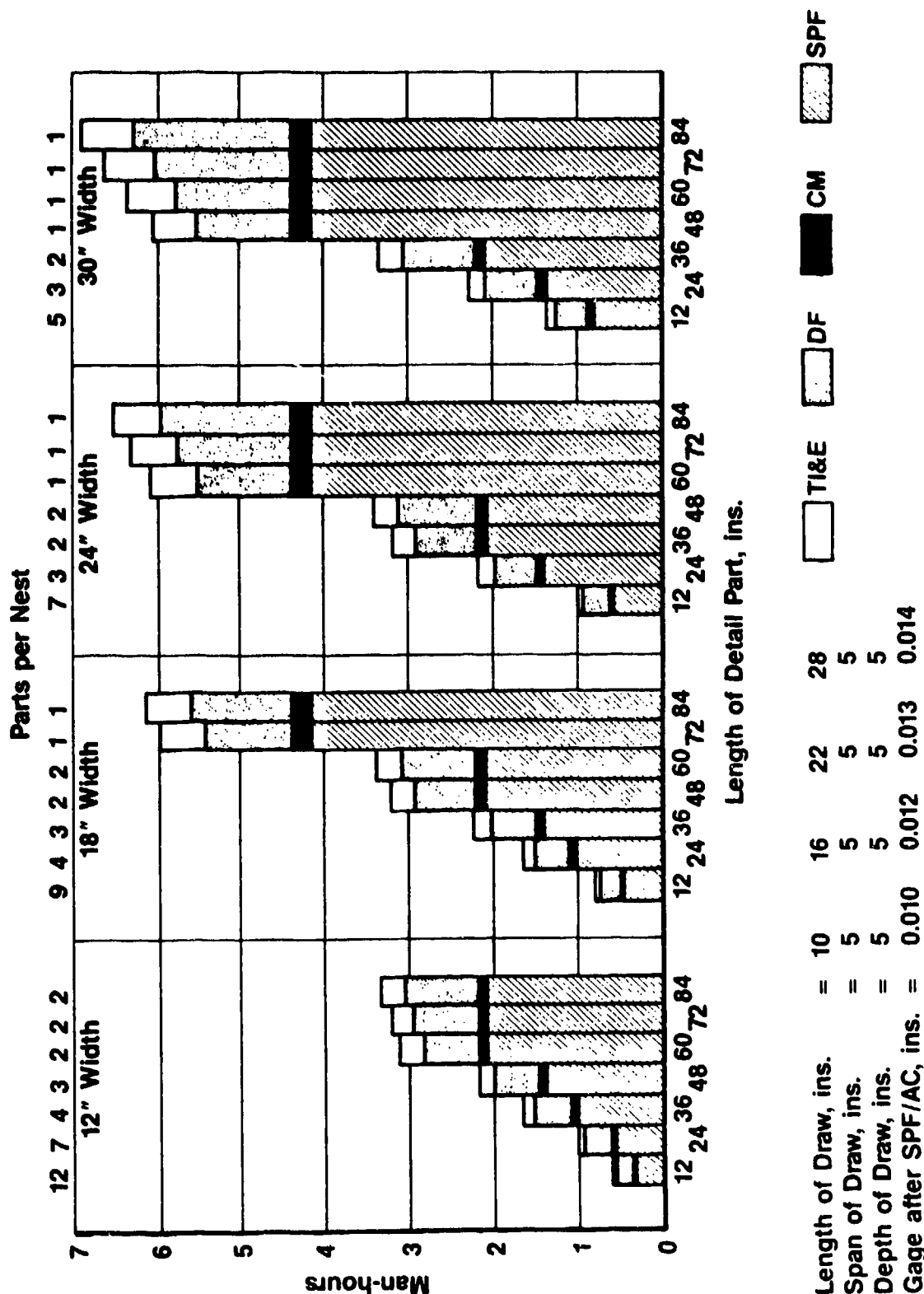
IMPACT OF SPF/DB COMPLEXITY ON TOOLING COST (CDE)



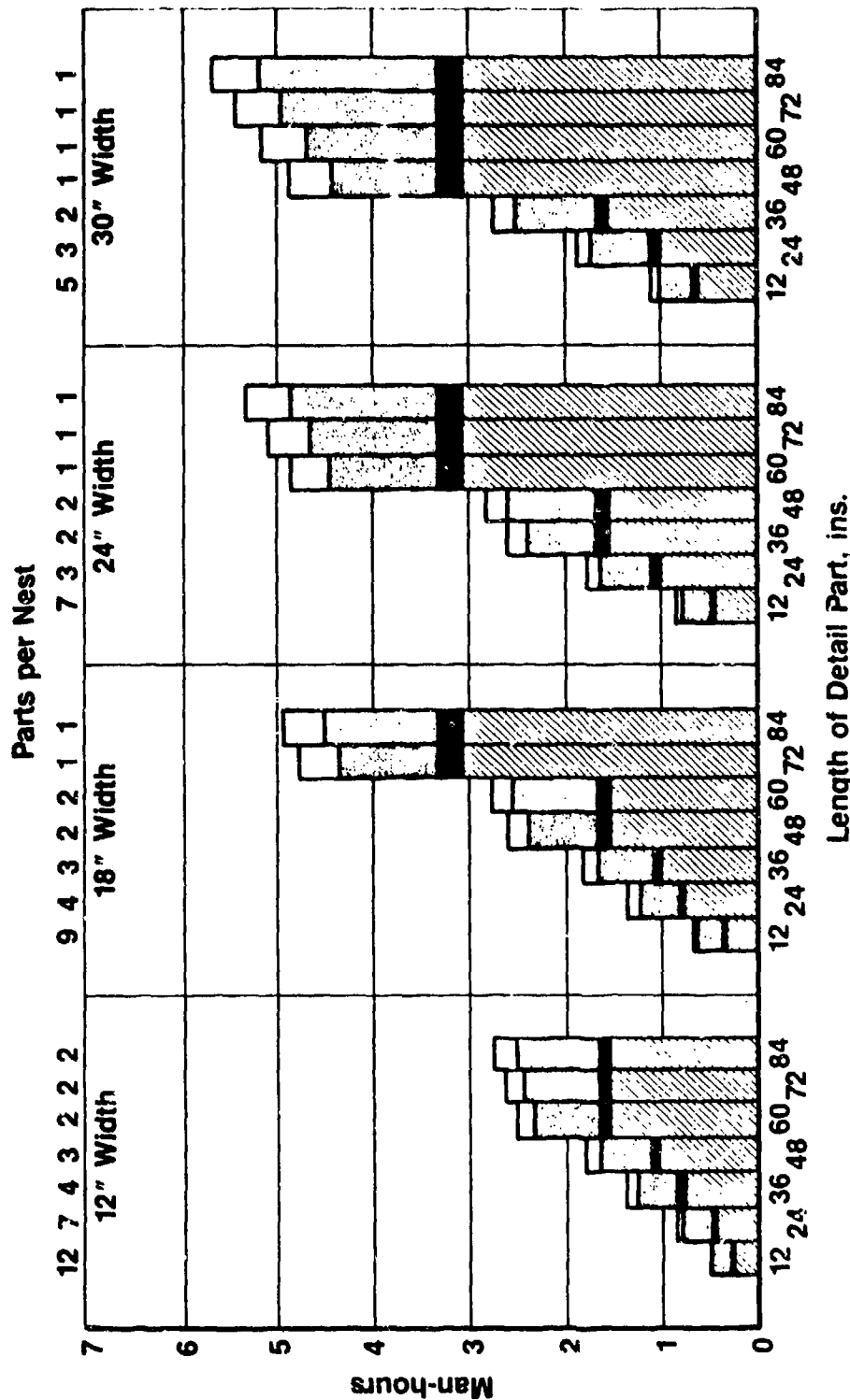
COST ELEMENTS:

- Laminating tools (graphite, refractory metals, etc.) designed for vacuum furnace operation
- Multi-sheet sandwich designed with provisions for numerous tubes and seals for SPF/DB pressure management

IMPACT OF ASPECT RATIO AND PART DIMENSIONS ON SPF DIAPHRAGM FORMING MAN-HOURS **Thickness 0.080", Aspect Ratio=1**



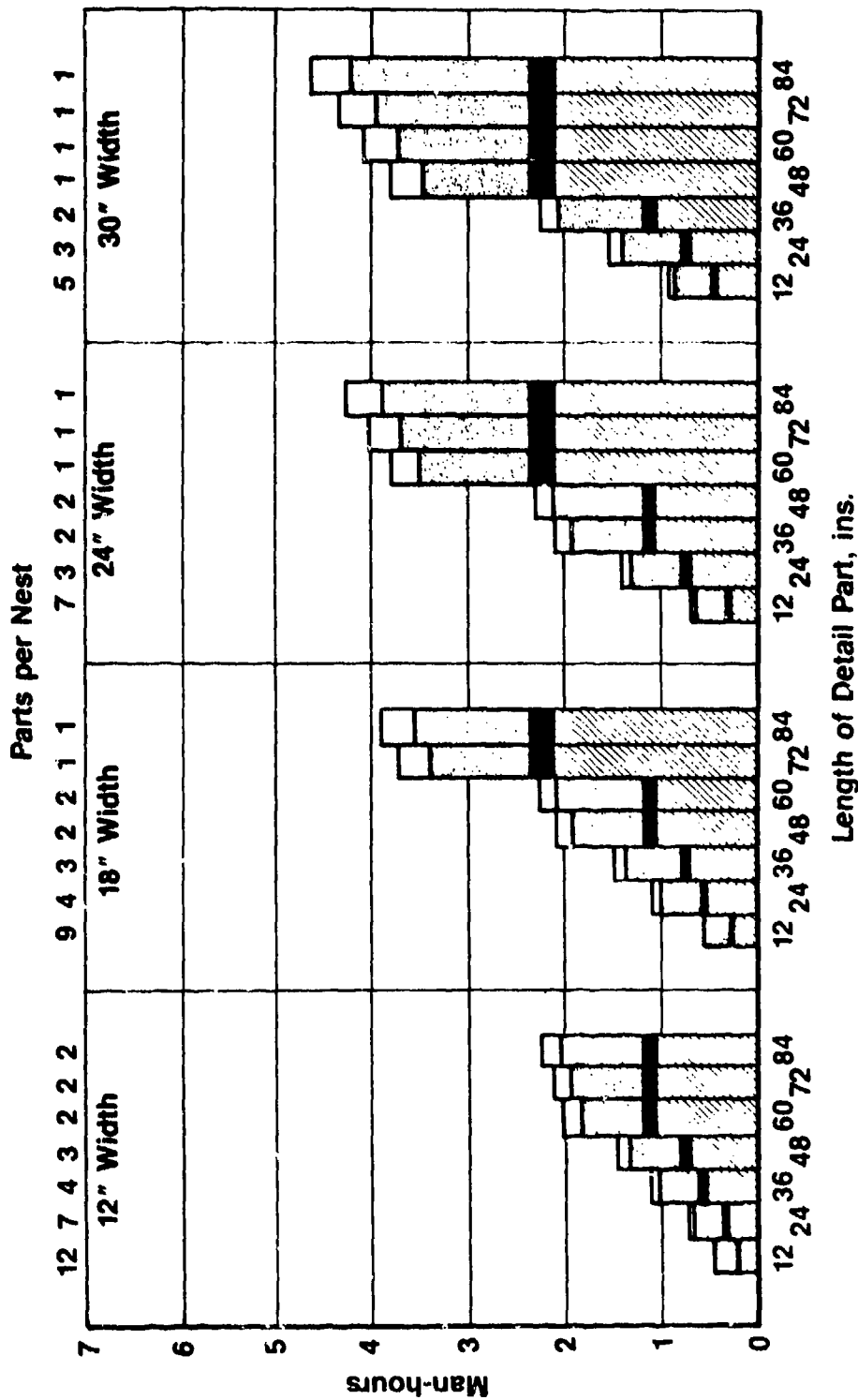
IMPACT OF ASPECT RATIO AND PART DIMENSIONS ON SPF DIAPHRAGM FORMING MAN-HOURS **Thickness 0.080", Aspect Ratio=2**



Length of Draw, ins. = 10 28
 Span of Draw, ins. = 5 5
 Depth of Draw, ins. = 2.50 2.50 2.50
 Gage after SPF/AC, ins. = 0.022 0.025 0.026 0.027

CED-SPF-2

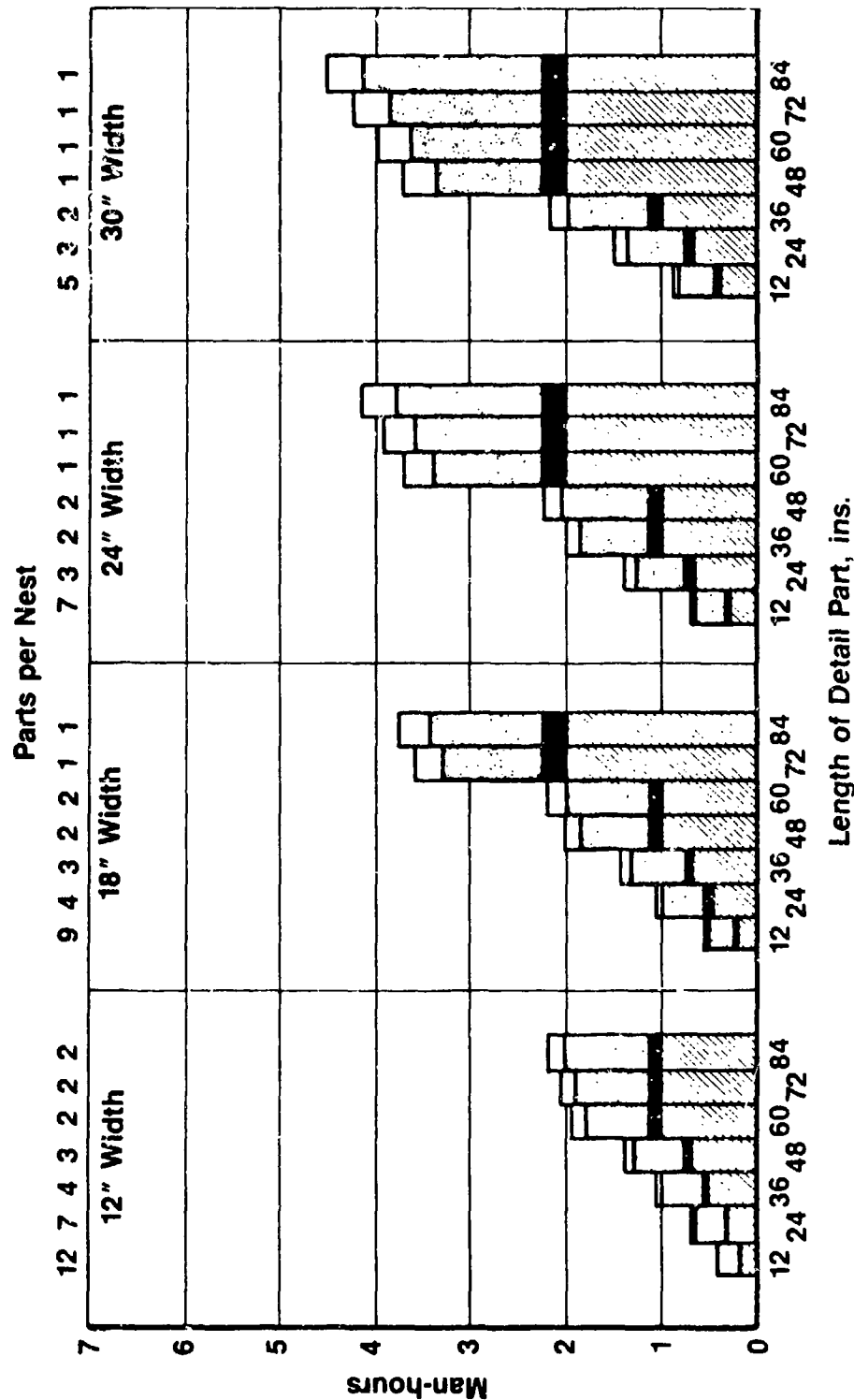
IMPACT OF ASPECT RATIO AND PART DIMENSIONS ON SPF DIAPHRAGM FORMING MAN-HOURS **Thickness 0.080", Aspect Ratio=3**



Length of Draw, ins. = 10 22 28
 Span of Draw, ins. = 5 5 5
 Depth of Draw, ins. = 1.67 1.67 1.67
 Gage after SPF/AC, ins. = 0.030 0.033 0.034 0.035

CED-SPF-3

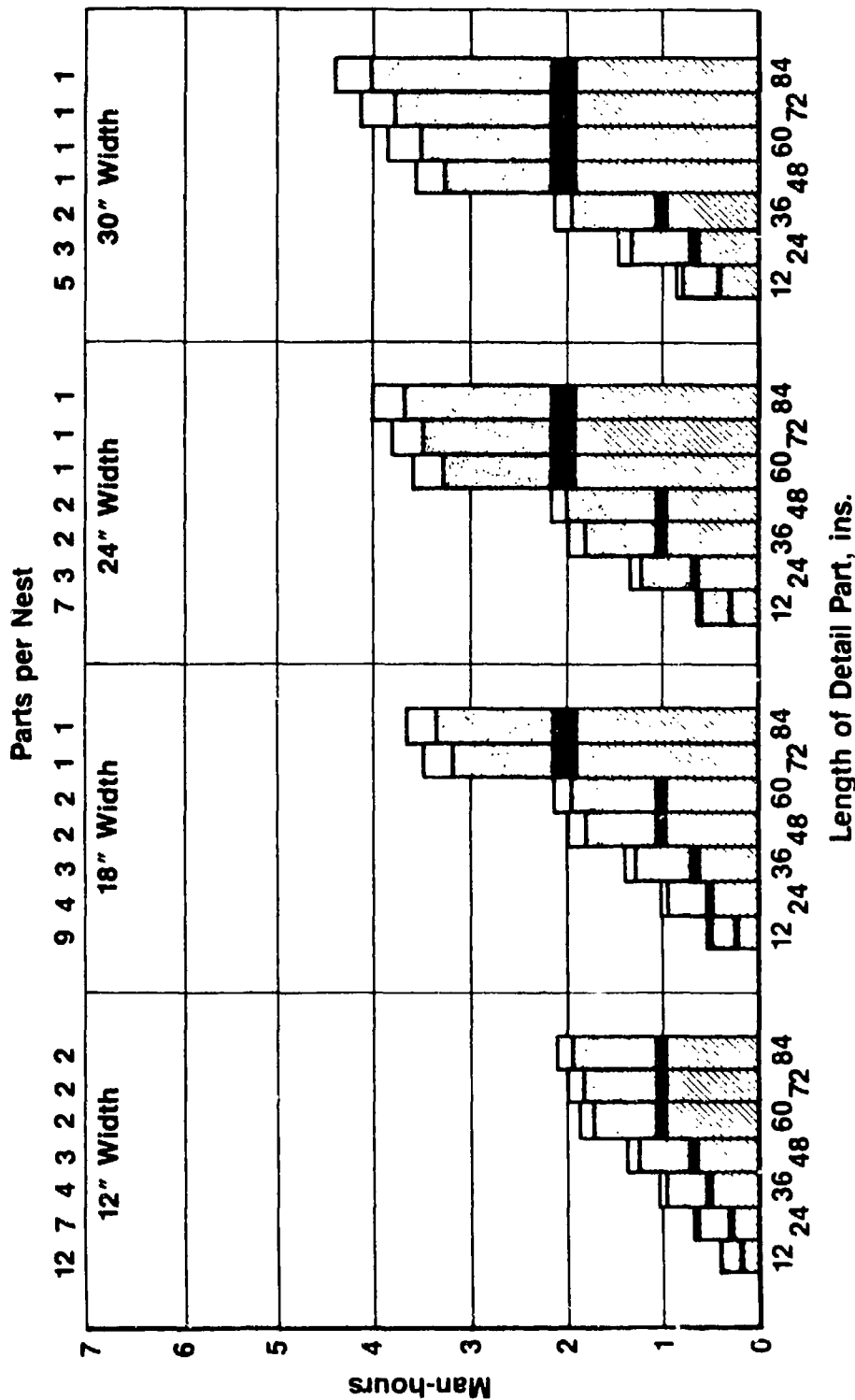
IMPACT OF ASPECT RATIO AND PART DIMENSIONS ON SPF DIAPHRAGM FORMING MAN-HOURS **Thickness 0.080", Aspect Ratio=4**



Length of Draw, ins. = 10
Span of Draw, ins. = 5
Depth of Draw, ins. = 1.25
Gage after SPF/AC, ins. = 0.036

28 22 16 10
5 5 5 5
1.25 1.25 1.25 1.25
0.040 0.038 0.036 0.040

IMPACT OF ASPECT RATIO AND PART DIMENSIONS ON SPF DIAPHRAGM FORMING MAN-HOURS **Thickness 0.080", Aspect Ratio=5**

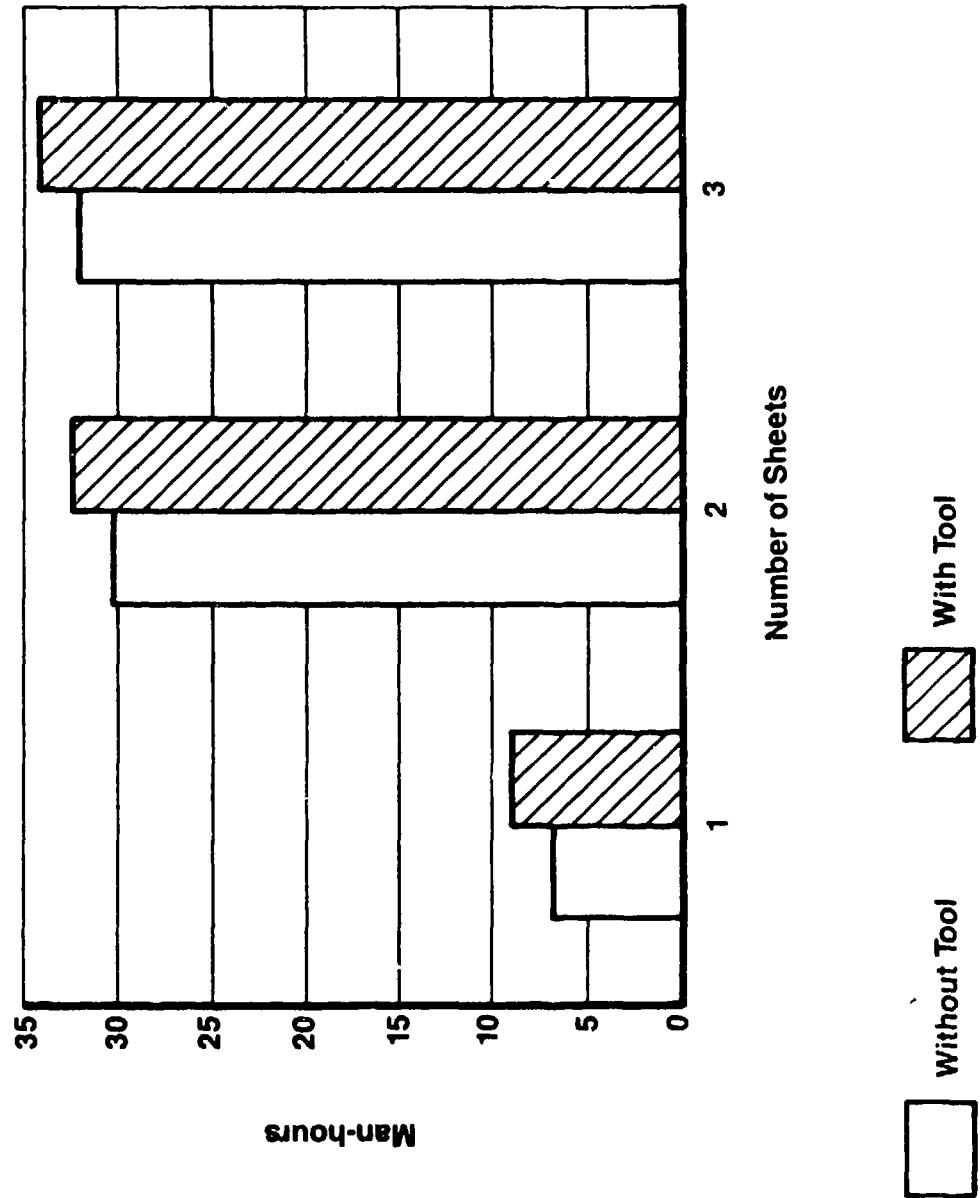


Length of Draw, ins. = 10 22 28
 Span of Draw, ins. = 5 5 5
 Depth of Draw, ins. = 1 1 1
 Gage after SPF/AC, ins. = 0.040 0.042 0.044 0.044

CED-SPF-5

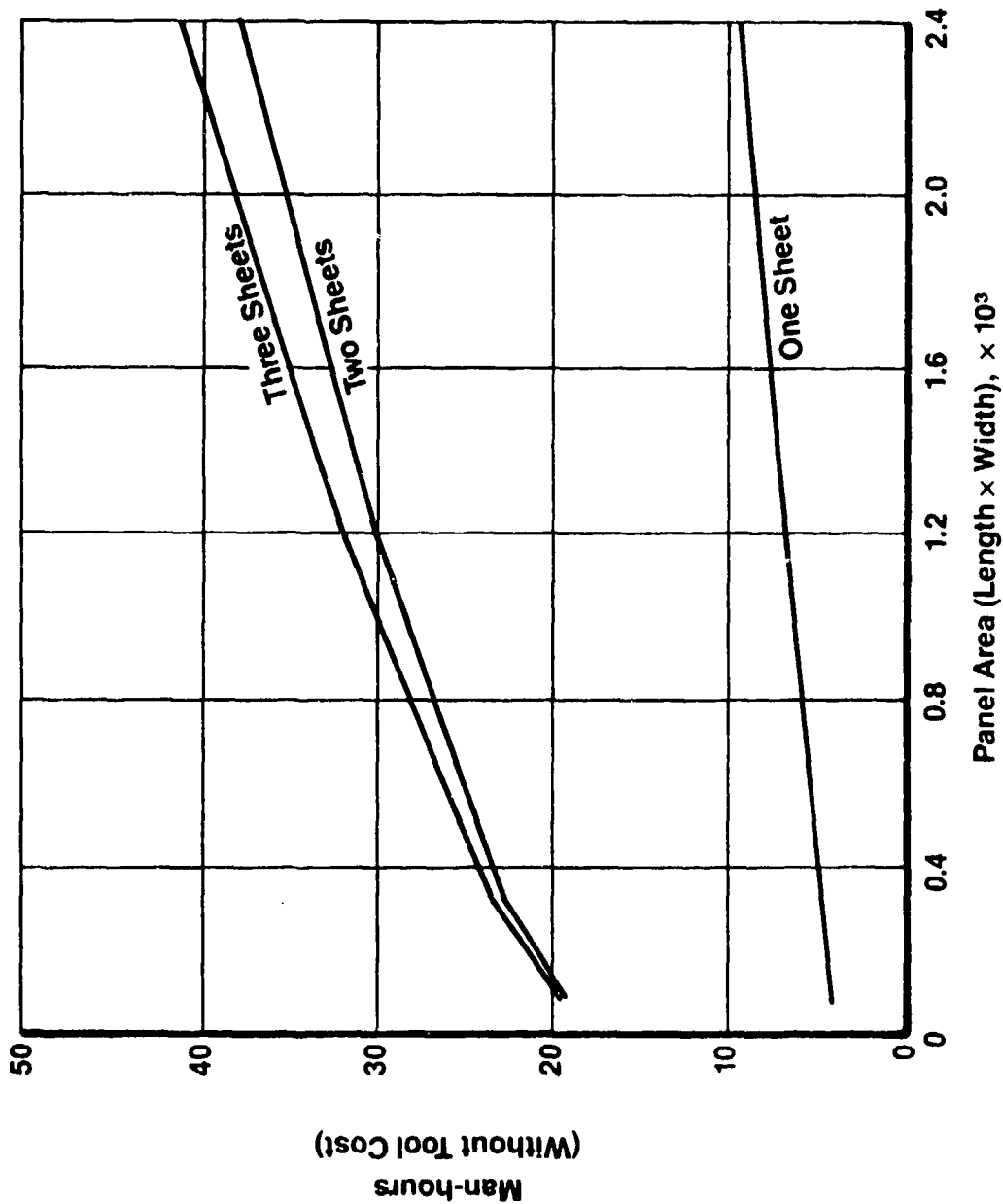
IMPACT OF NUMBER OF SHEETS ON MANUFACTURING COST

One, Two, and Three Sheets

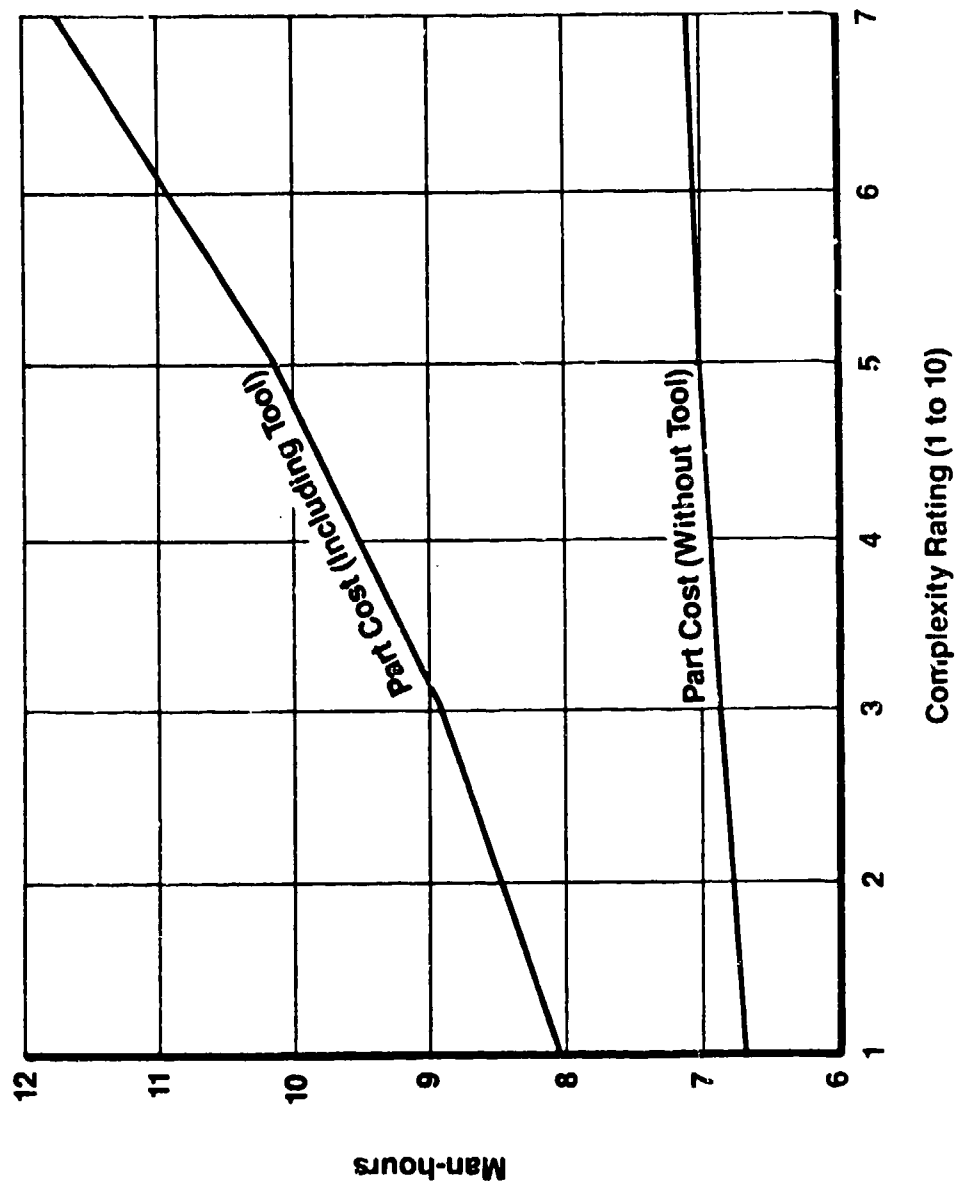


IMPACT OF PLAN AREA ON SPF PART COST

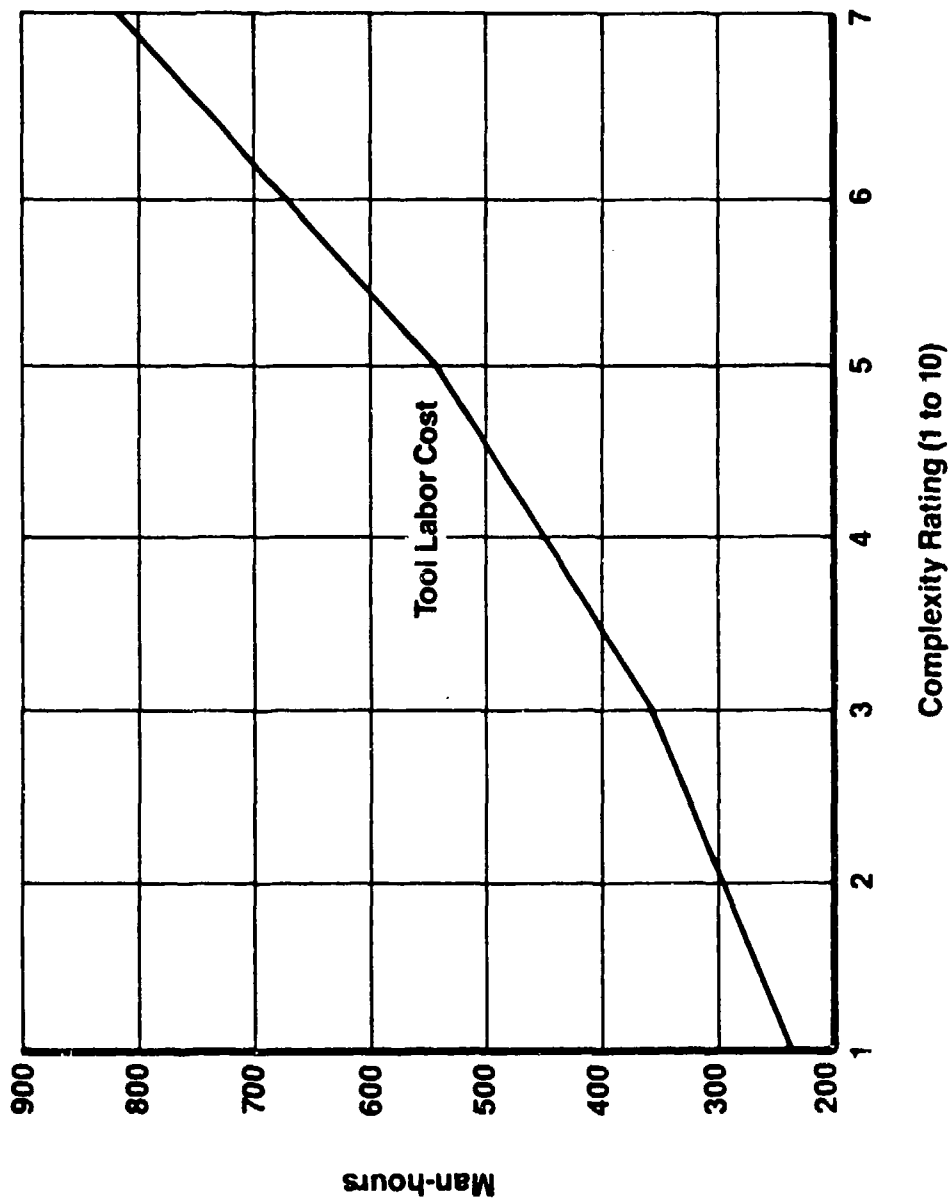
One, Two, and Three Sheets



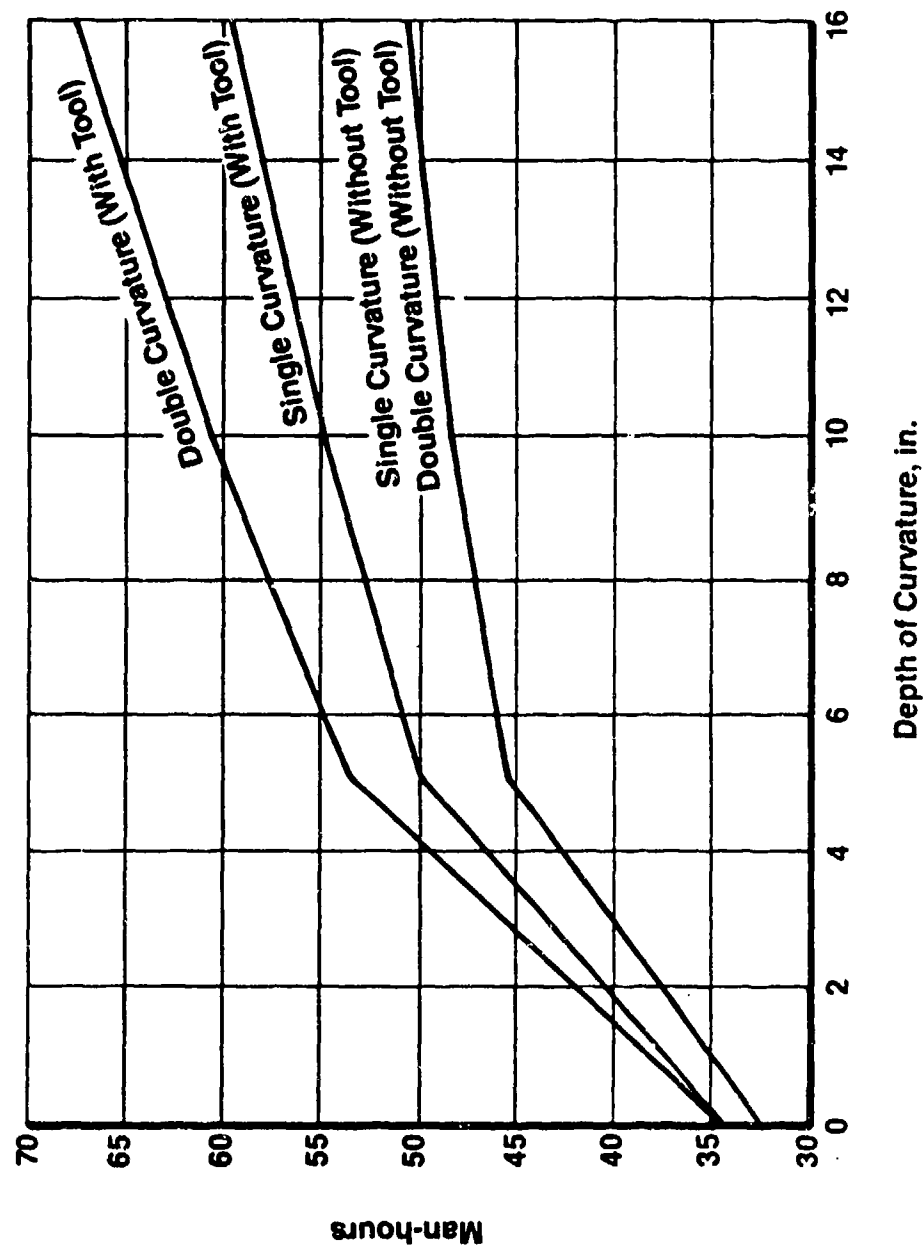
IMPACT OF SURFACE COMPLEXITY ON SPF PART COST (Fabrication Only; Material Not Included)



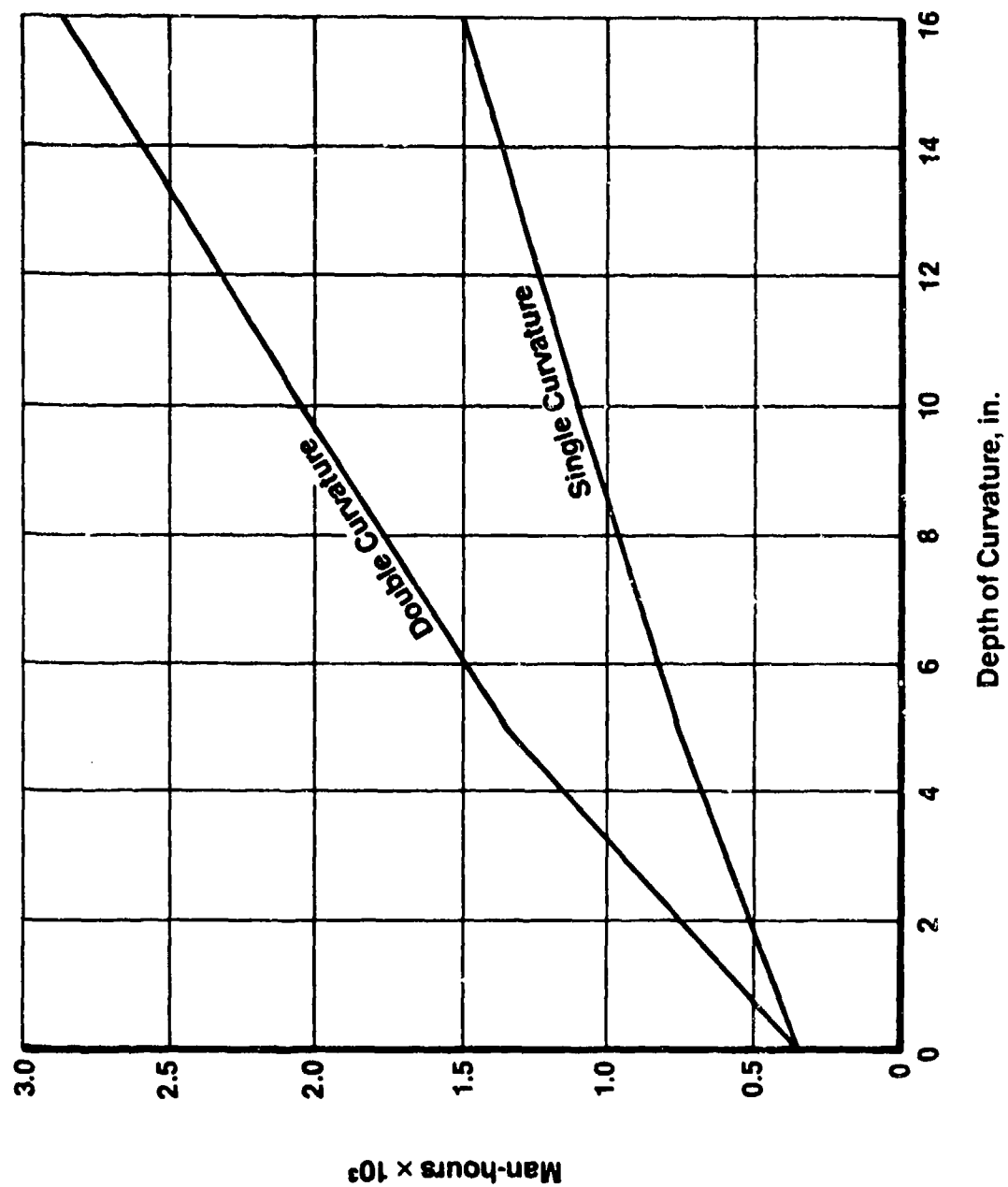
IMPACT OF SURFACE COMPLEXITY ON SPF TOOLING COST (Tool Fabrication Cost Only)



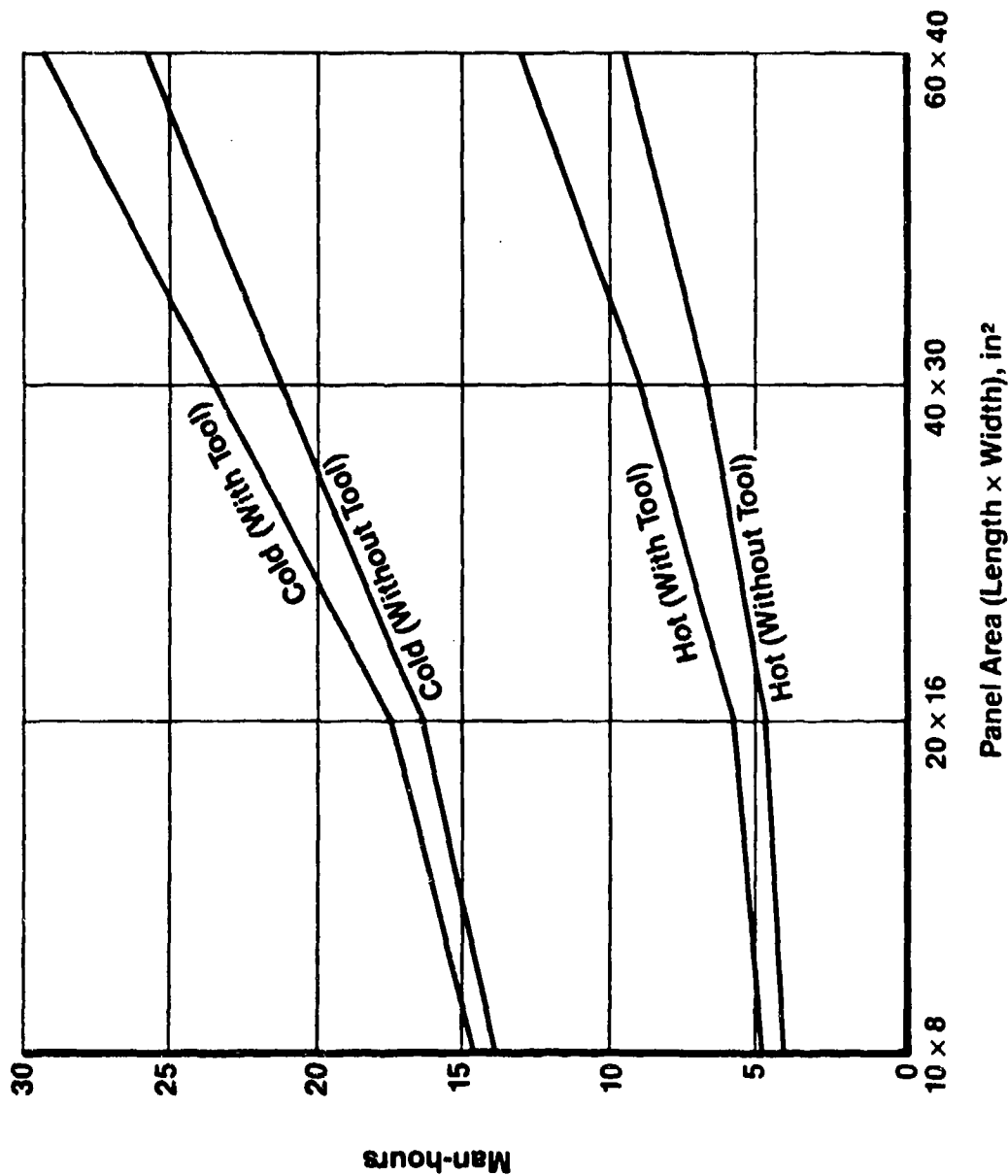
**IMPACT OF COMPLEXITY (CURVATURE)
ON SPF PART COST
(Fabrication Only; Material Not Included)**



**IMPACT OF COMPLEXITY (CURVATURE)
ON SPF TOOL COST
(Tool Fabrication Cost Only)**

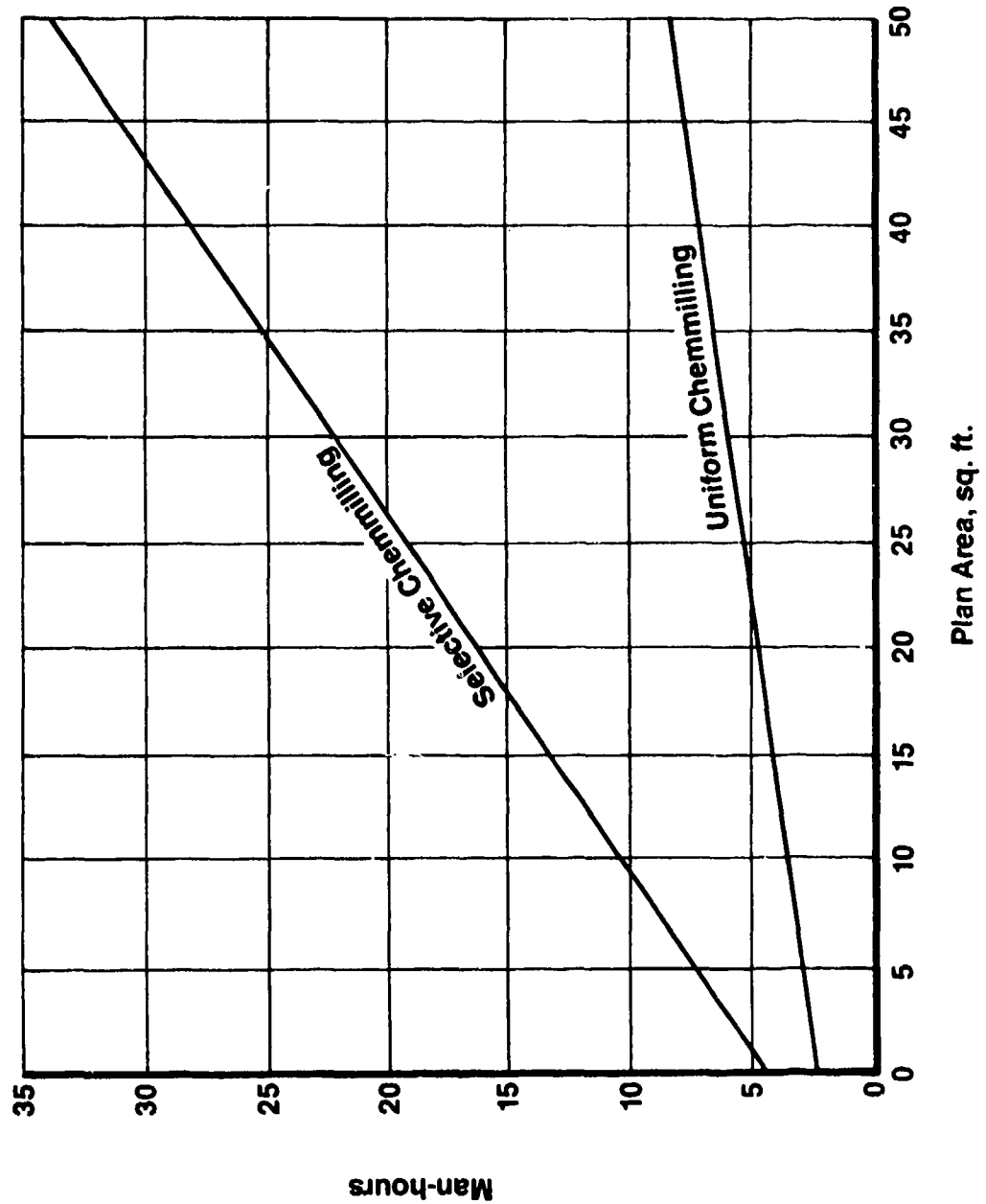


IMPACT OF HOT AND COLD LOADING ON SPF PART FABRICATION COST (One Sheet Only) (Fabrication Only; Material Not Included)

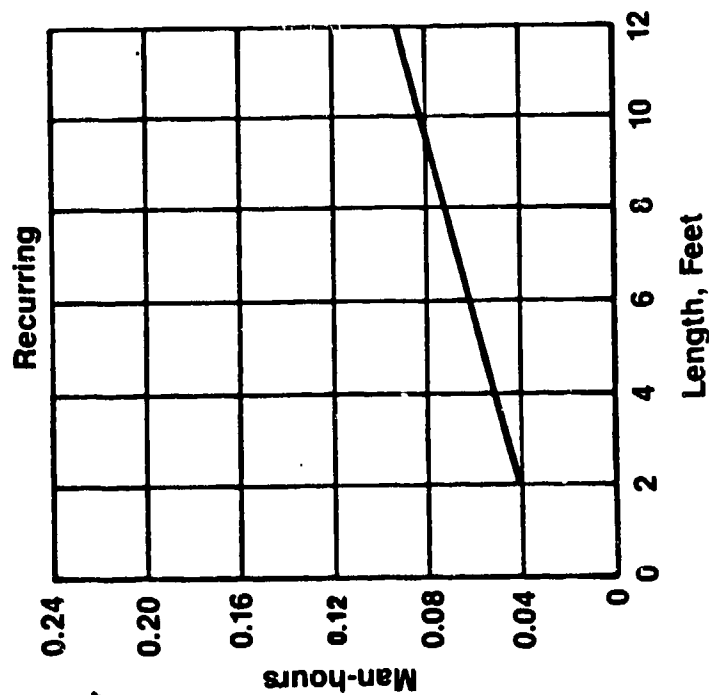
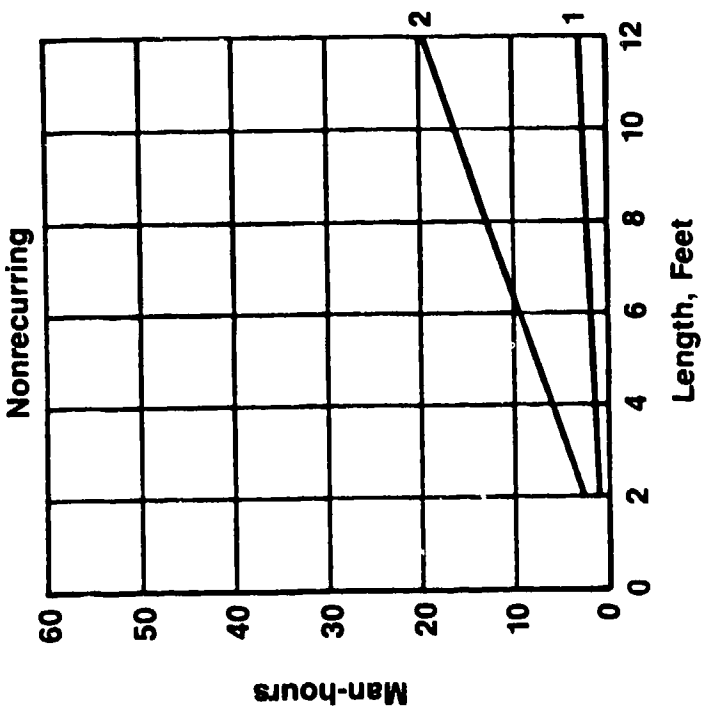


IMPACT OF CHEMMILLING ON SPF PART COST

Selective and Uniform Chemmilling



TI&E **TITANIUM ANGLE, STRAIGHT MEMBER**

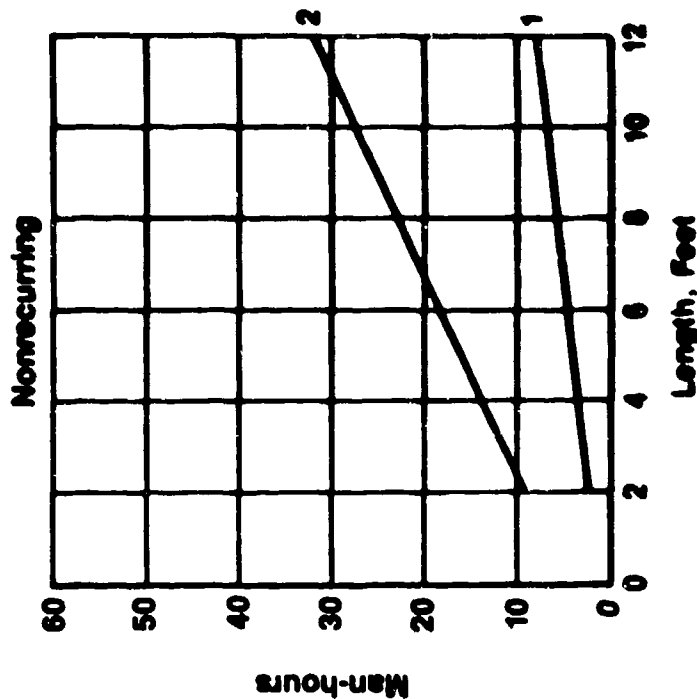
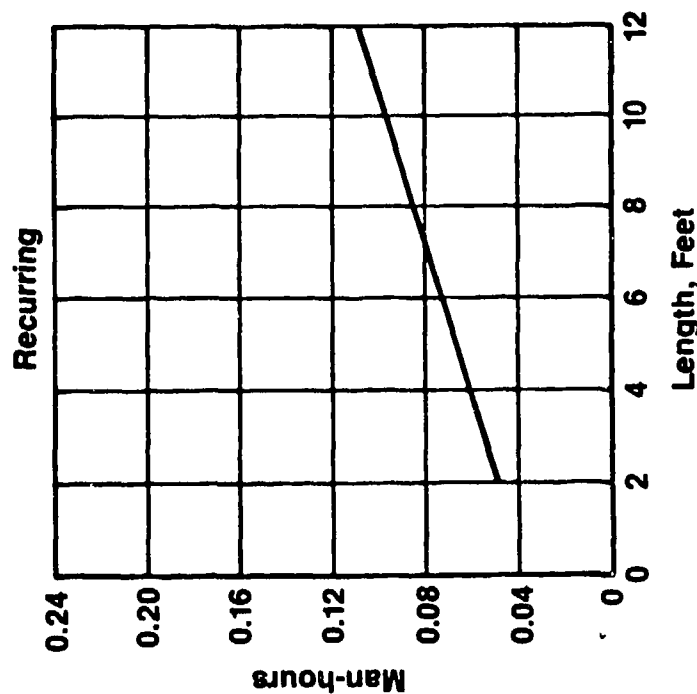


Applicable DICE (A,B,D)

1. Room Temperature Brake Formed, Minimum Bend Radius = 5t.
2. Preform/Hot Size, Minimum Bend Radius = 2t.

CED-SPF-14

TI&E **TITANIUM ZEE, STRAIGHT MEMBER**

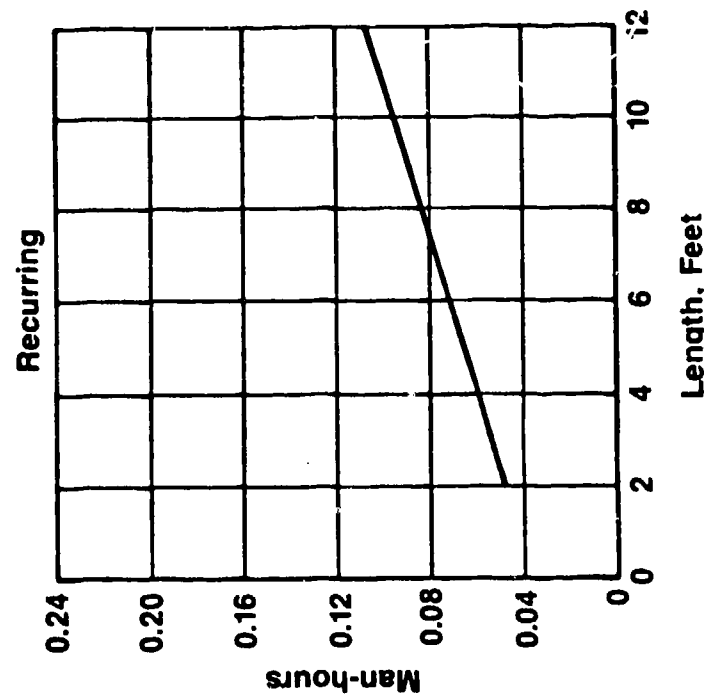
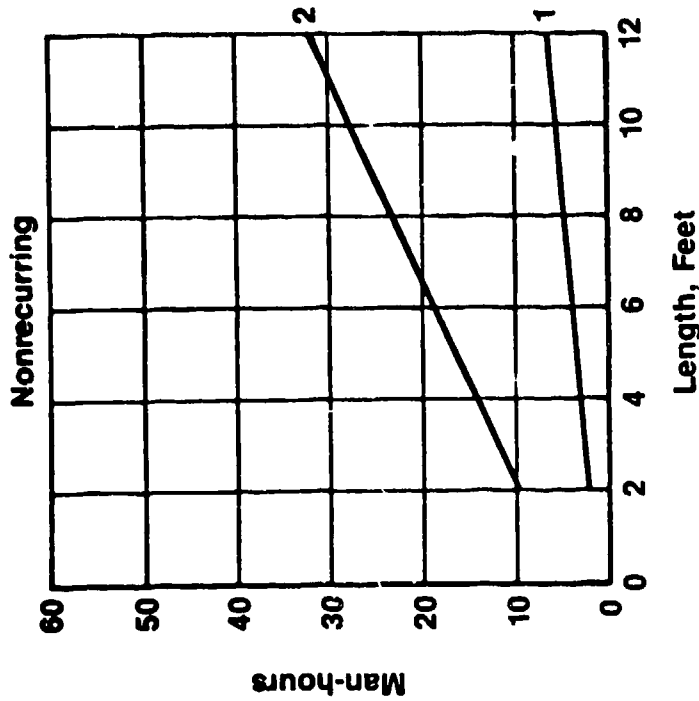


Applicable DICE (A,B,D,E)

1. Room Temperature Brake Form, Minimum Bend Radius = 5t.
2. Preform/Hot Size, Minimum Bend Radius = 2t.

CED-SPF-15

TI&E **TITANIUM CHANNEL, STRAIGHT MEMBER**

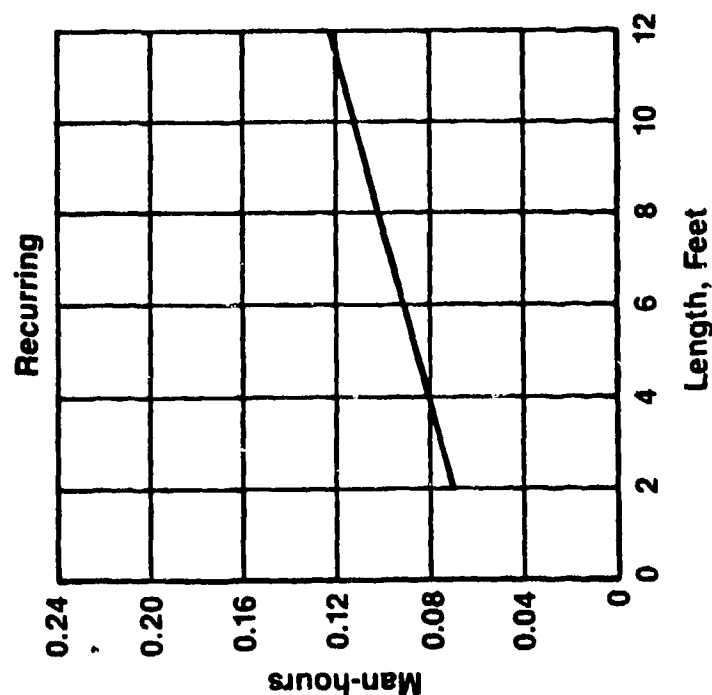
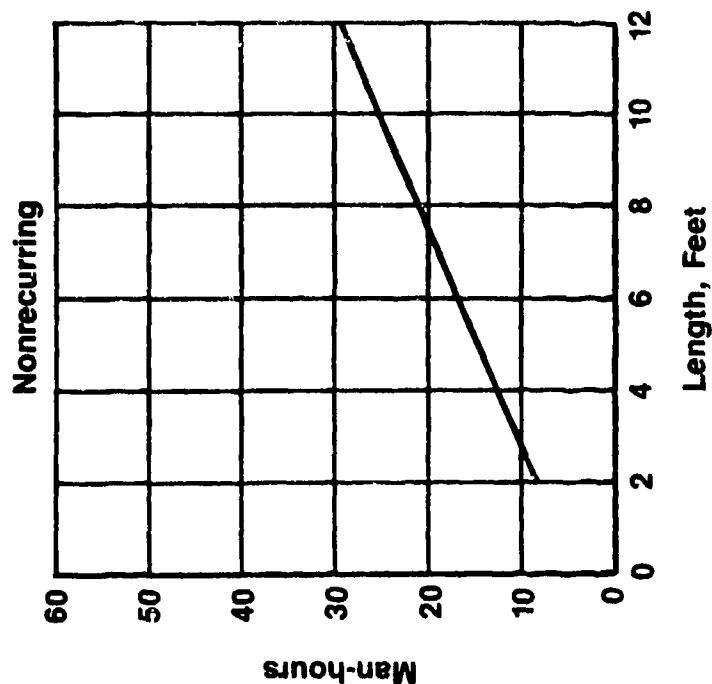


Applicable DICE (A,B,D,E)

1. Room Temperature Brake Form, Minimum Bend Radius = 5t.
2. Preform/Hot Size, Minimum Bend Radius = 2t.

CED-SPF-16

TI&E **TITANIUM ANGLE, CONTOURED MEMBER***

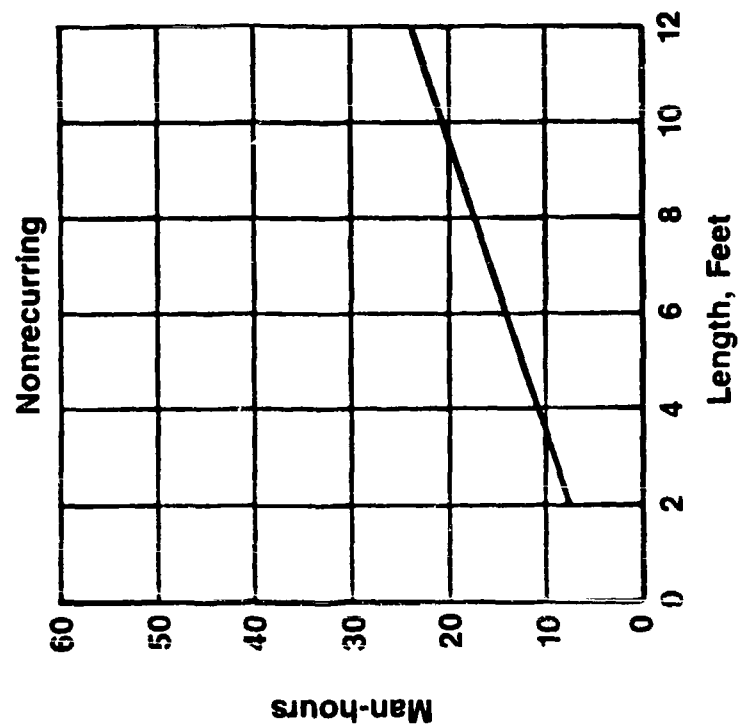
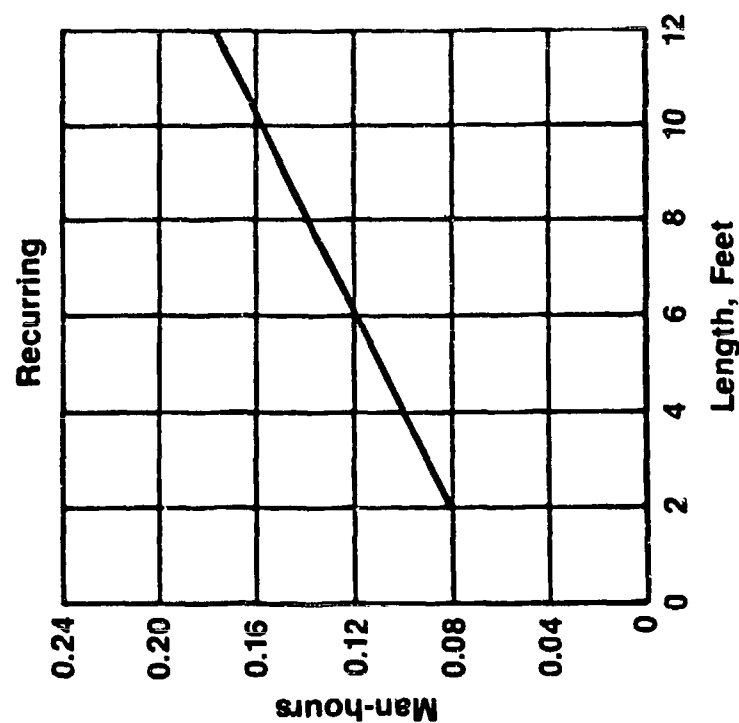


*No Reverse Curvature

Applicable DICE (A,B,D,E)

CED-SPF-17

TI&E **TITANIUM ZEE, CONTOURED MEMBER***

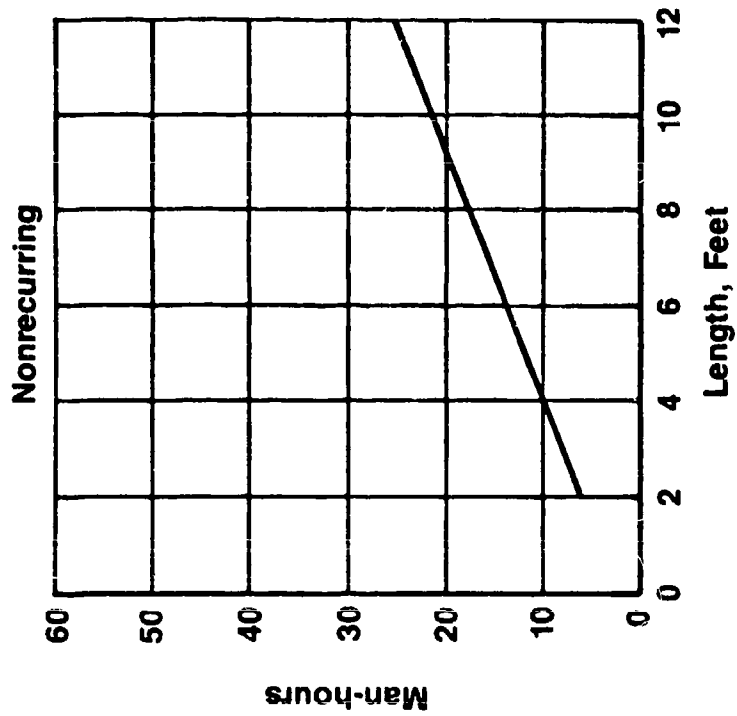
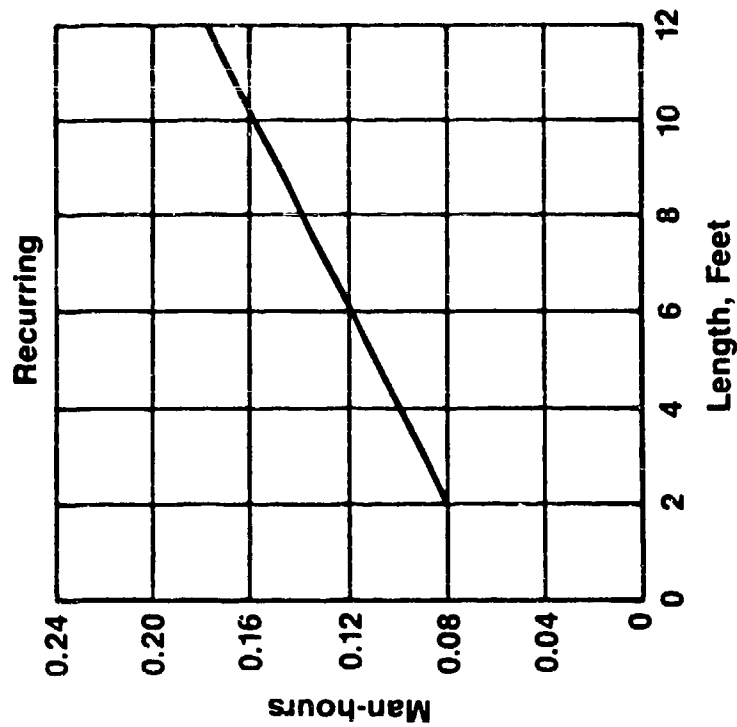


*No Reverse Curvature

Applicable DICE (A,B,E)

CED-SPF-18

TI&E **TITANIUM CHANNEL, CONTOURED MEMBER***

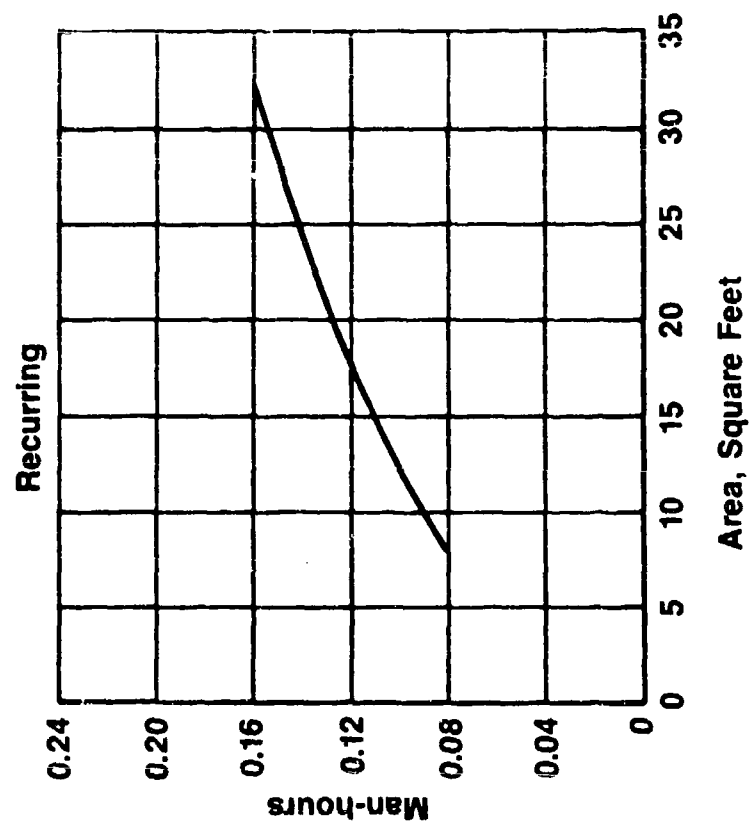
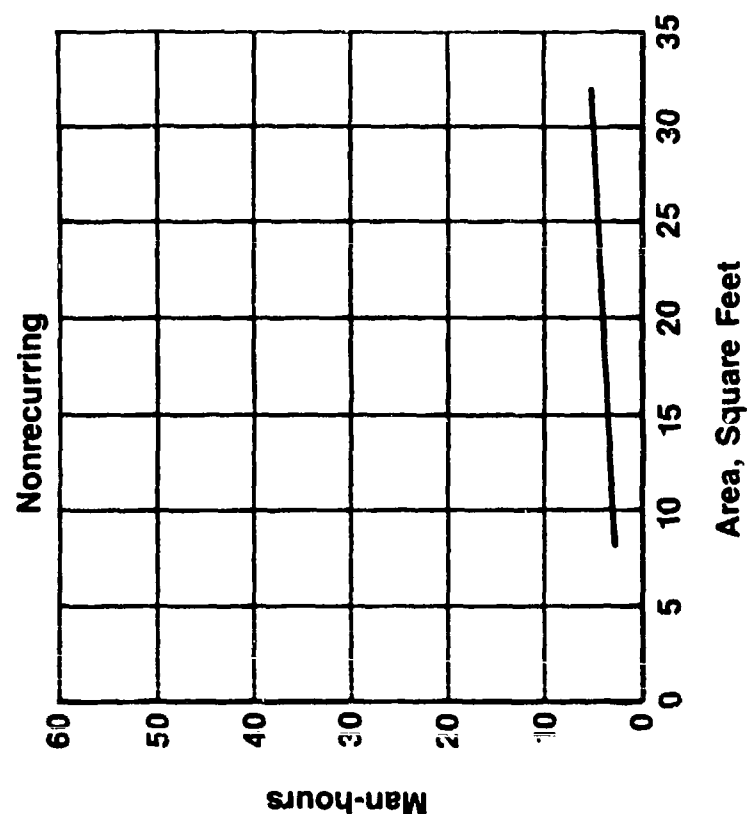


*No Reverse Curvature

Applicable DICE (A,B,D)

CED-SPF-19

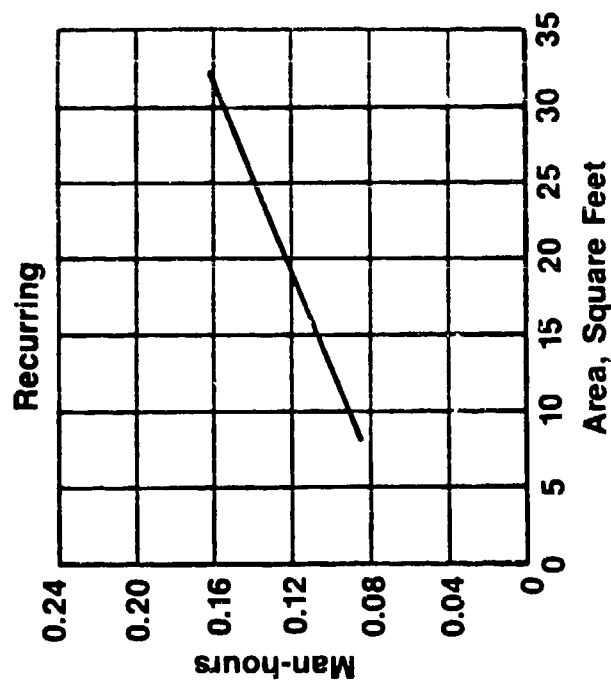
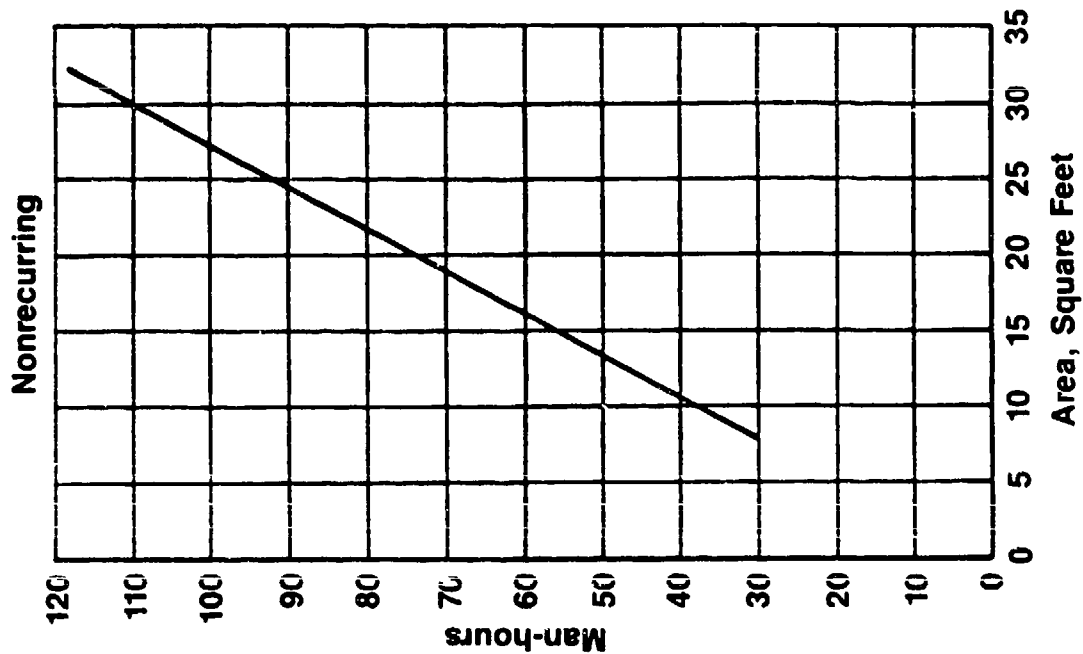
T1&E **TITANIUM CYLINDRICAL CURVATURE SKIN**



Applicable DICE (D,E)

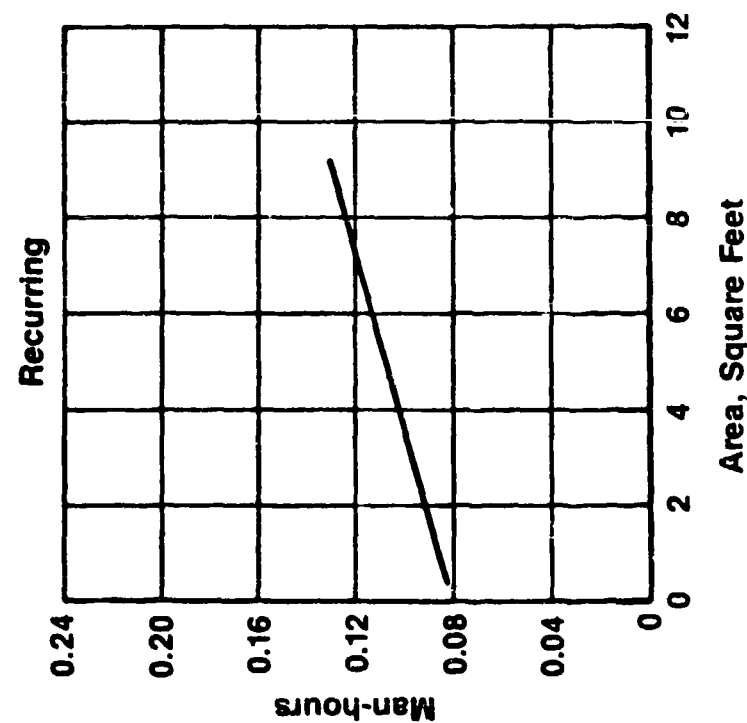
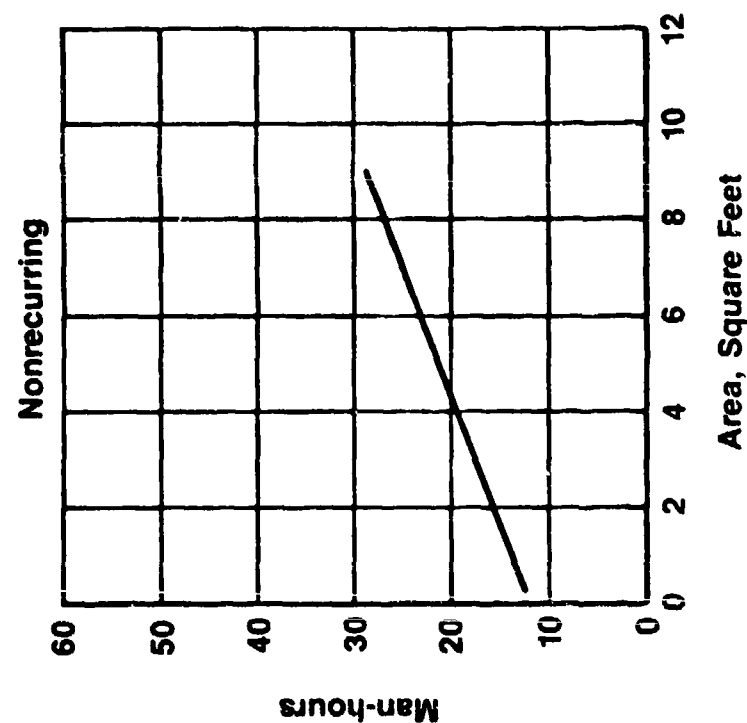
CED-SPF-20

TI&E **TITANIUM NONCYLINDRICAL** **CURVATURE SKIN***



*No Reverse Curvature
 Applicable DICE (D,E)

T1&E TITANIUM FRAME



Applicable DICE (A,B,D,E)

CED-SPF-22

TI&E DICE—SHEET METAL LINEAL SHAPES TITANIUM

**TI&E Man-hours per
Characteristic Inspected**

PART & METHOD	SIZE	A	B	C	D	E	F	G
• Straight								
• Brake Formed								
• Room Temperature	All	0.007	0.005		0.006	0.010		
• Straight								
• Elevated Temperature Forming	All	0.007	0.005		0.006	0.010		
• Contoured								
• Elevated Temperature Forming	All	0.012	0.003		0.010	0.010		
• Contoured								
• Elevated Temperature Forming	All	0.008	0.007			0.010		

- A. Standard Joggle
- B. Standard Flanged Hole
- C. Heat Treatment (Removed from DICE)
- D. Cutout Without Flanges
- E. Trim-Lineal, Ends, Corners
- F. Clean
- G. NDT (Penetrant)

NOTE: These DICE Designations Do Not Correspond with the Designations Used in the Sheet-Metal Forming Section.

CED-SPF-23

TI&E DICE—SHEET METAL NON-LINEAL SHAPES TITANIUM

TI&E Man-hours per
Characteristic Inspected

PART & METHOD	SIZE	A	B	C	D	E	F	G
• Cylindrically Contoured Skin	All							
• Farnham Roll					0.012	0.010		
• Non-Cylindrically Contoured Skin	All							
• Elevated Temperature Forming					0.012	0.010		
• Frame	All							
• Elevated Temperature Forming		0.012	0.008		0.010	0.010		

- A. Standard Joggle
- B. Standard Flanged Hole
- C. Heat Treatment (Removed from DICE)
- D. Culout Without Flanges
- E. Trim-Lineal, Ends, Corners
- F. Clean
- G. NDT (Penetrant)

NOTE: These DICE Designations Do Not Correspond with the Designations Used in the Sheet-Metal Forming Section.

SECTION 7.0 MECHANICALLY FASTENED ASSEMBLY

This section contains format selection aids, identification of the types of parts analyzed for data to determine the manufacturing man-hour data, examples of how the data are utilized in airframe design and a set of mechanically fastened assembly formats. These formats include cost-driver effects (CDE), cost-estimating data (CED), and designer-influenced cost elements (DICE).

7.1 Format Selection Aids

Format selection aids are presented to provide the user with a building-block approach to determine manufacturing cost data for alternative designs or processes. The designer can review the format selection trees and identify those areas that have an impact on his design. The formats provide CDE for qualitative guidance to lowest cost and CED in man-hours for conducting trade-off studies.

FORMAT SELECTION AID **Mechanically Fastened Assemblies**

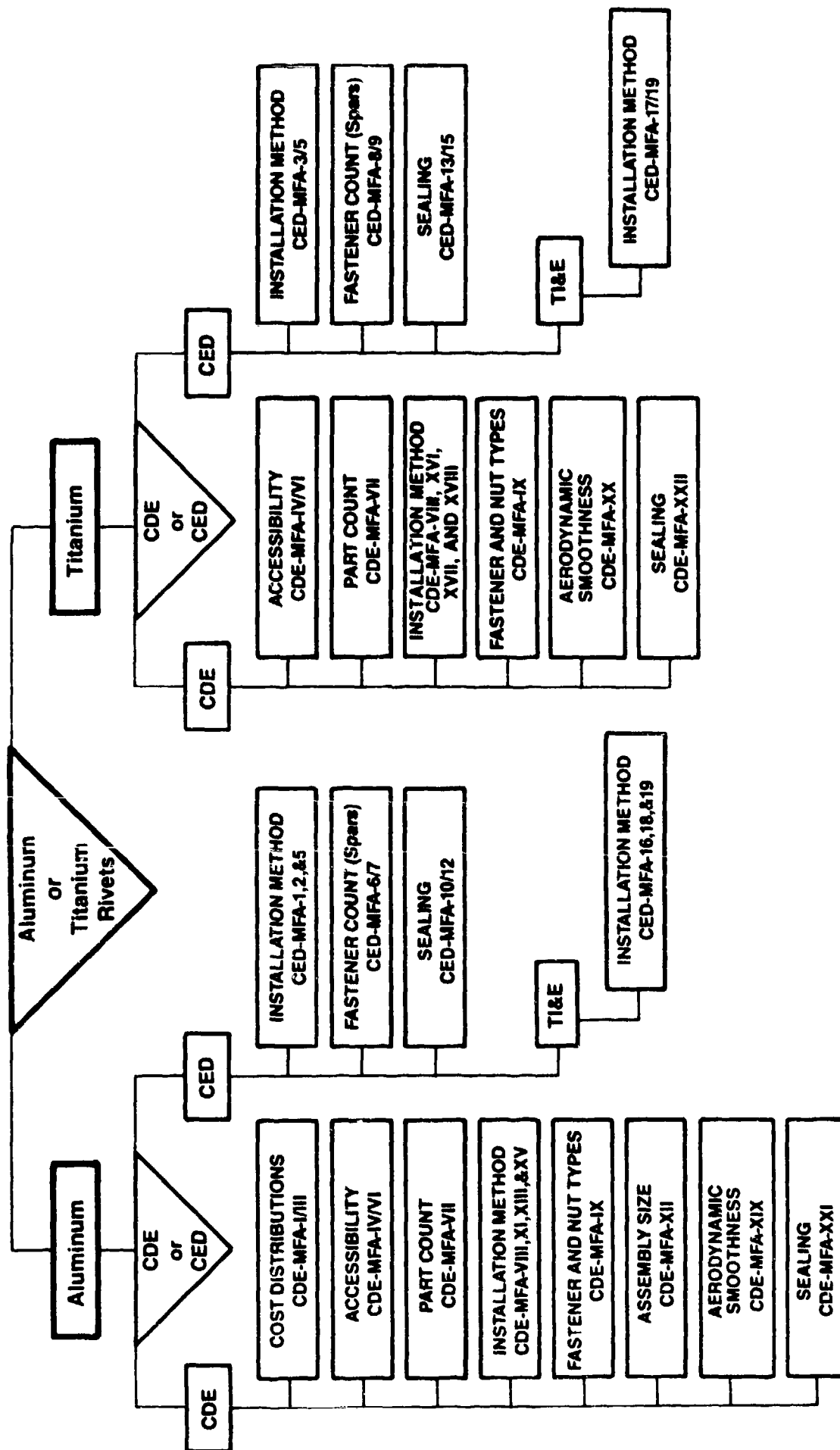


FIGURE 7-1

7.2 Example of Utilization

This example demonstrates to the designer how the mechanically fastened assembly data are utilized on a specific design problem. The example shows how to identify applicable formats, how to extract data from the formats, and provides a discussion on how the data are used to determine the part cost in man-hours or dollars. The MC/DG cost worksheet can be used to record the cost data for easy reference and to determine the total program cost. (Table 4-3).

7.2.1 Utilization Example of Aluminum First Level Assembly

Problem Statement

Determine manufacturing cost (man-hours) for an aluminum (2024) first level assembly shown in Figure 7-1. The order will be for 200 units. Assume 80% automatic and 20% manual riveting.

Procedure

The following procedure is used to determine the manufacturing cost (man-hours) for the assembly.

1. Review the Format Selection Aid (Fig. 7-1) for Mechanically Fastened Assemblies.
2. Determine the formats to use. In this case, Formats CED-MFA-11 and CED-MFA-5 are required.
3. Study the formats to determine the parameters and conditions needed for use. To use CED-MFA-11, the number of fasteners and parts, and fastening method must be specified. The sketch indicates 133 fasteners with the faying surface sealed. To use CED-MFA-5, the part perimeter (feet) and fastening method is required. The perimeter in this case is 14.4 feet, and again, manual riveting will be considered by the designer.

4. Determine the values for recurring cost and nonrecurring tooling cost (NRTC) from the formats:

(a) 80% Automatic and 20% Manual

- From CED-MFA-11, read that the recurring cost = approximately 3.5 man-hours per part
- From CED-MFA-5, read that NRTC = approximately 420 man-hours per 200 parts = 2.10 man-hours per part
- The learning curve factor to convert unit cost at 200 to cumulative average cost for an 80 percent curve and a quantity of 200 is 1.45.

Total cost = $1.45 (3.5) + 2.1 = 7.18$ man-hours per part.

5. No applicable DICE are indicated, and therefore, the costs determined above are the final total costs for assembling the part.

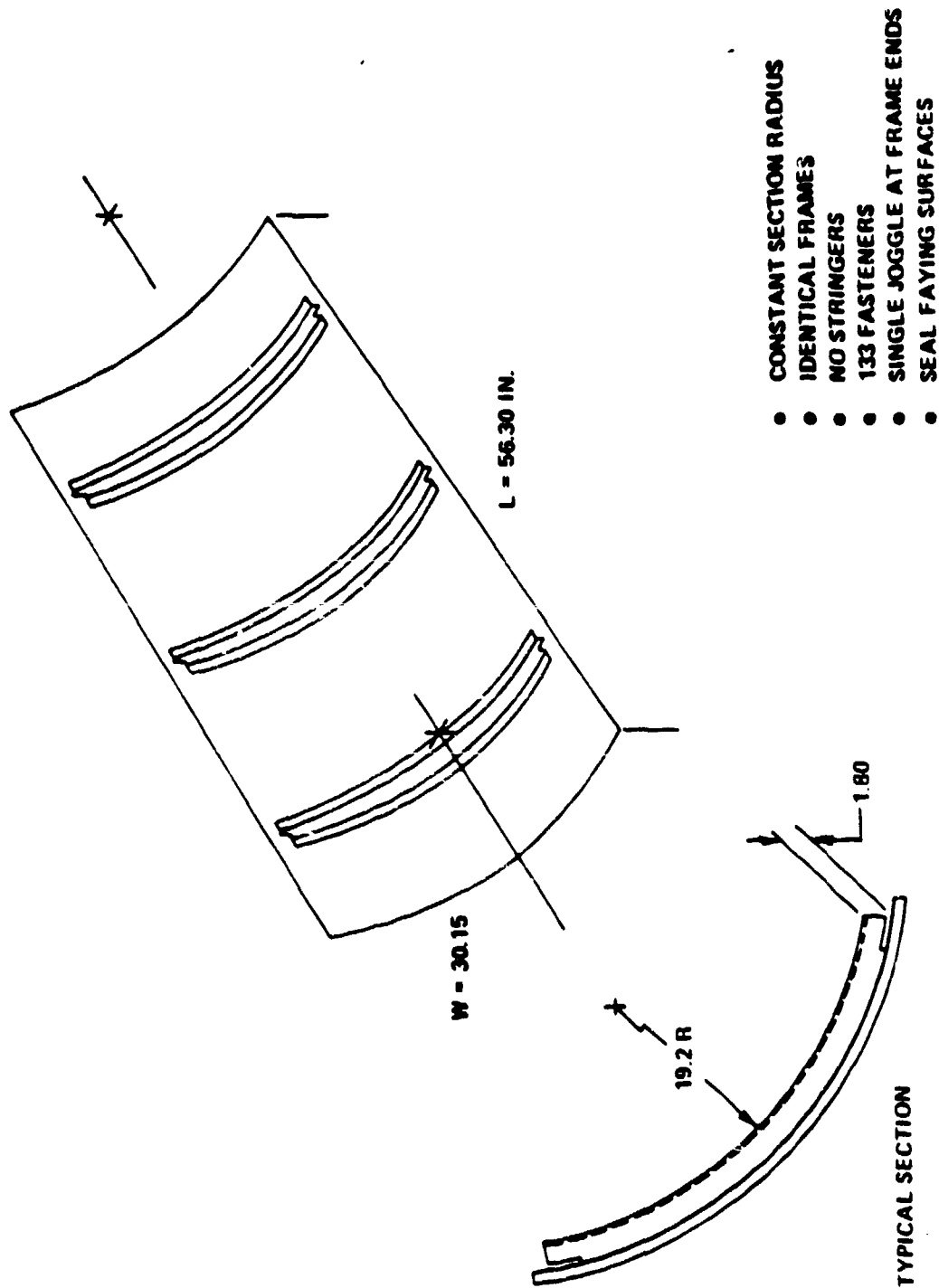


FIGURE 7-2. ALUMINUM (2024) FIRST LEVEL ASSEMBLY

7.3 Airframe Assemblies

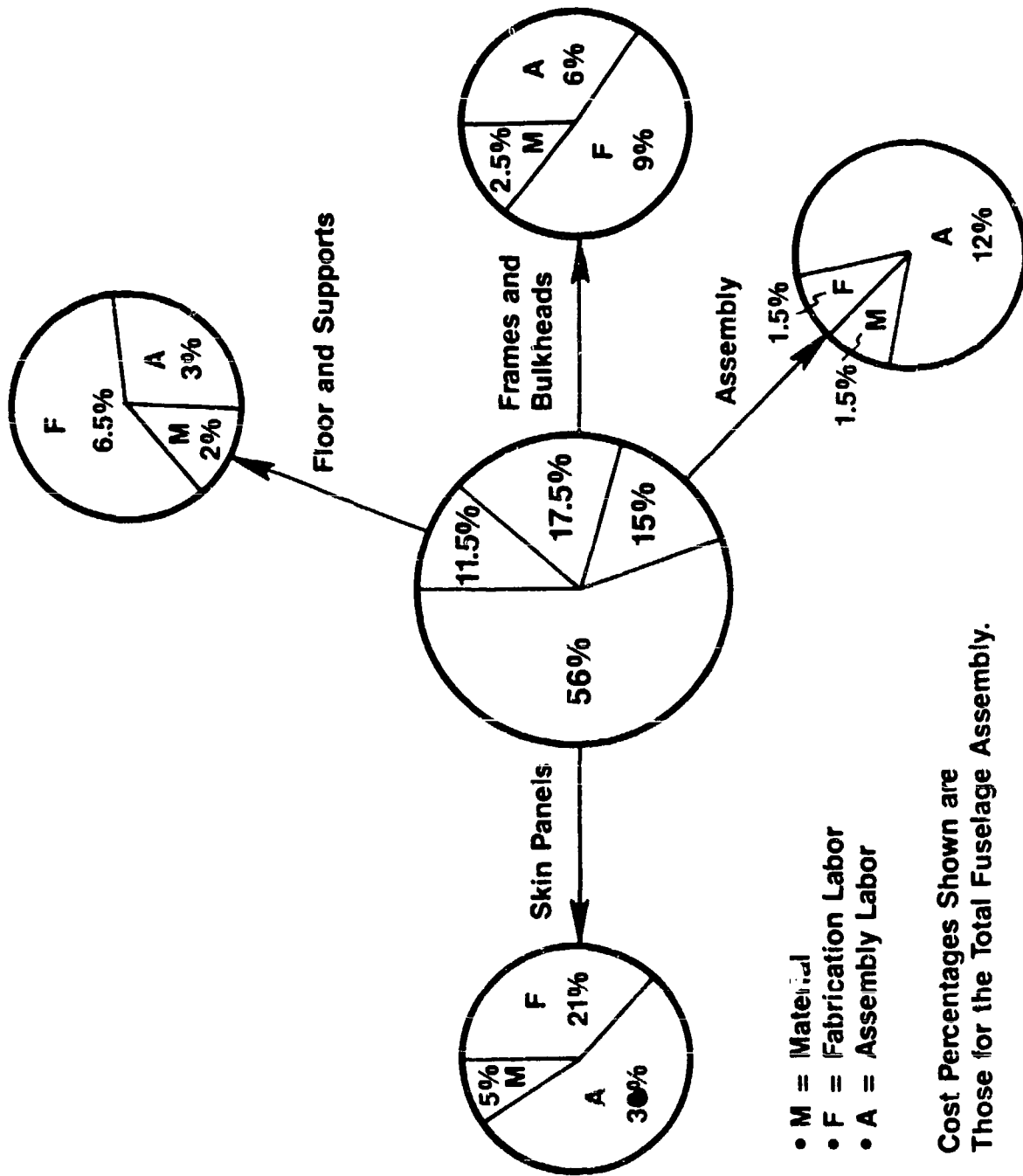
To determine the manufacturing man-hours for first level mechanically-fastened assemblies, the following structures were analyzed:

- Avionics Panels
- Fuselage Panels
- Fuselage Doors
- Inspection Hatches
- Wing Spars
- Wing Panels.

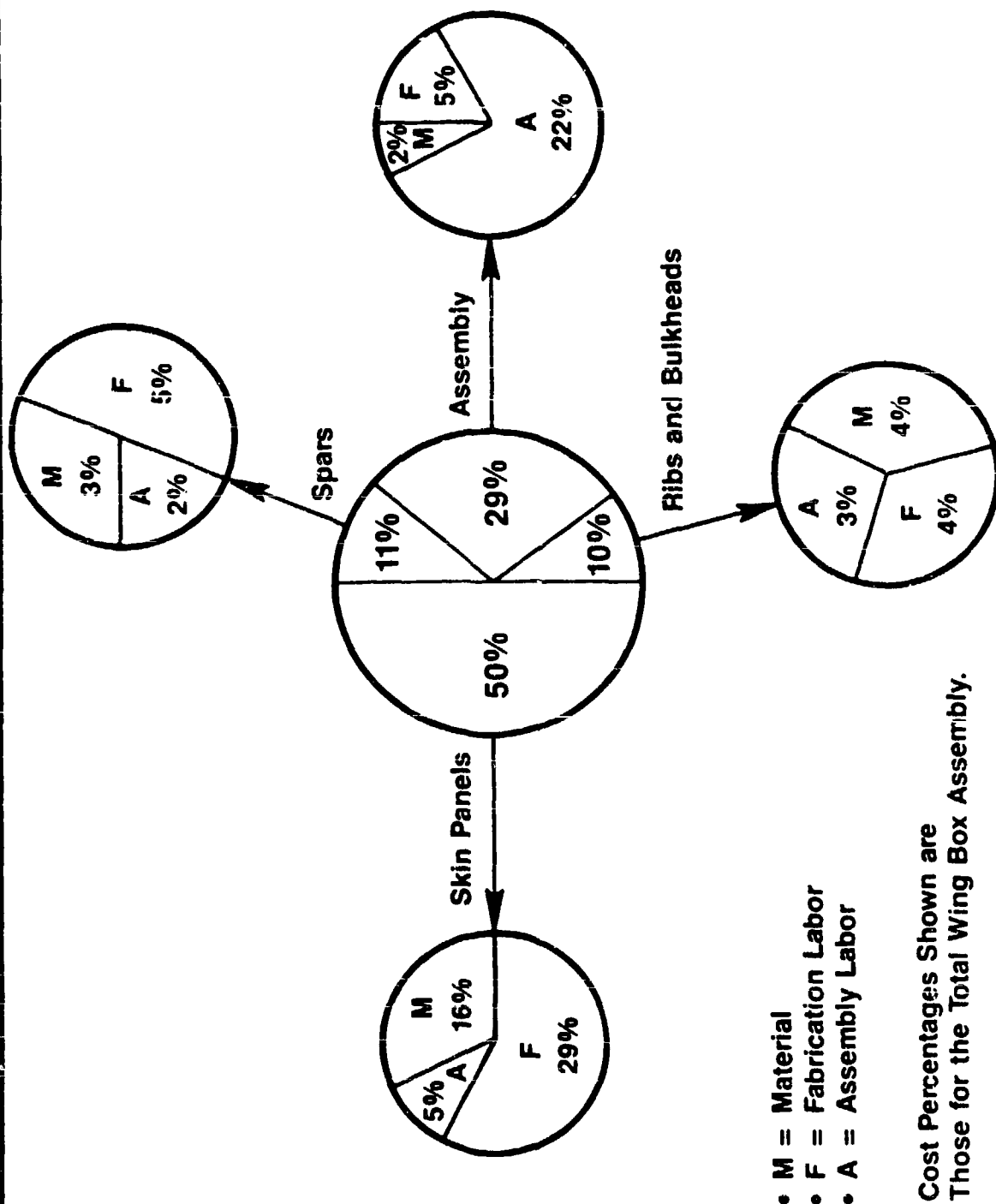
7.4 Manufacturing Data for Airframe Assemblies

The following data for airframe assemblies are presented using CED and CDE formats for conducting trade-studies.

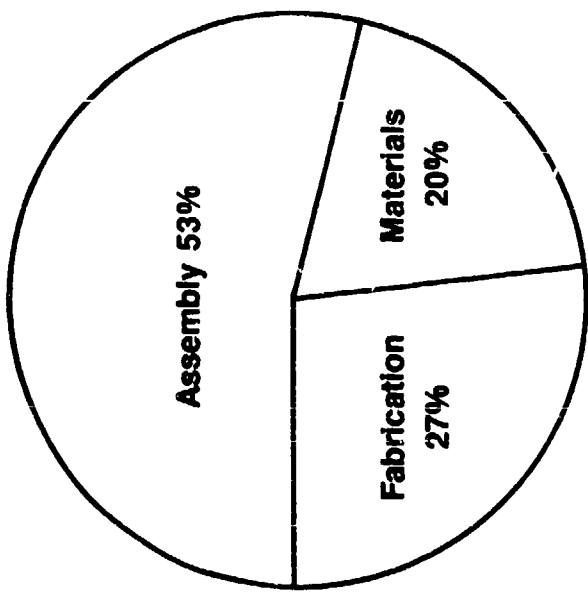
COST DISTRIBUTION FOR ALUMINUM FUSELAGE STRUCTURE OF MEDIUM TO LARGE COMMERCIAL/MILITARY TRANSPORT



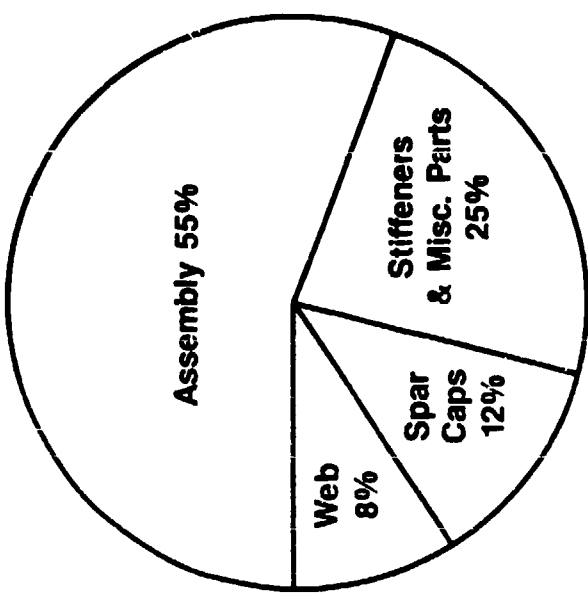
COST DISTRIBUTION FOR ALUMINUM WING-BOX STRUCTURE OF MEDIUM TO LARGE COMMERCIAL/MILITARY TRANSPORT



COST BREAKDOWN FOR A TYPICAL ALUMINUM SPAR



By Cost Element:



By Component
(Fabrication: Materials and Labor)

ACCESSIBILITY FACTORS FOR MANUAL ASSEMBLY OF ALUMINUM AND TITANIUM STRUCTURES (Continued)

FINAL ASSEMBLY

Factor: 2.5	4.5	6.0
• No Removable Jig Components • Average Finger Dexterity Required • Hydraulic Fittings are Mechanical Only • No Wire Terminations Required • Good Communication Between Workers • Good Visibility • Standard Man-Hour Goal Achieved in Less Than 50 Assemblies • Few Two-Piece Fasteners • No Hand-Trimming at Assembly • Work at Floor Level • Comfortable Working Position • May Require Working in Dark Areas with Drop-Lights • No Tool Interference	• Some Removable Jig Components • Above Average Finger Dexterity Required • Limited Number of Hydraulic Tubing Installations • Limited Number of Wire Terminations • Impaired Communication Between Workers • Fair Visibility • Some Close Tolerance Holes • Some In-Process Inspection Required • Limited Hand Trimming at Assembly • May Require Work Above Floor Level or Overhead Cramped Area—Requires Small Operator • Uncomfortable Worker Position • Staging Required • Working in Prone Position Required • Tool/Jig Interference	• Numerous Jig Components to be Located and Removed to Permit Accessibility • Use of Slings/Hoists Required to Position Subassemblies • In-Place Brazing of Tubing Required • Termination of Wiring Required • Poor Communication Between Workers • Operator Working Blind or with Mirrors • Close Tolerance Holes • Two-Piece Fasteners Required • Some Hand-Trimming at Assembly • Fuel Sealing Requirements • Requires Critical Loading Sequence of Parts/Subassemblies to Provide Accessibility • Highly Skilled Technicians Required • Continued In-Process Inspection Required • Removable Staging Required • Working in Small Confined Area with Lack of Good Ventilation • Special Riveting Tools Required • Distorted Worker Position

• Obtain base assembly cost from CED-MFA-1 or 2; multiply cost by accessibility factor from above table. An accessibility factor may apply to a portion of the total fastener count/cost.

• The above accessibility factors are not applicable to automatic fastening.

ACCESSIBILITY FACTORS FOR MANUAL ASSEMBLY OF ALUMINUM AND TITANIUM STRUCTURES (Continued)

MAJOR ASSEMBLY

Factor: 1.5	3.0	4.0
• Simple Assembly Fixture Required • All Parts are Jig Located • Average Finger Dexterity Required • Some Heavy Portable Tooling Required • Few Close Tolerance Holes • Flat or Slightly Contoured Surfaces • No Hand-Fitting or Trimming at Assembly • Good Worker Position • No Tooling Interference	• Requires Rotary Type Fixture to Provide Accessibility • Most Parts are Jig Located • Impaired Communication Between Workers • Above Average Finger Dexterity Required • Heavy Portable Tooling Requiring Hoist • Limited Number of Parts to Locate • Fuel Sealing in Confined Areas • Sharp Contours • Use of Standard Tools Impaired • Uncomfortable Worker Position • In-Process Inspection Required • May Require Work Above Floor Level • May Require Operator Working on Step-Stand	• Need for Complex Assembly Tooling • Large Number of Parts to Locate • Requires Partial Disassembly of Heavy Fixture Components to Unload Fixture • Poor Communication Between Workers • Requires Excellent Finger Dexterity • Special Riveting Tools Needed • Fuel Sealing Requirements • Some Trimming and Fit-Up Required • Shimming Required • Different Sized Fasteners Required • Distorted Worker Position • In-Process Inspection Required • Removable Staging Required • Sharp Contoured Surfaces • Protective Clothing Required

• Obtain base assembly cost from CED-MFA-1 or 2; multiply cost by accessibility factor from above table. An accessibility factor may apply to a portion of the total fastener count/cost.

• The above accessibility factors are not applicable to automatic fastening.

ACCESSIBILITY FACTORS FOR MANUAL ASSEMBLY OF ALUMINUM AND TITANIUM STRUCTURES

BENCH SUBASSEMBLY

Factor:	1.0
• No Assembly Tooling Required	
• Pilot Holes in All Detail Parts	
• Performed by One Operator	
• Average Finger Dexterity Required	
• Standard Tools Used	
• Simple Subassembly	
• Only Light Portable Hand Tooling Required	
• Consistent Rivet Pattern	
• All Rivets of Same Diameter	
• No Close Tolerance Holes	
• No Trimming Required	
• No Tool Interference	

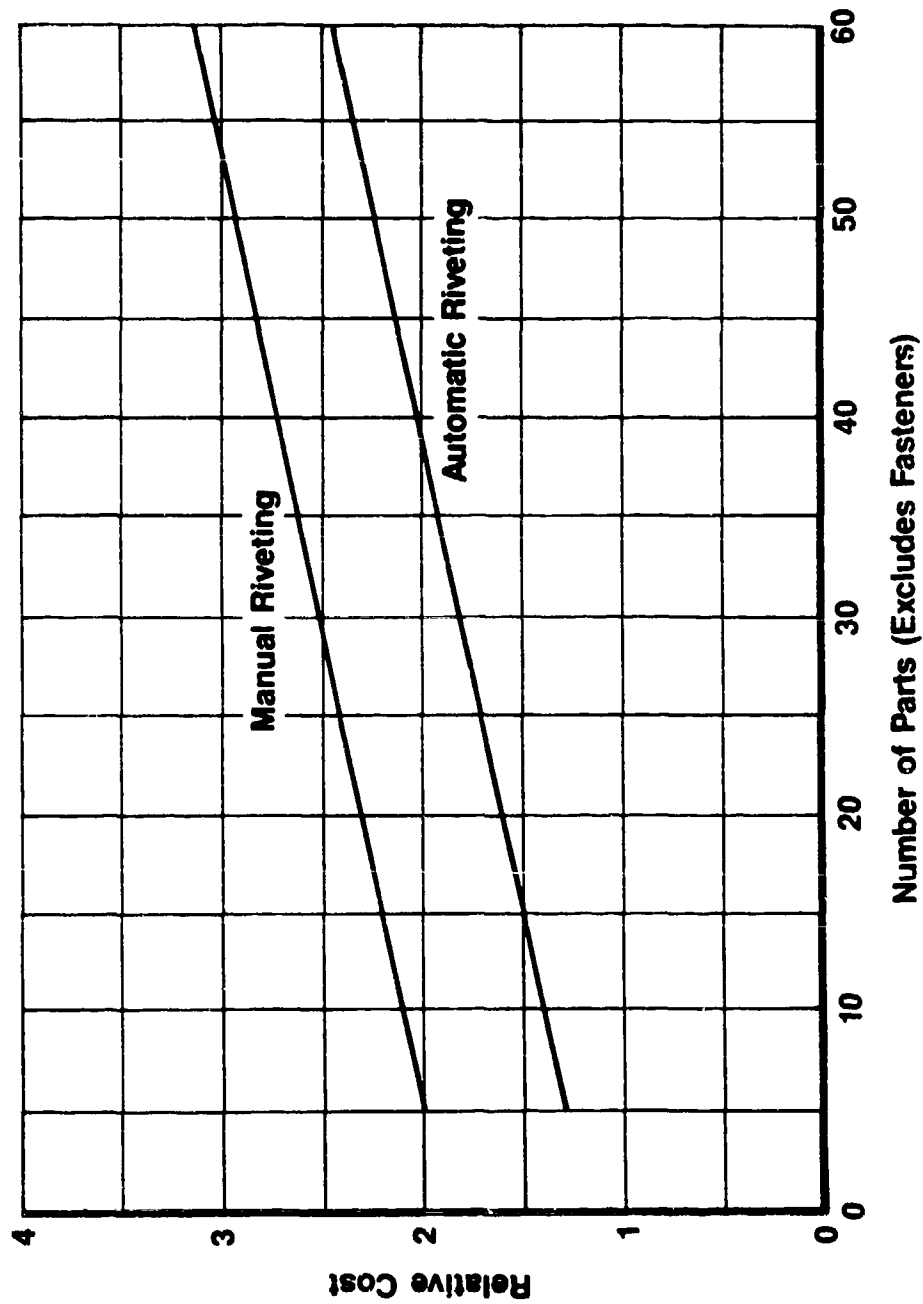
1.5
• Simple Assembly Fixture Required
• Subassembly Handled by One Operator
• Above Average Finger Dexterity Required
• Standard Riveting Tools Used
• Light Weight
• May Require Some Lay-Out of Hole Spacing
• Varied Rivet Spacing
• Multiple Rivet Diameters and Lengths Required
• Restricted Access

2.5
• Complex Assembly Fixture Required
• Requires Lifting and Rotation of Fixture to Provide Accessibility to Assemble
• Requires Excellent Finger Dexterity
• Special Riveting Tools Needed
• Varied Rivet Sizes and Spacing
• Some Lay-Out of Hole Pattern Required
• Close Tolerance Holes
• Fit-Up and Trimming Required
• Some Shimming Required
• Requires Second Operator
• Skilled Special Operator Required
• May Require Handling Device
• Critical Assembly Sequence Necessary

• Obtain base assembly cost from CED-MFA-1 or 2; multiply cost by accessibility factor from above table. An accessibility factor may apply to a portion of the total fastener count/cost.

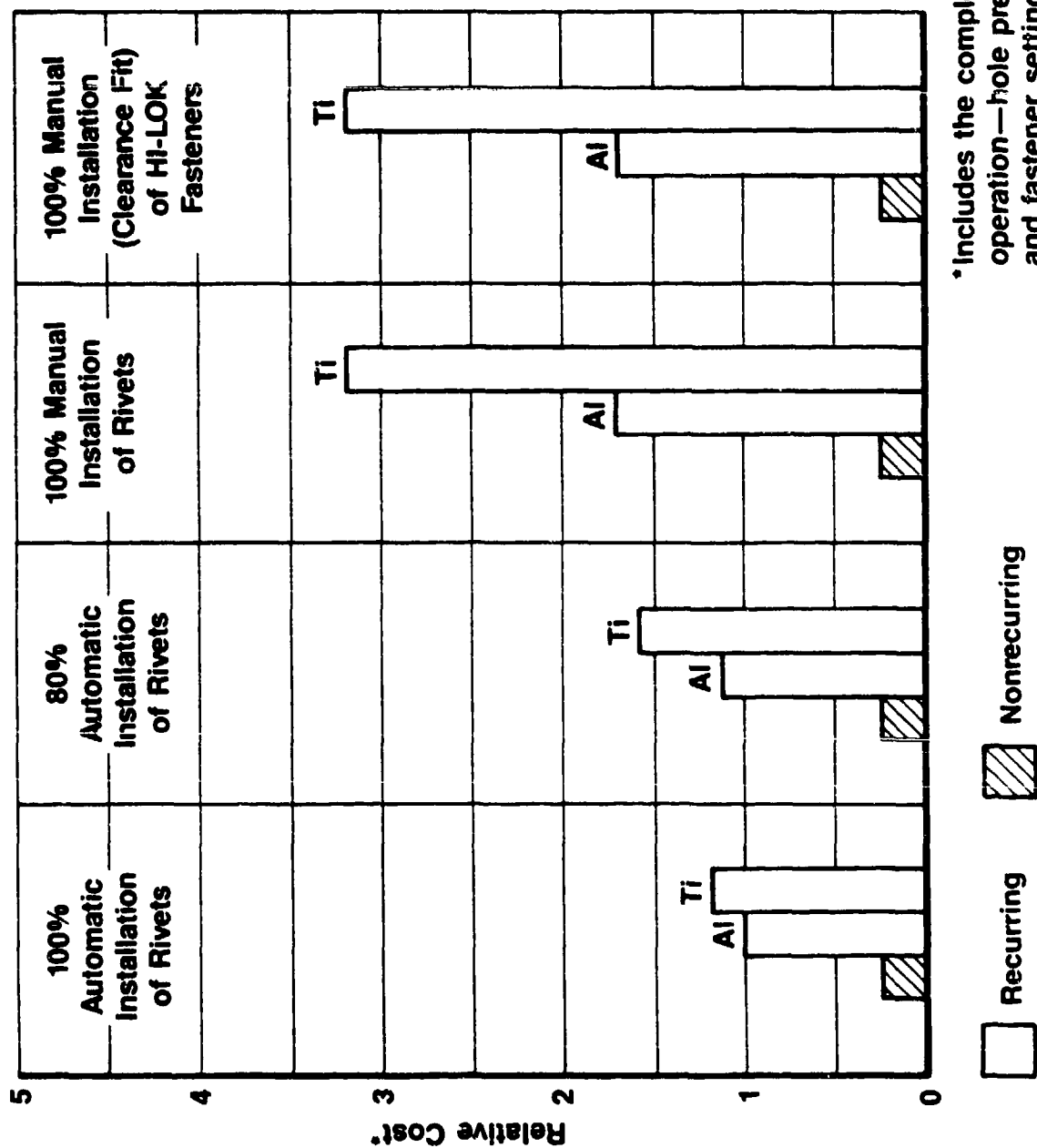
• The above accessibility factors are not applicable to automatic fastening.

MECHANICALLY FASTENED ASSEMBLIES EFFECT OF PART COUNT AND FASTENING METHOD

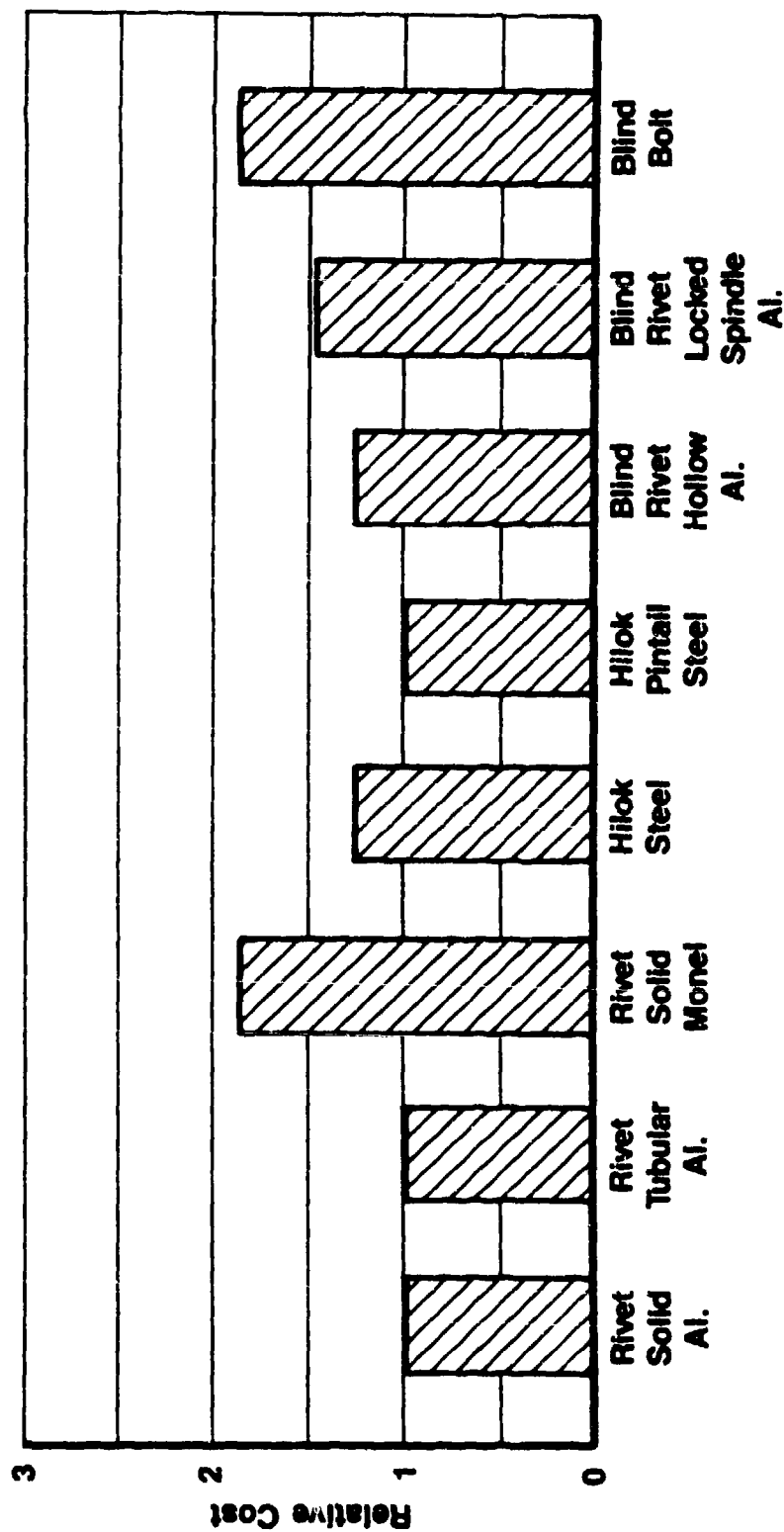


CDE-MFA-VII

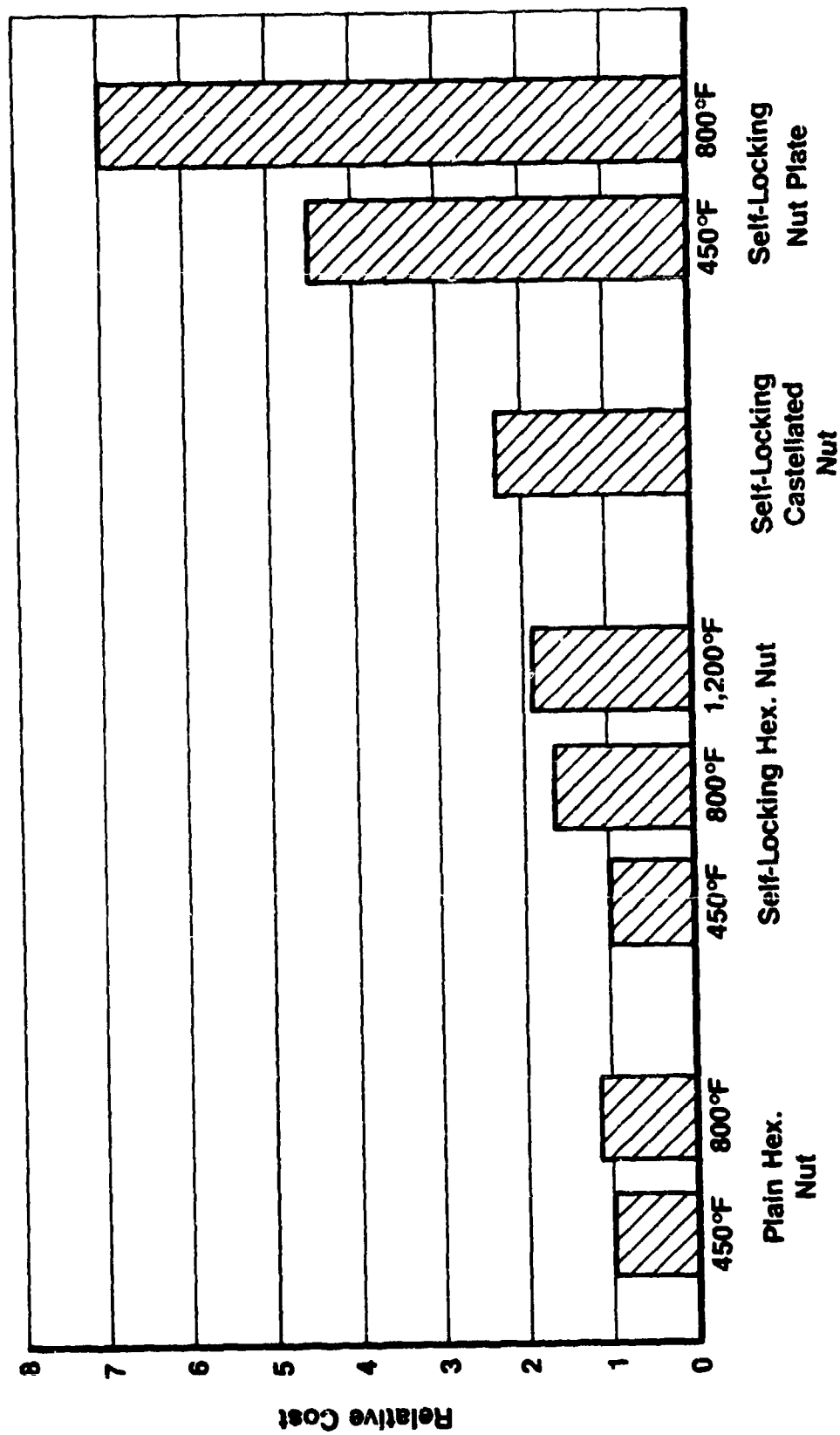
COST IMPACT OF INSTALLATION METHOD FOR ALUMINUM AND TITANIUM MECHANICALLY FASTENED ASSEMBLIES



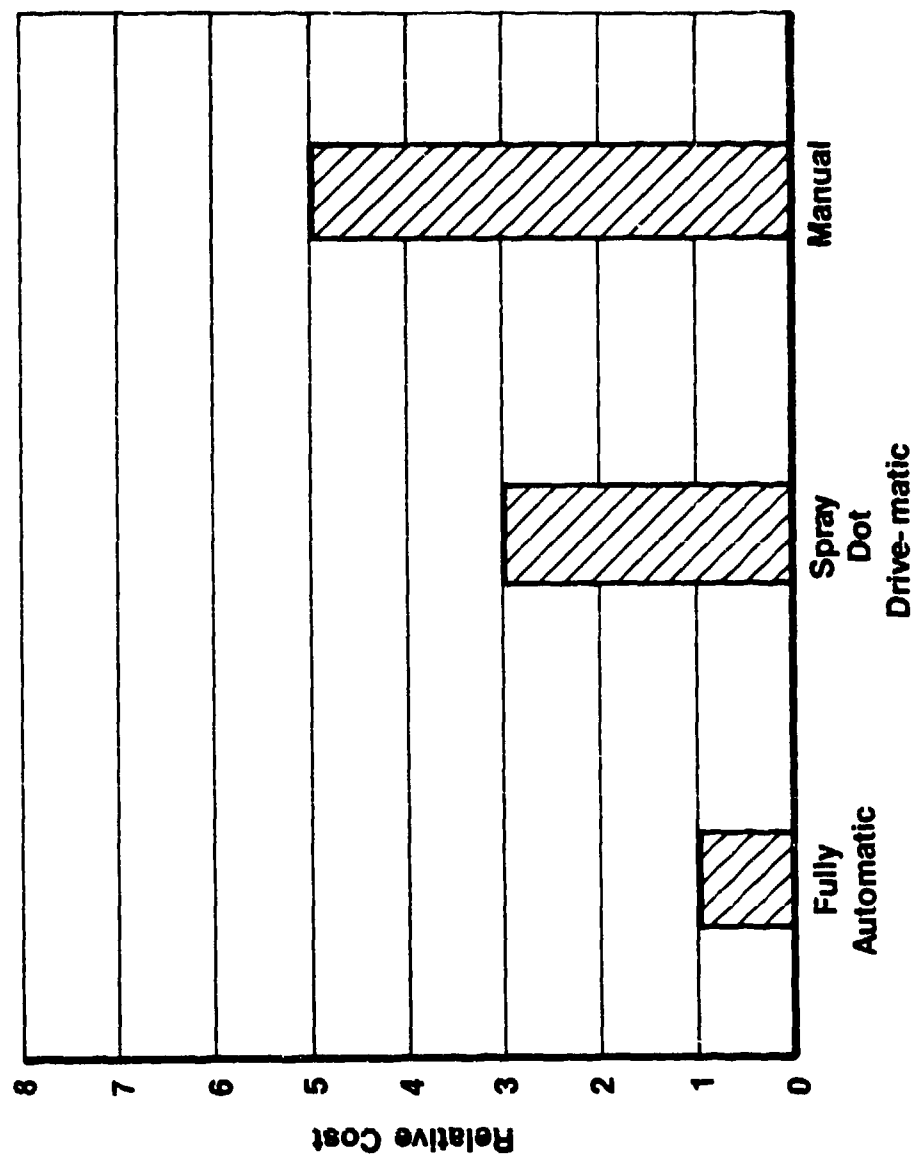
IMPACT OF FASTENER TYPE ON TOTAL INSTALLED COST MANUAL INSTALLATION



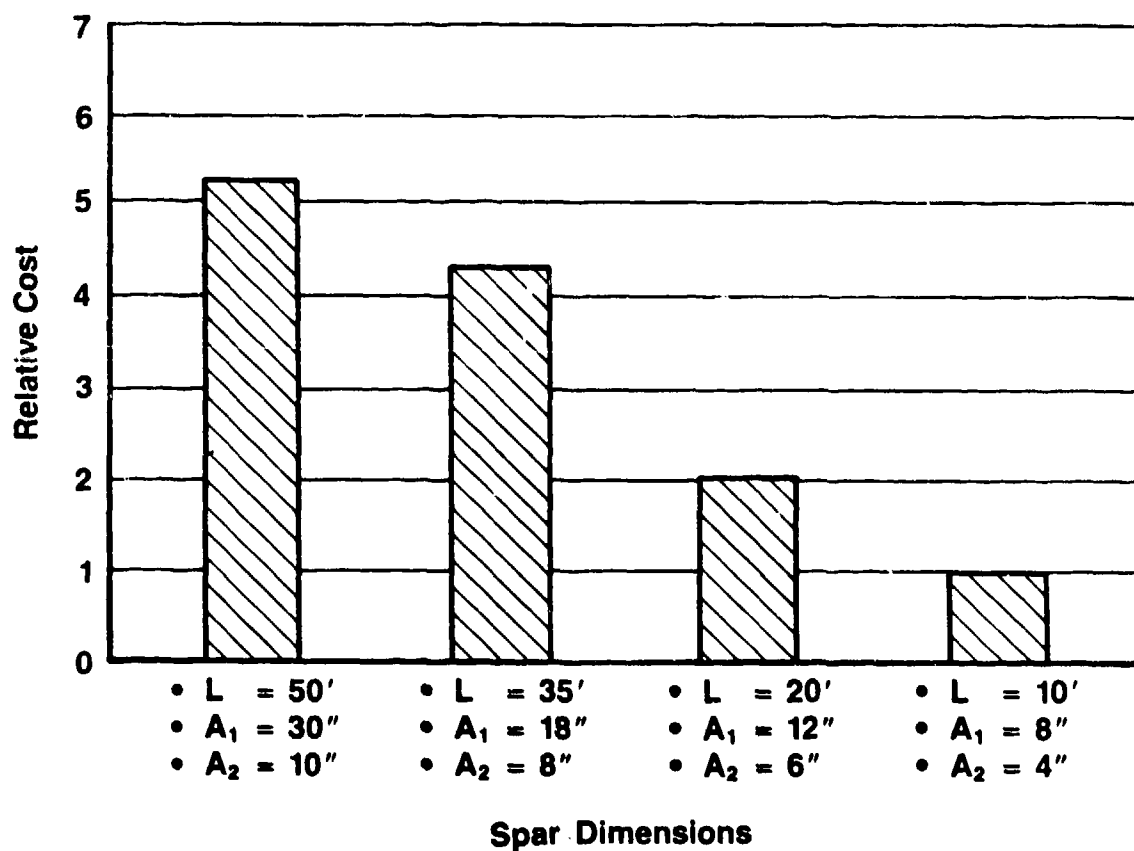
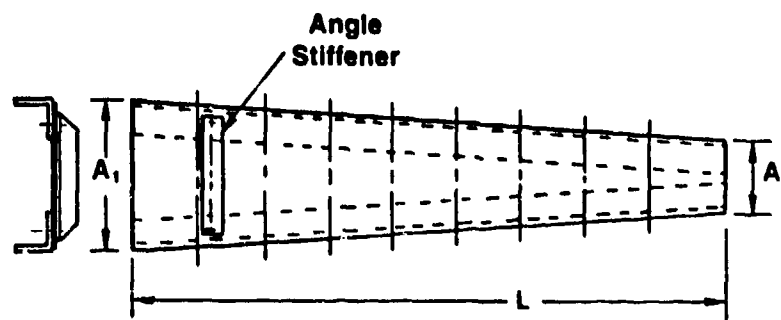
IMPACT OF NUT TYPE ON INSTALLED COST MANUAL INSTALLATION



IMPACT OF INSTALLATION METHOD ON TOTAL INSTALLED COST OF ALUMINUM SOLID RIVETS (MS 20426 & MS 20470)

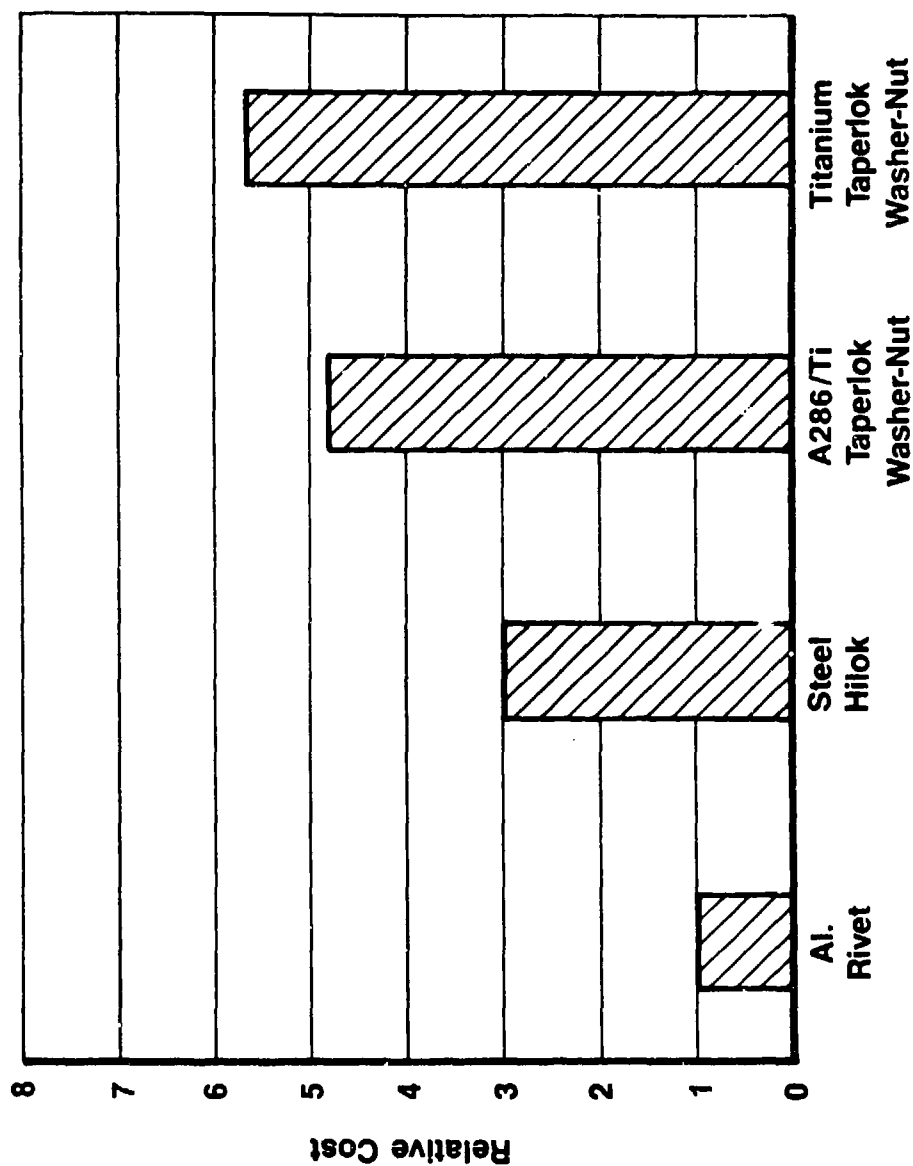


IMPACT OF SIZE ON RECURRING COST OF TYPICAL METALLIC SPARS (CDE)

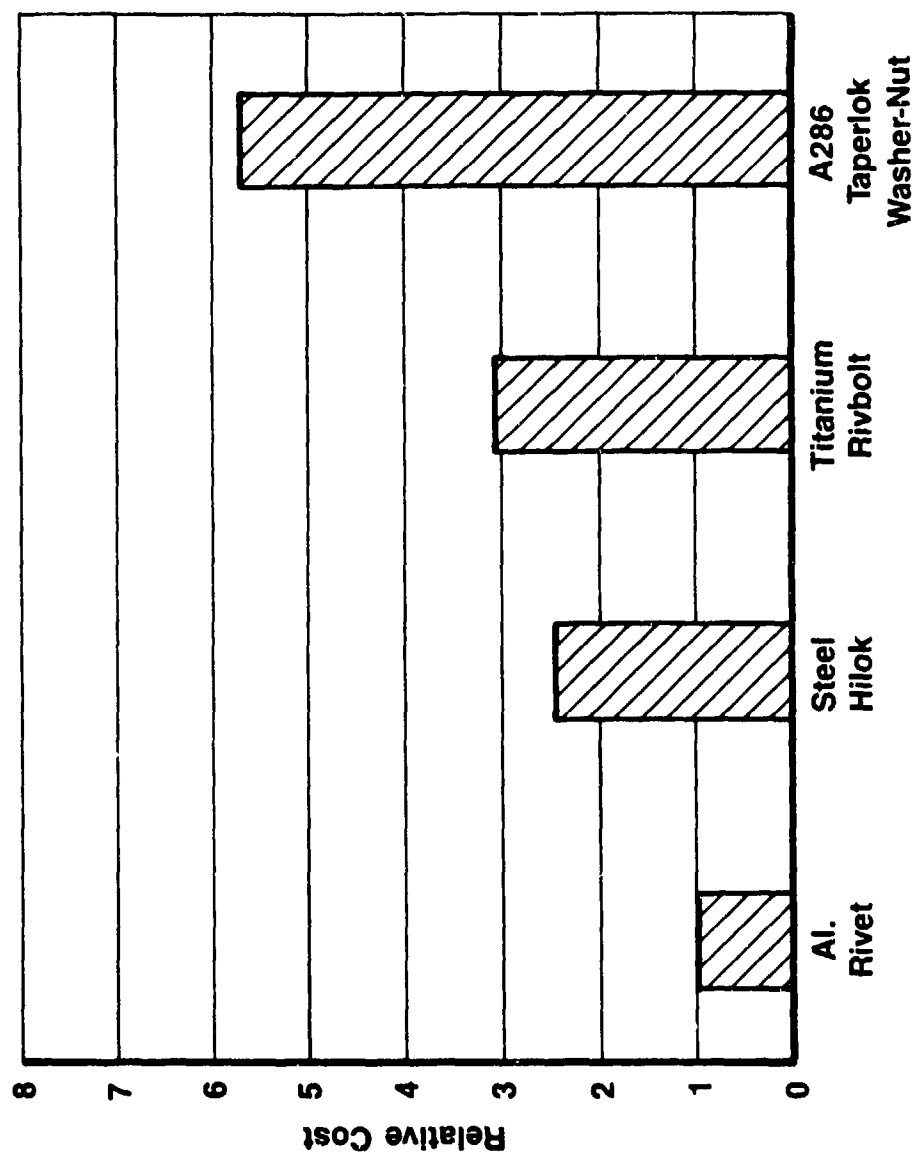


*Based on aluminum alloys stiffened by angle stiffeners

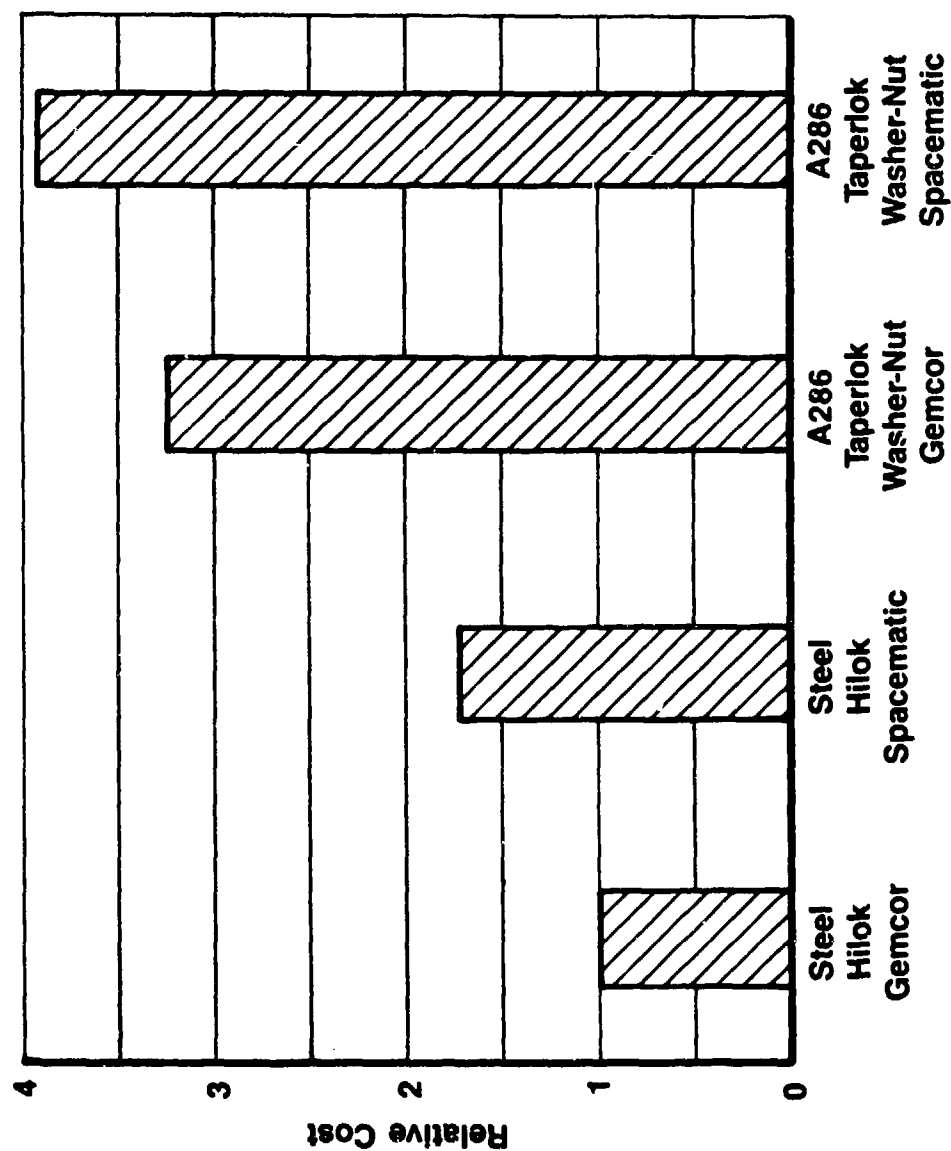
IMPACT OF FASTENER MATERIALS AND TYPE ON THE INSTALLED FASTENER COST FOR ALUMINUM ASSEMBLY USING GEMCOR METHOD



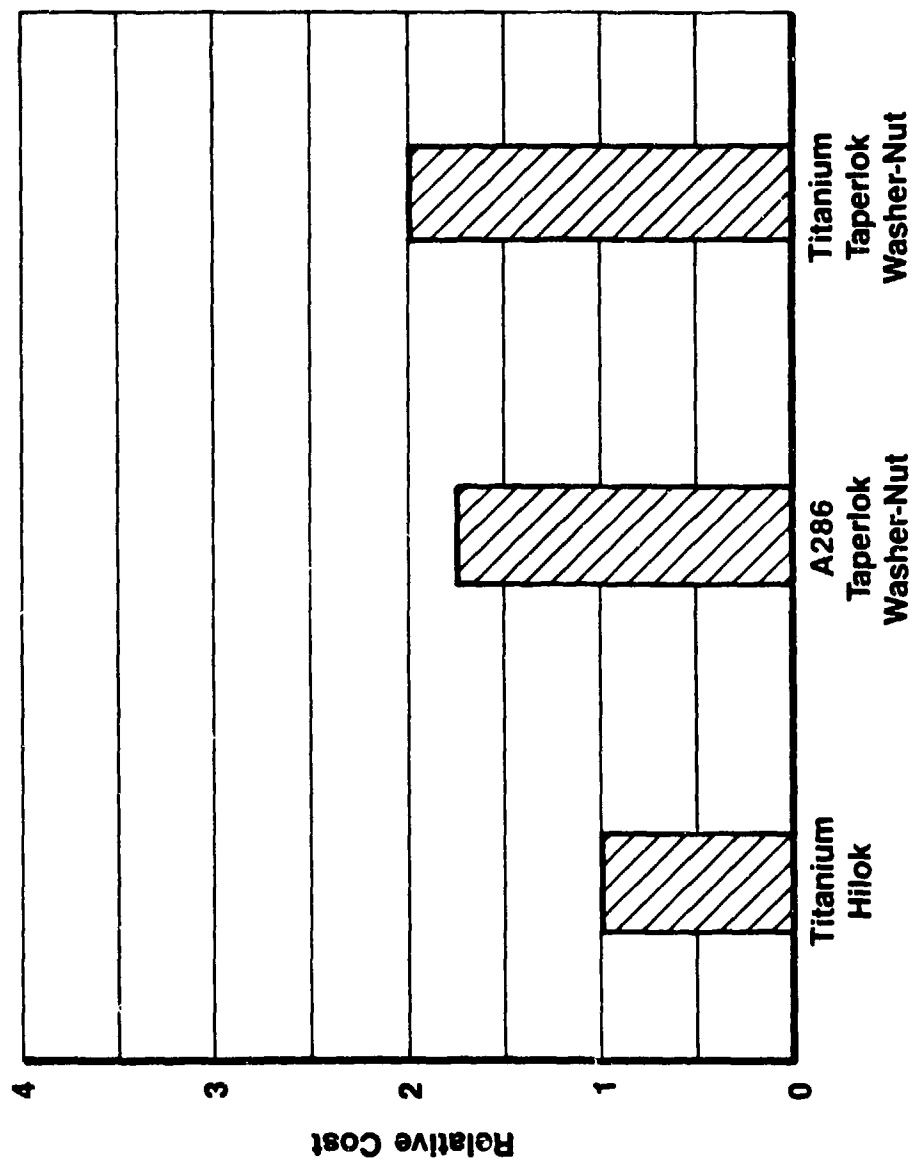
IMPACT OF FASTENER MATERIAL AND TYPE ON THE INSTALLED FASTENER COST FOR ALUMINUM ASSEMBLY USING SPACEMATIC TEMPLATES



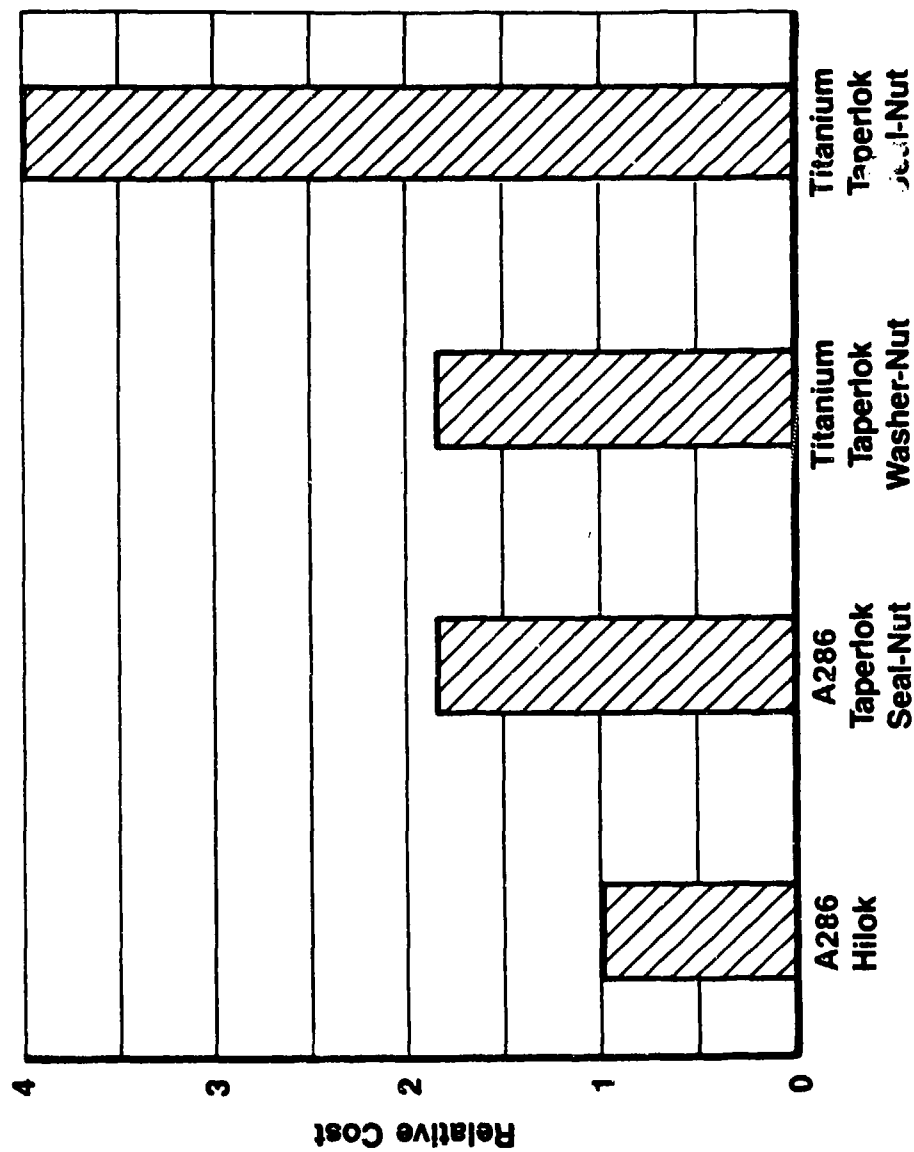
IMPACT OF INSTALLATION METHOD ON INSTALLED FASTENER COST IN ALUMINUM ASSEMBLY SPACEMATIC VS. GEMCOR



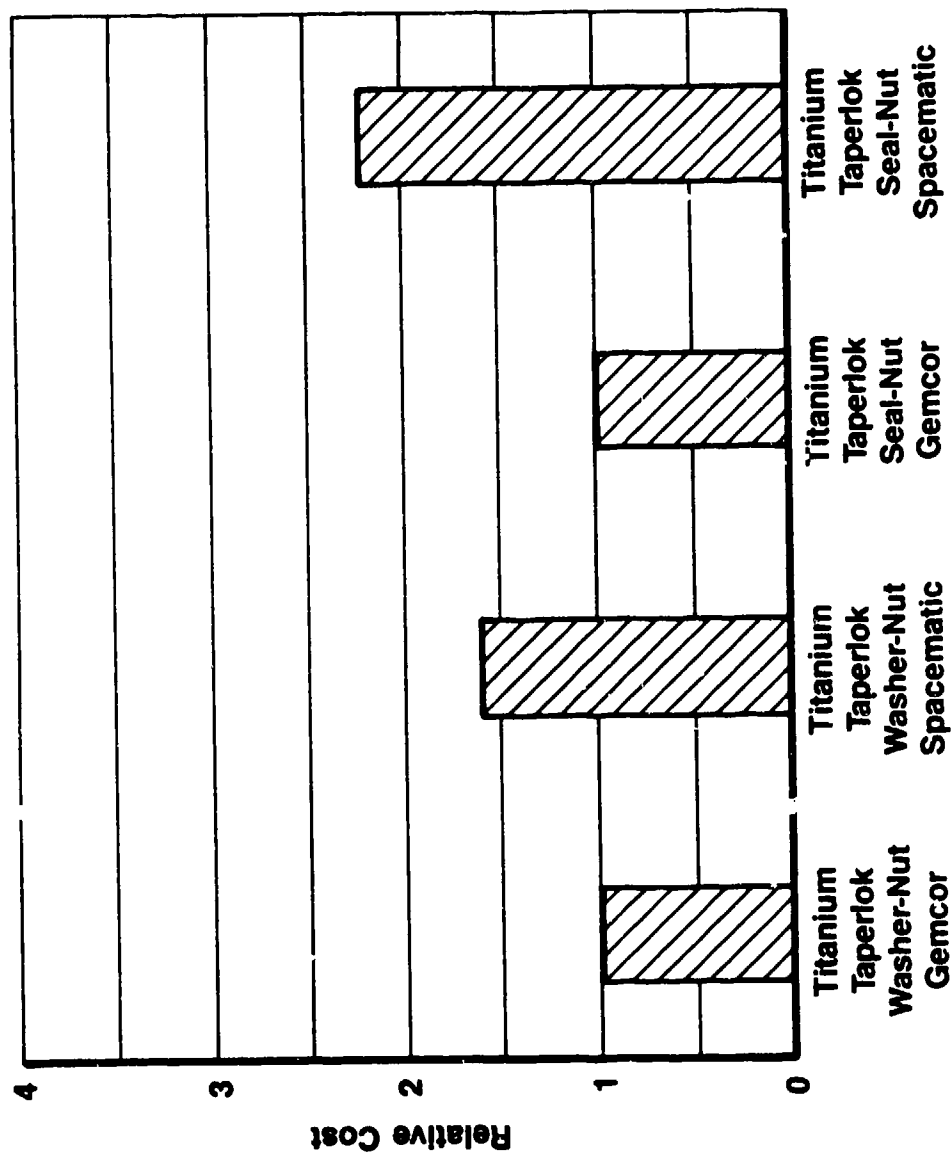
COMPARISON OF INSTALLED FASTENER COST IN TITANIUM ASSEMBLY GEMCOR METHOD TAPERLOK VS. HILOK



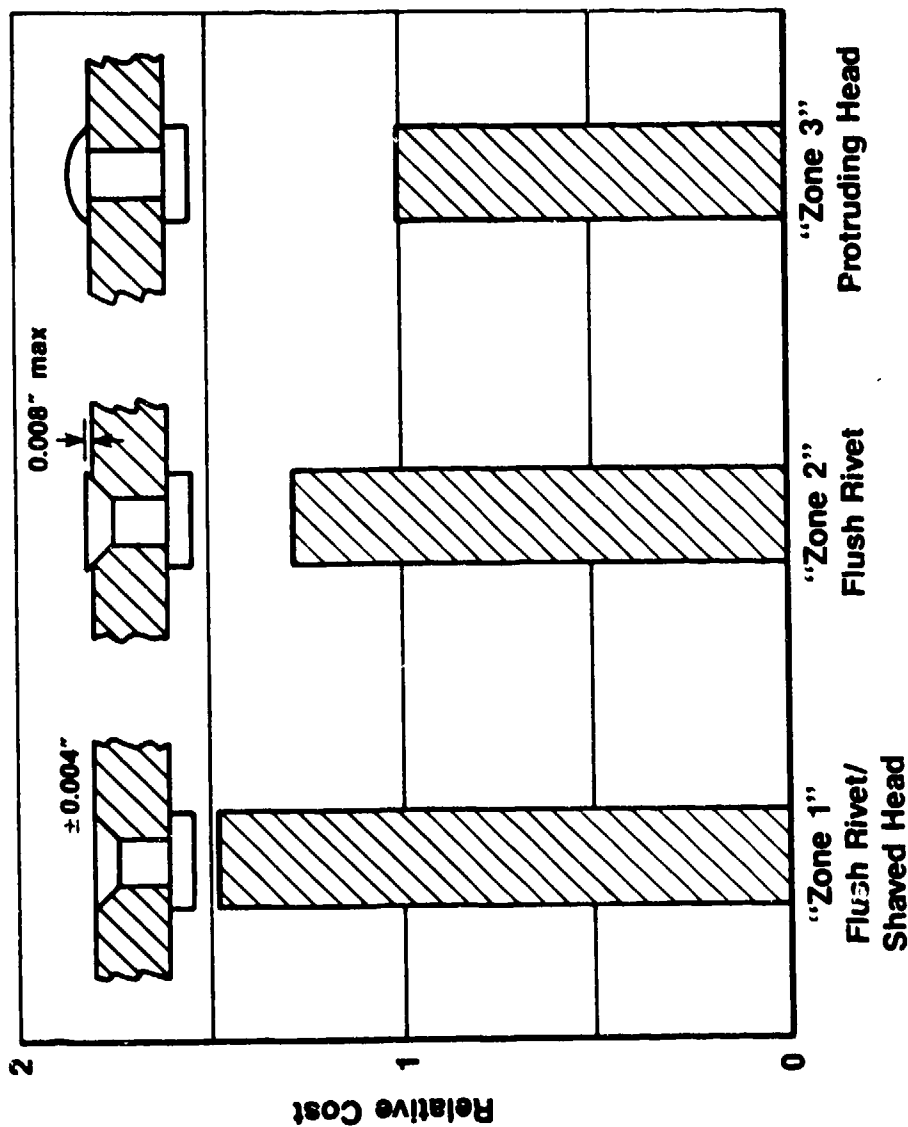
COMPARISON OF INSTALLED FASTENER COST IN TITANIUM ASSEMBLY SPACEMATIC METHOD TAPERLOK VS. HILOK



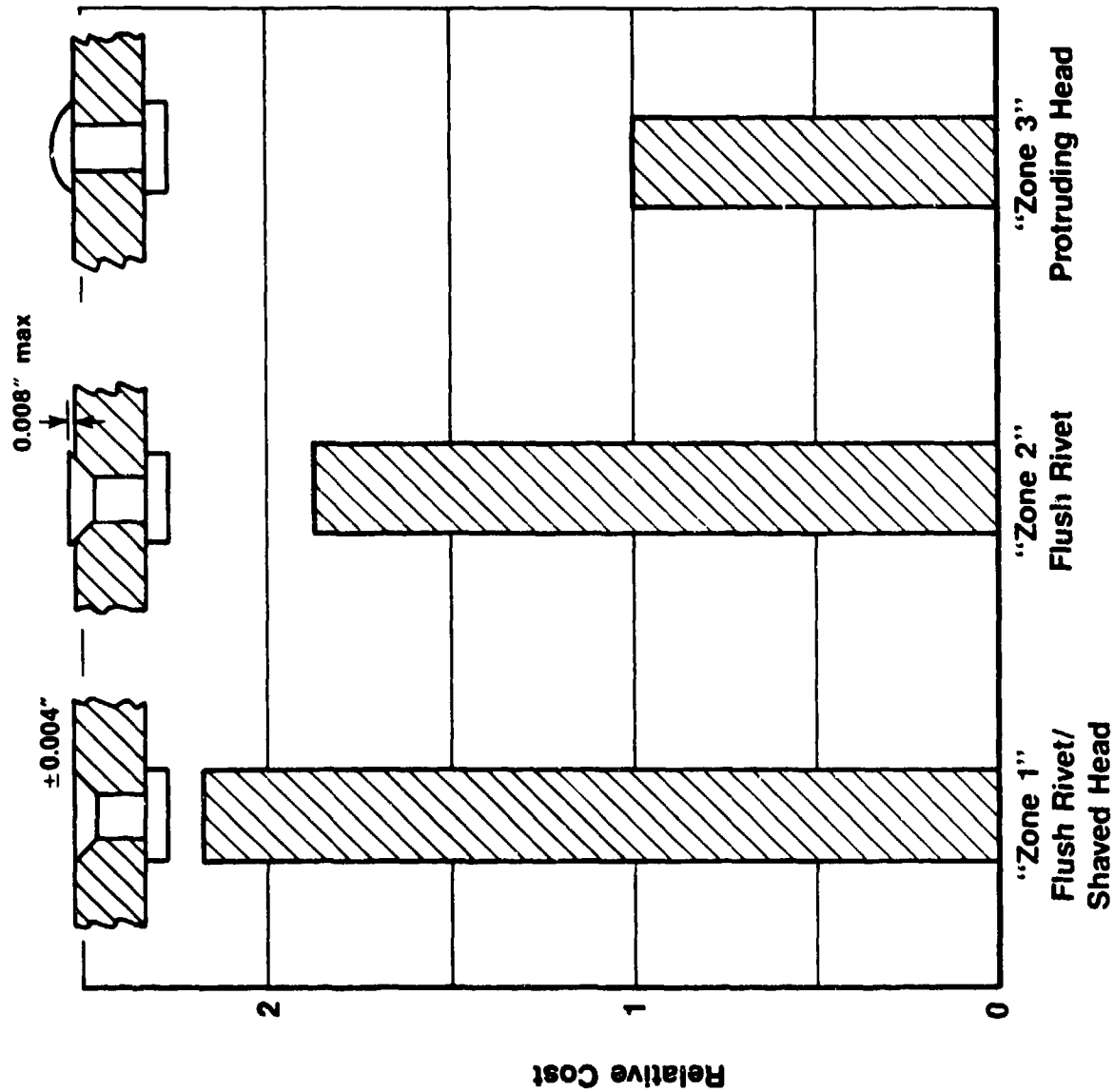
IMPACT OF INSTALLATION METHOD ON INSTALLED FASTENER COST IN *TITANIUM* ASSEMBLY SPACEMATIC VS. GEMCOR



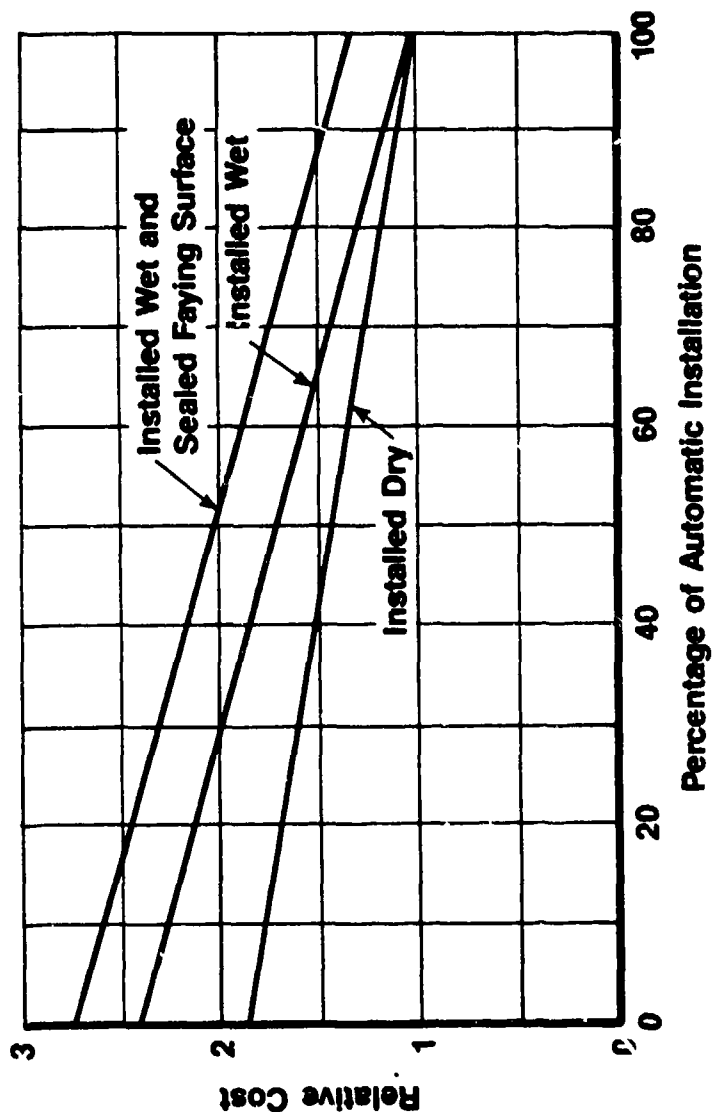
RELATIVE COST OF INSTALLING AERODYNAMICALLY CRITICAL ALUMINUM FASTENERS



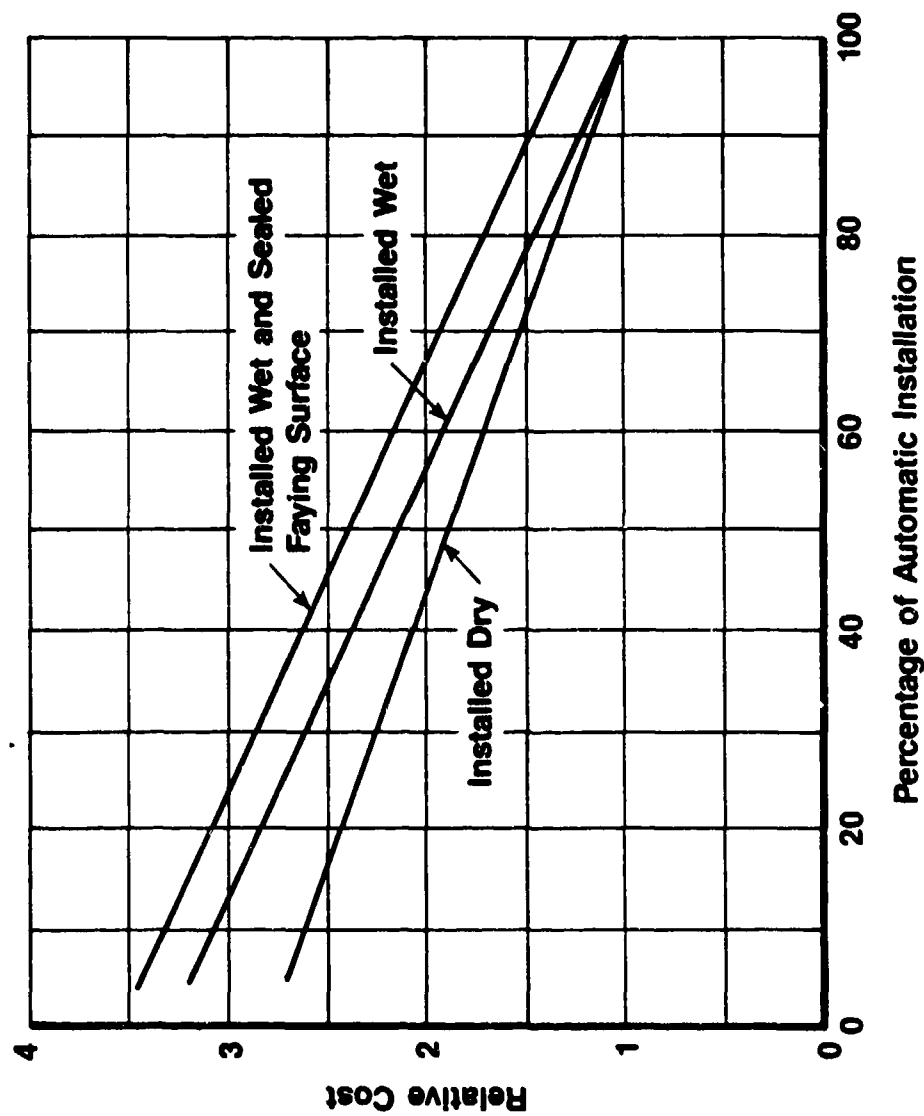
RELATIVE COST OF INSTALLING AERODYNAMICALLY CRITICAL TITANIUM FASTENERS



COST IMPACT OF SEALING FOR ALUMINUM ASSEMBLIES

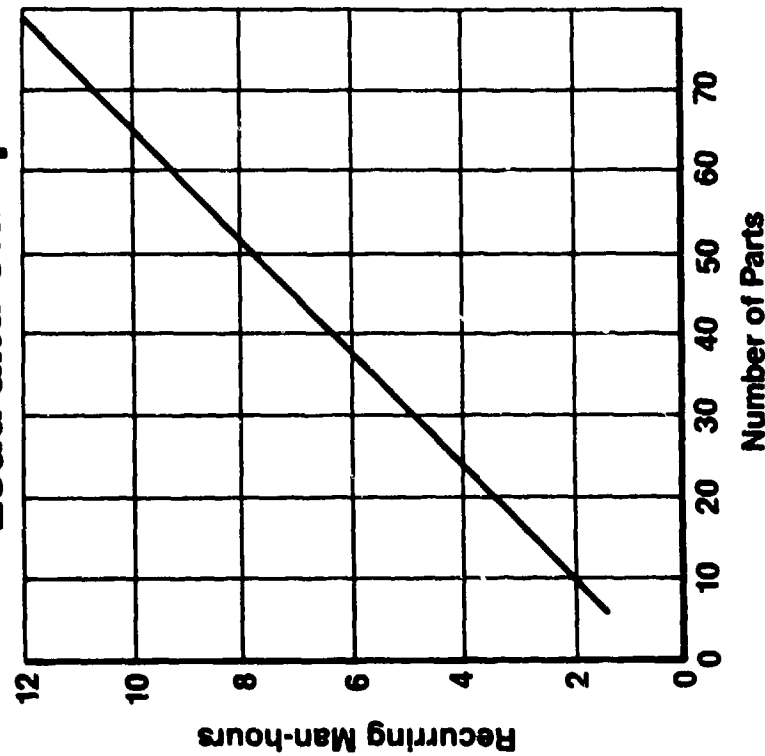


COST IMPACT OF SEALING FOR TITANIUM ASSEMBLIES

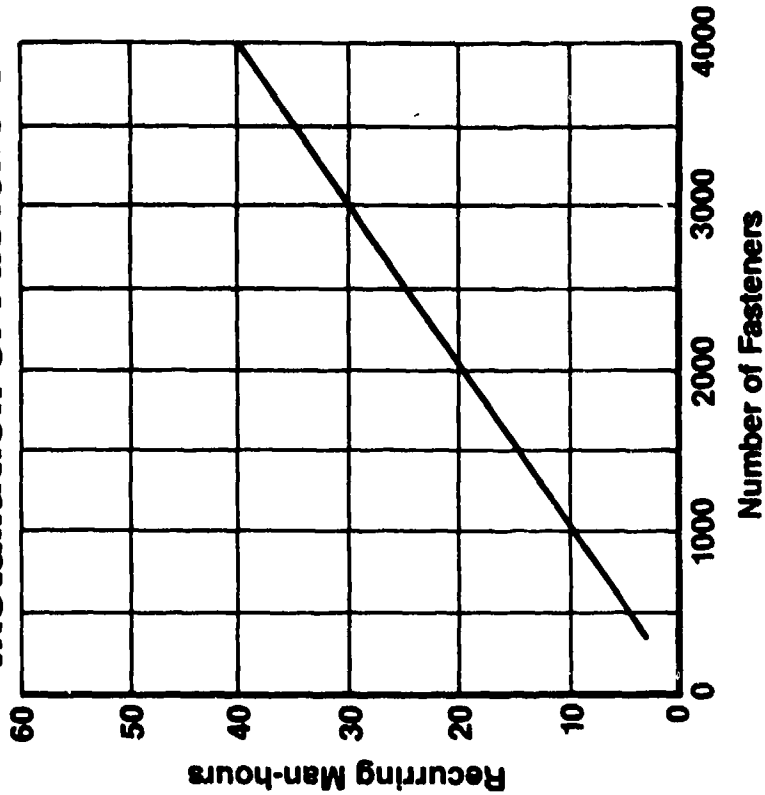


MANUAL INSTALLATION COST FOR ALUMINUM RIVETS

Load and Clamp



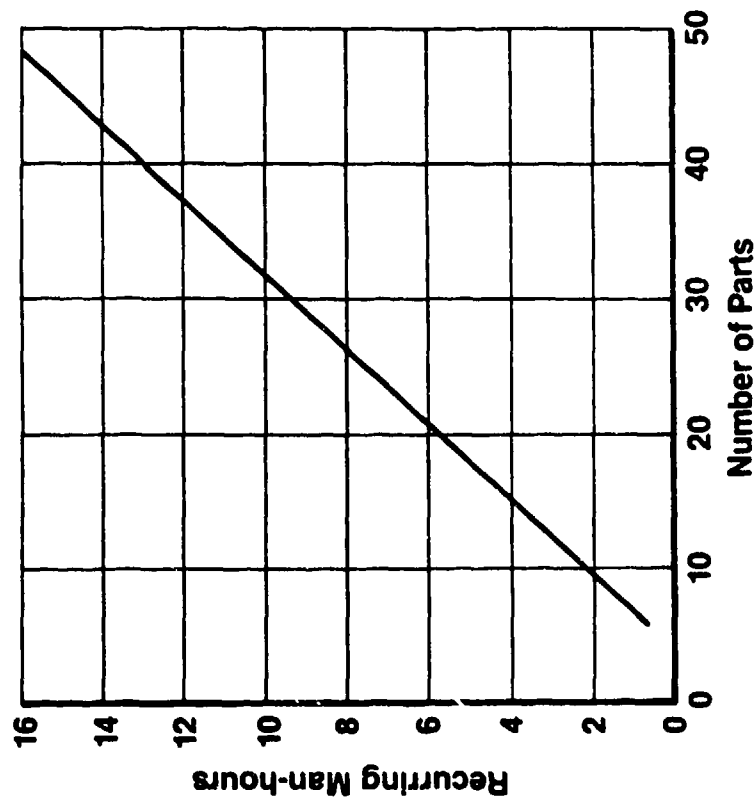
Installation of Fasteners



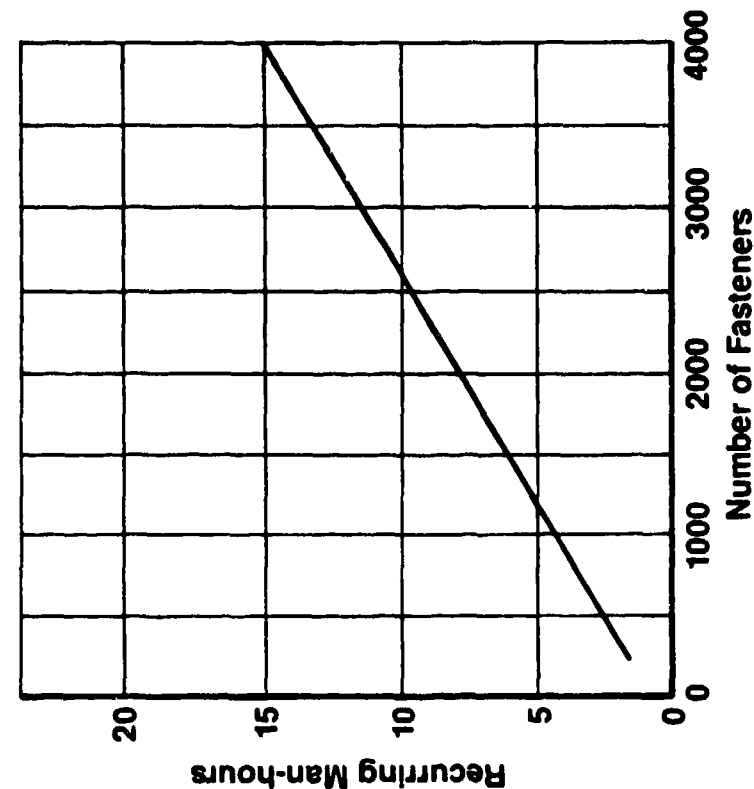
- Assembly Cost = Load and Clamp + Fastener Installation Man-hours
- For Wet Prime/Sealant on Fasteners Add 0.0075 Man-hours per Fastener
- For Wet Prime/Sealant on Fasteners Plus Faying Surfaces, Add 0.010 Man-hours per Fastener

AUTOMATIC INSTALLATION COST FOR ALUMINUM RIVETS

Load and Tack Rivet



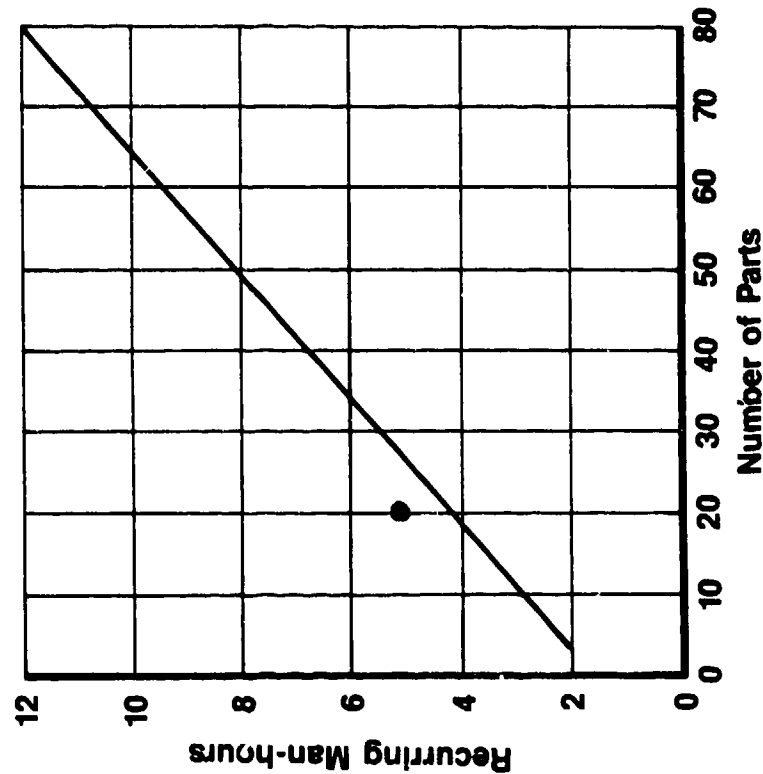
Installation of Fasteners



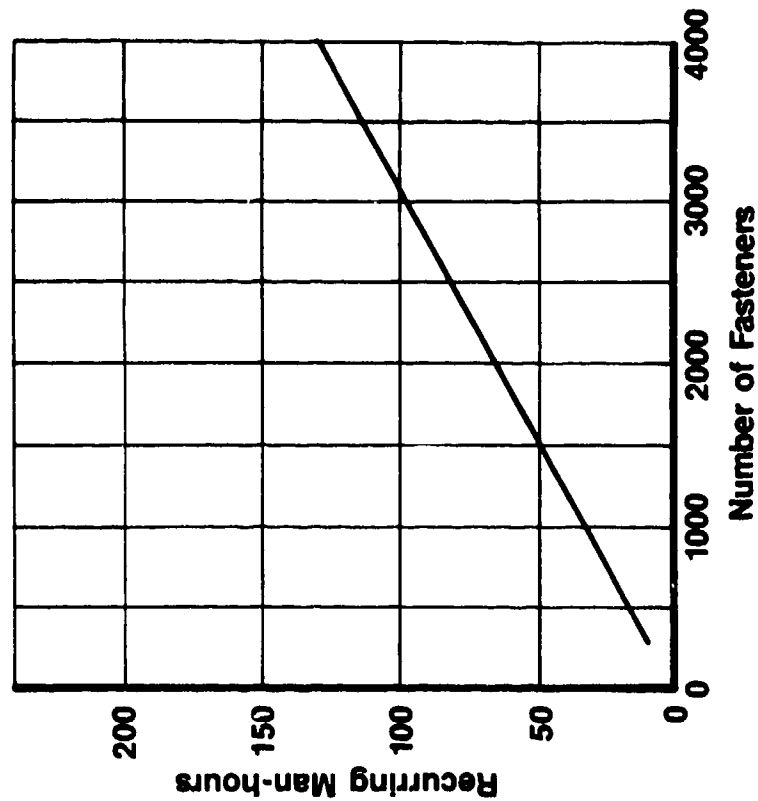
- Assembly Cost = Load and Tack + Fastener Installation Man-hours
- Cost Data Valid for Dry or Wet Fastener Installation
- For Wet Prime/Sealant on Fasteners Add 0.0075 Man-hours per Fastener
- For Wet Prime/Sealant on Fasteners Plus Faying Surfaces, Add 0.065 Man-hours per Fastener

MANUAL INSTALLATION COST FOR TITANIUM RIVETS

Load and Clamp



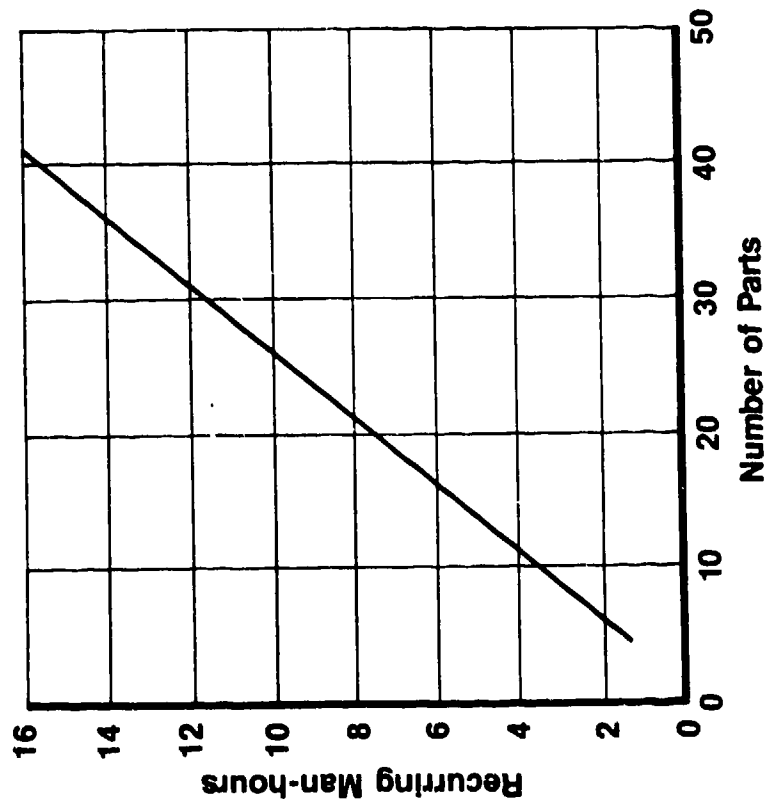
Installation of Fasteners



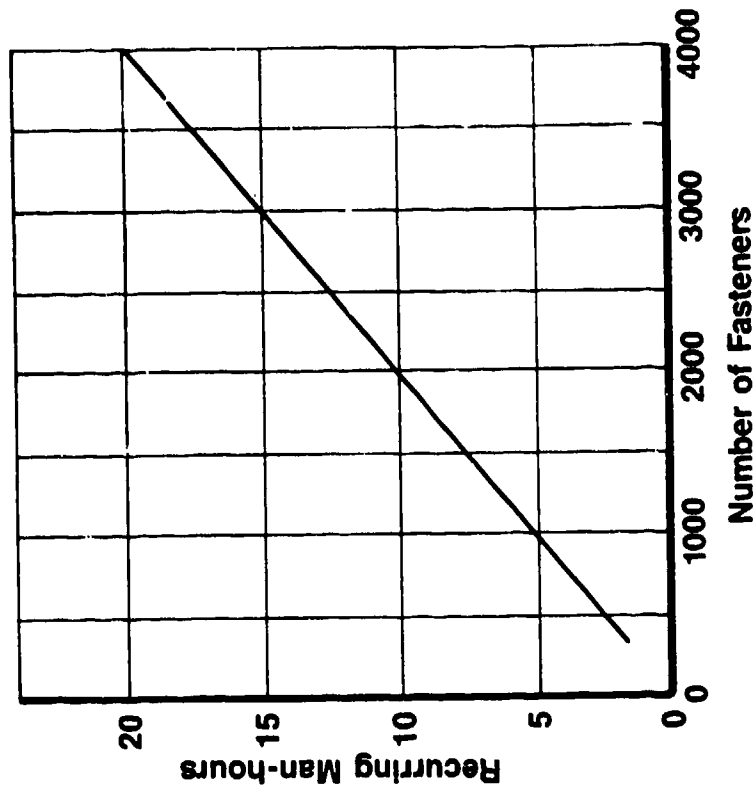
- Assembly Cost = Load and Clamp + Fastener Installation Man-hours
- For Wet Prime/Sealant on Fasteners Add 0.007 Man-hours per Fastener
- For Wet Prime/Sealant on Fasteners Plus Faying Surfaces, Add 0.011 Man-hours per Fastener

AUTOMATIC INSTALLATION COST FOR TITANIUM RIVETS

Load and Tack Rivet

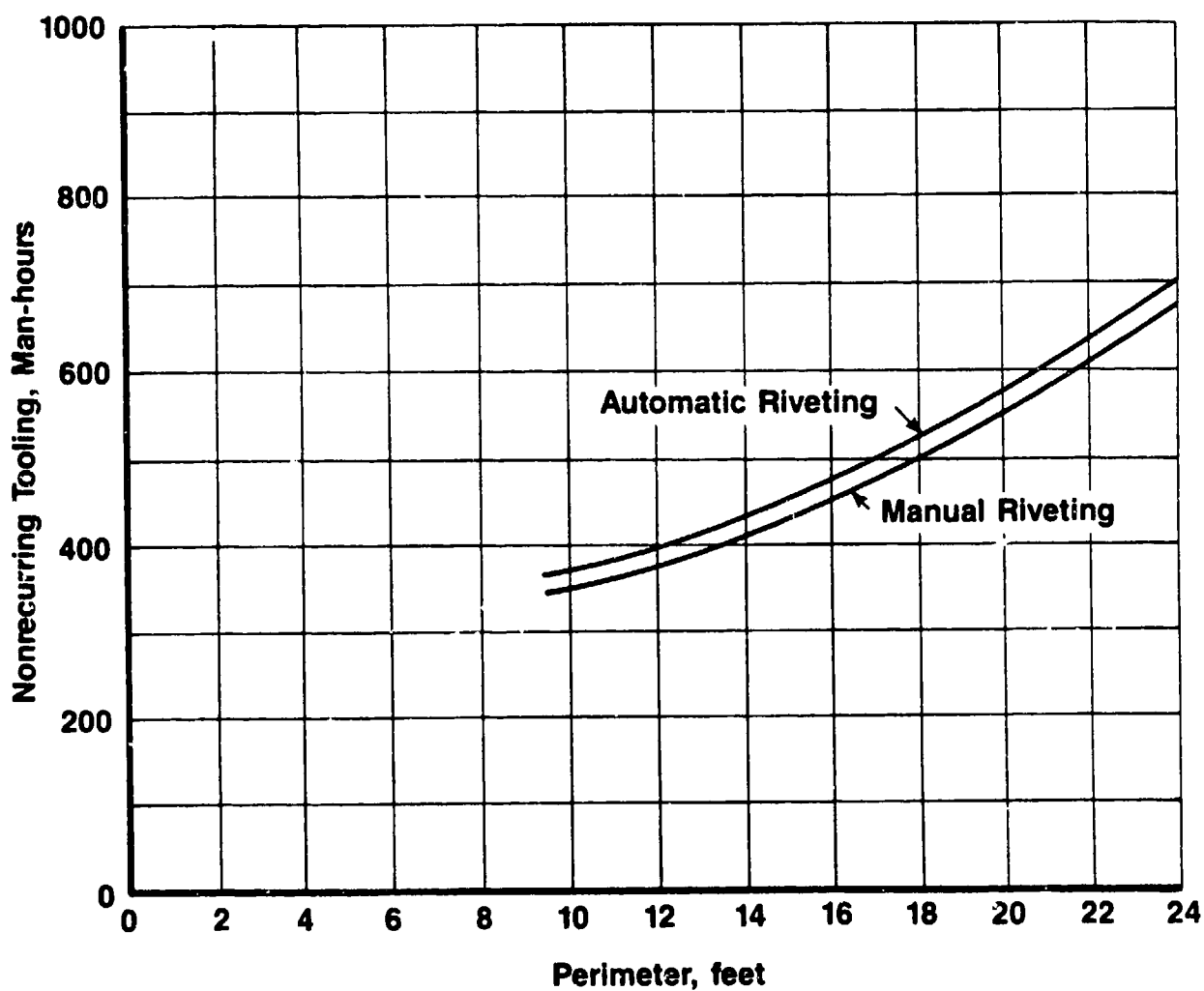


Installation of Fasteners

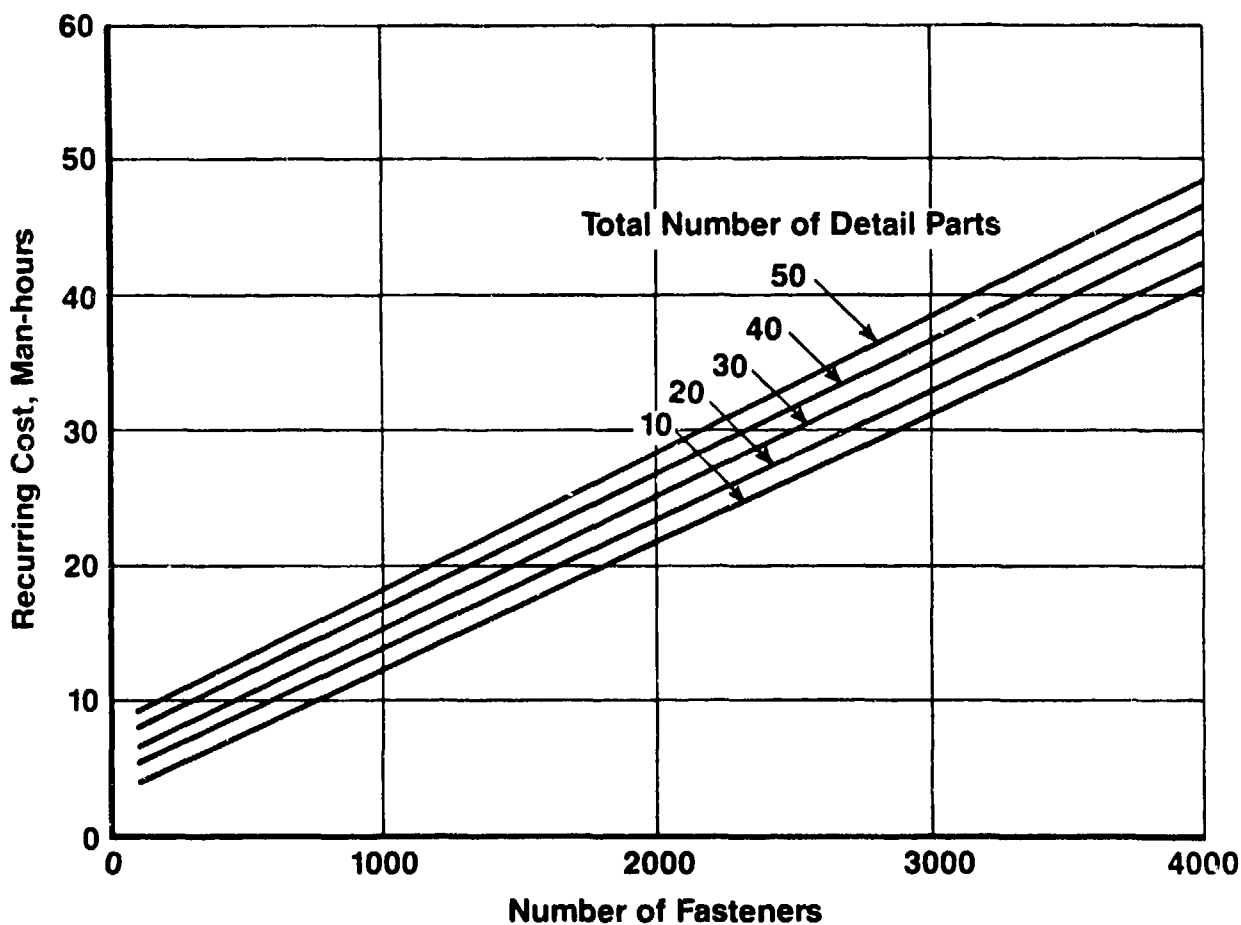


- Assembly Cost = Load and Tack + Fastener Installation Man-hours
- For Wet Prime/Sealant on Fasteners Plus Faying Surfaces, Add 0.004 Man-hours per Fastener
- Data Valid for Wet or Dry Fastener Installation

NONRECURRING TOOLING COST FOR ALUMINUM AND TITANIUM ASSEMBLIES

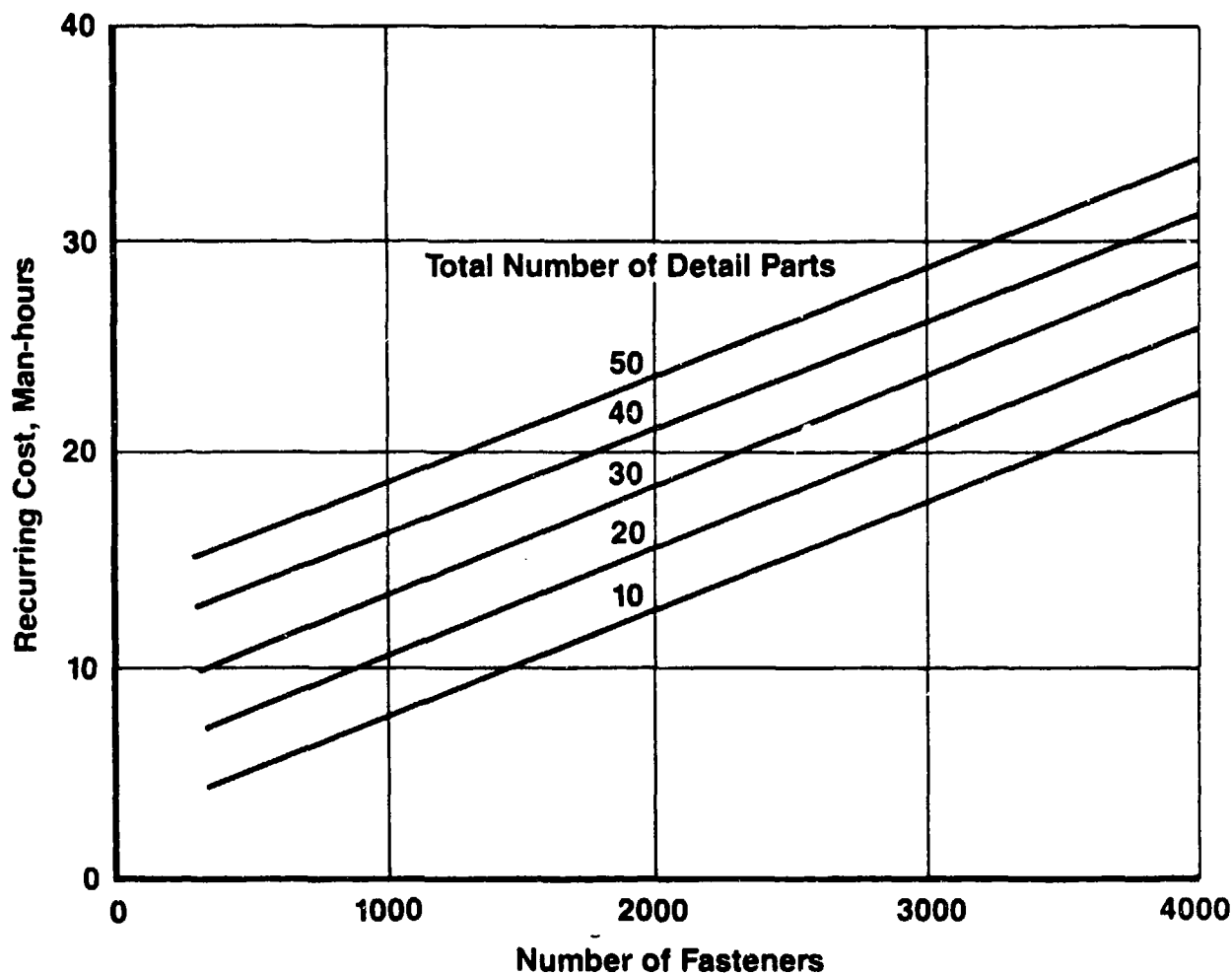


METALLIC SPARS **RECURRING ASSEMBLY COST/PART** **MANUAL INSTALLATION—ALUMINUM RIVETS** **(Installed Dry)**



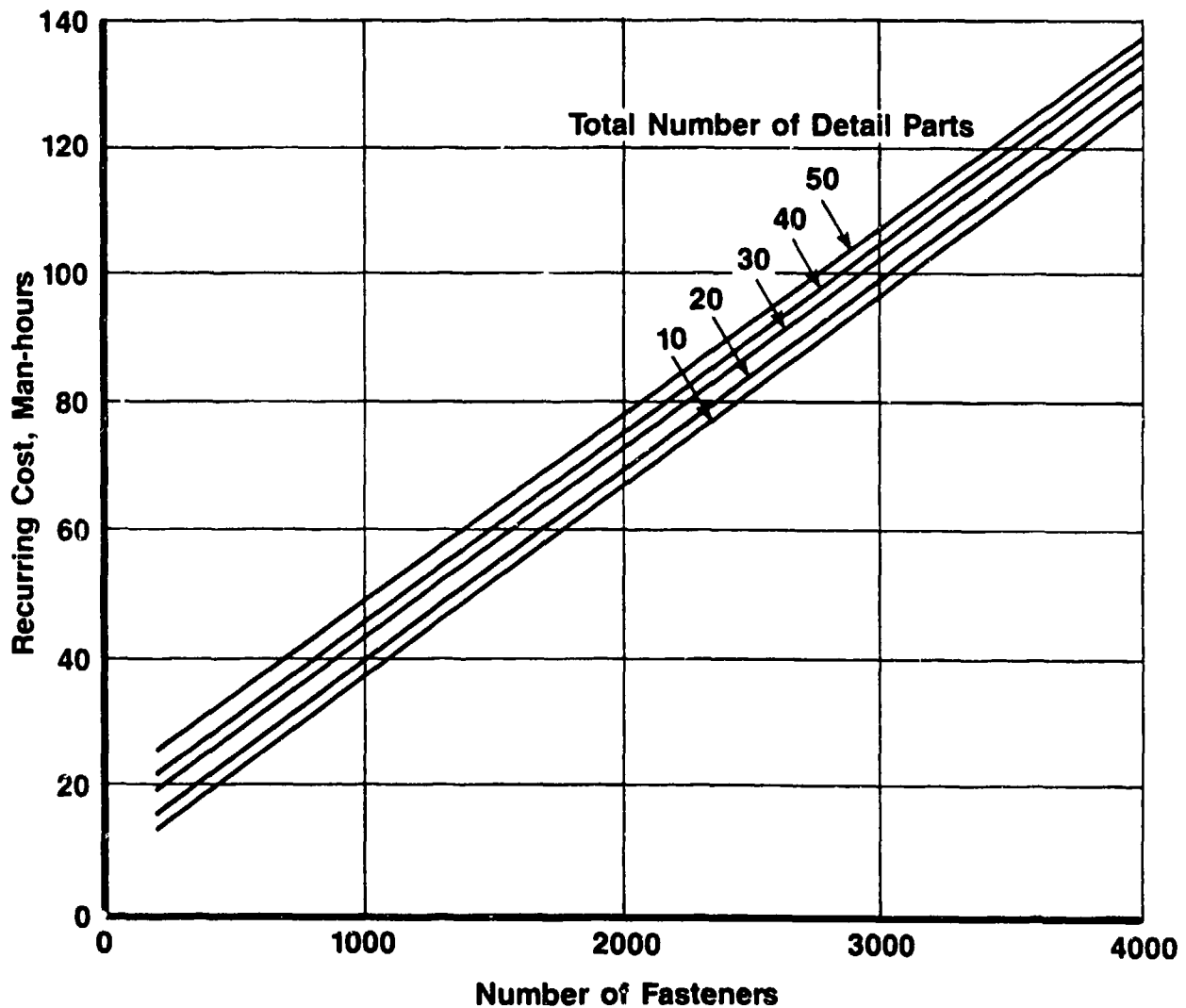
- Assembly Cost = Load and Clamp + Fastener Installation Man-hours
- For Wet Prime/Sealant on Fasteners Add 0.0075 Man-hours per Fastener
- For Wet Prime/Sealant on Fasteners Plus Faying Surfaces, Add 0.010 Man-hours per Fastener

METALLIC SPARS RECURRING ASSEMBLY COST/PART AUTOMATIC INSTALLATION—ALUMINUM RIVETS (Installed Dry)



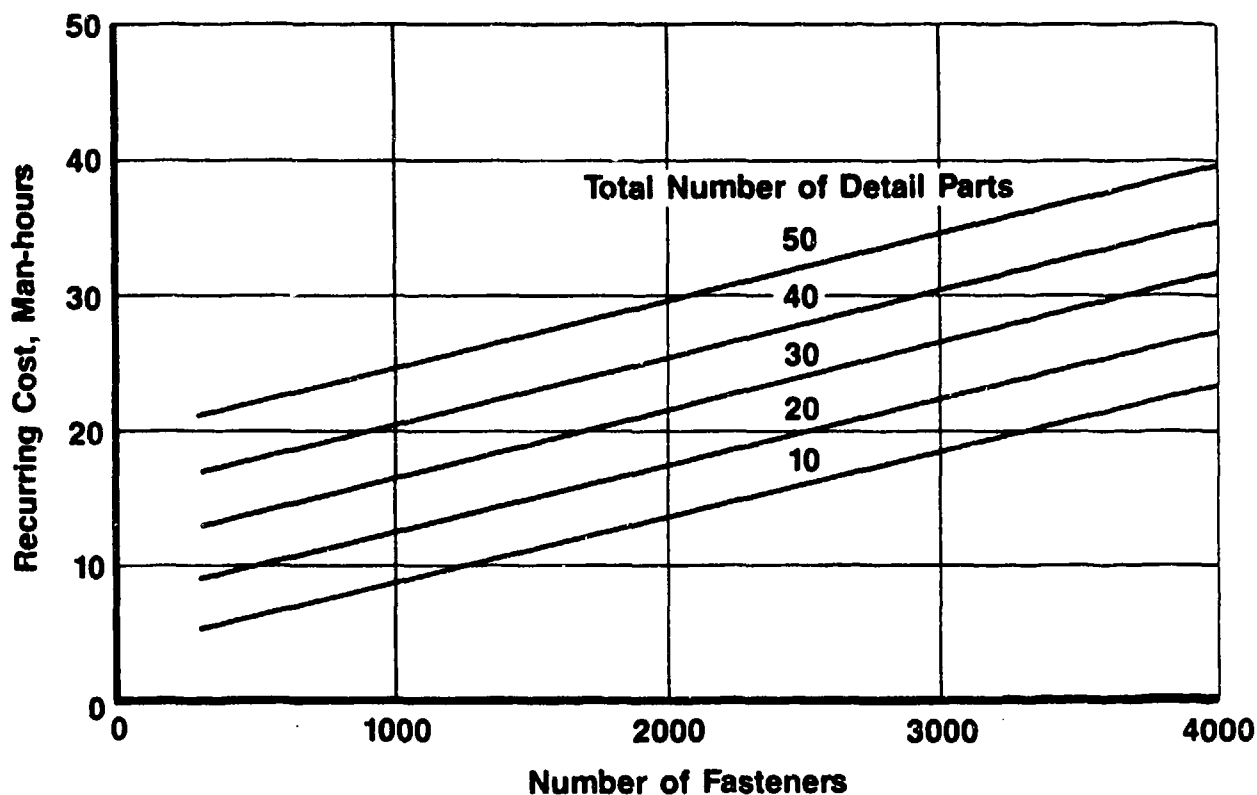
- Assembly Cost = Load and Clamp + Fastener Installation Man-hours
- For Wet Prime/Sealant on Fasteners Add 0.0075 Man-hours per Fastener
- For Wet Prime/Sealant on Fasteners Plus Faying Surfaces, Add 0.010 Man-hours per Fastener

METALLIC SPARS RECURRING ASSEMBLY COST/PART MANUAL INSTALLATION—TITANIUM RIVETS (Installed Dry)



- Assembly Cost = Load and Clamp + Fastener Installation Man-hours
- For Wet Prime/Sealant on Fasteners Add 0.007 Man-hours per Fastener
- For Wet Prime/Sealant on Fasteners Plus Faying Surfaces, Add 0.011 Man-hours per Fastener

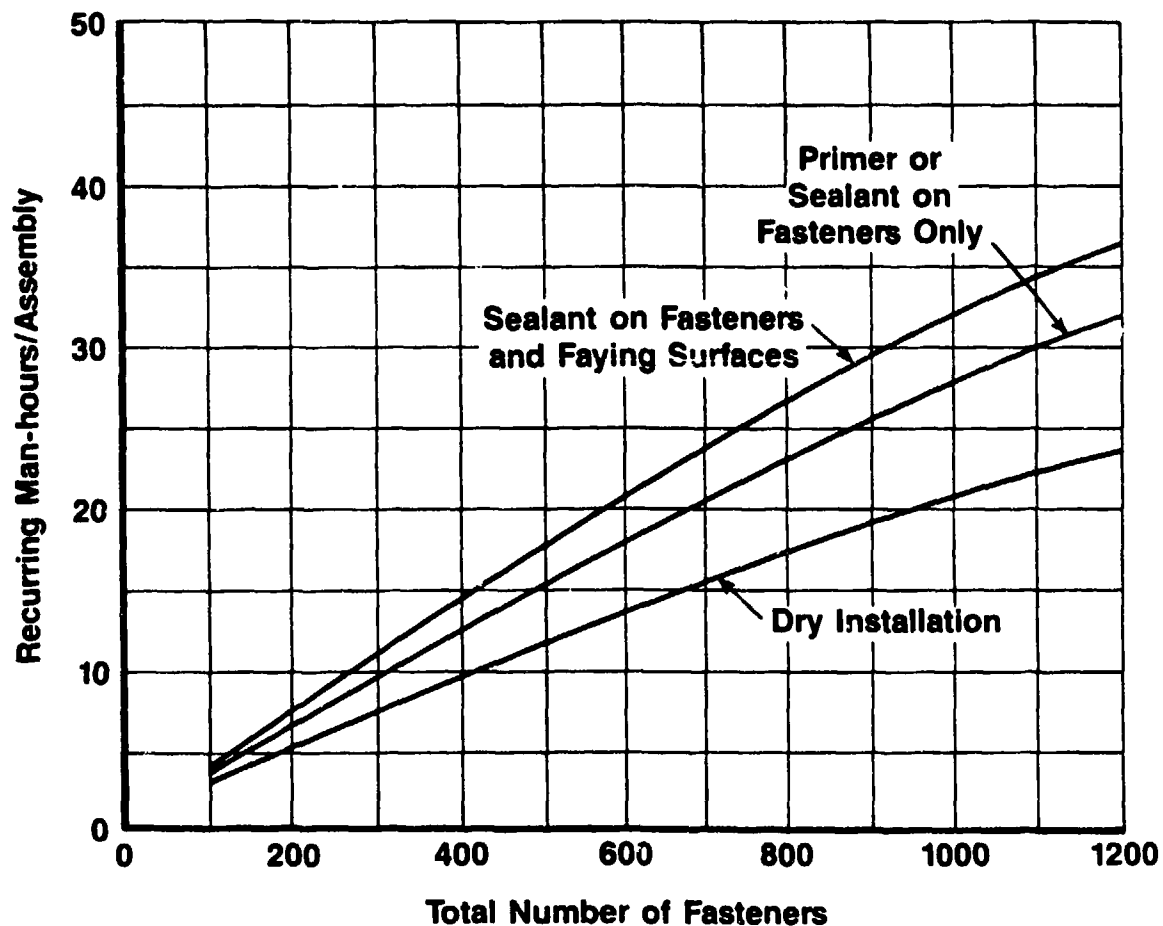
METALLIC SPARS **RECURRING ASSEMBLY COST/PART** **AUTOMATIC INSTALLATION—TITANIUM RIVETS** **(Installed Dry)**



- Assembly Cost = Load and Clamp + Fastener Installation Man-hours
- For Wet Prime/Sealant on Fasteners Add 0.007 Man-hours per Fastener
- For Wet Prime/Sealant on Fasteners Plus Faying Surfaces, Add 0.011 Man-hours per Fastener

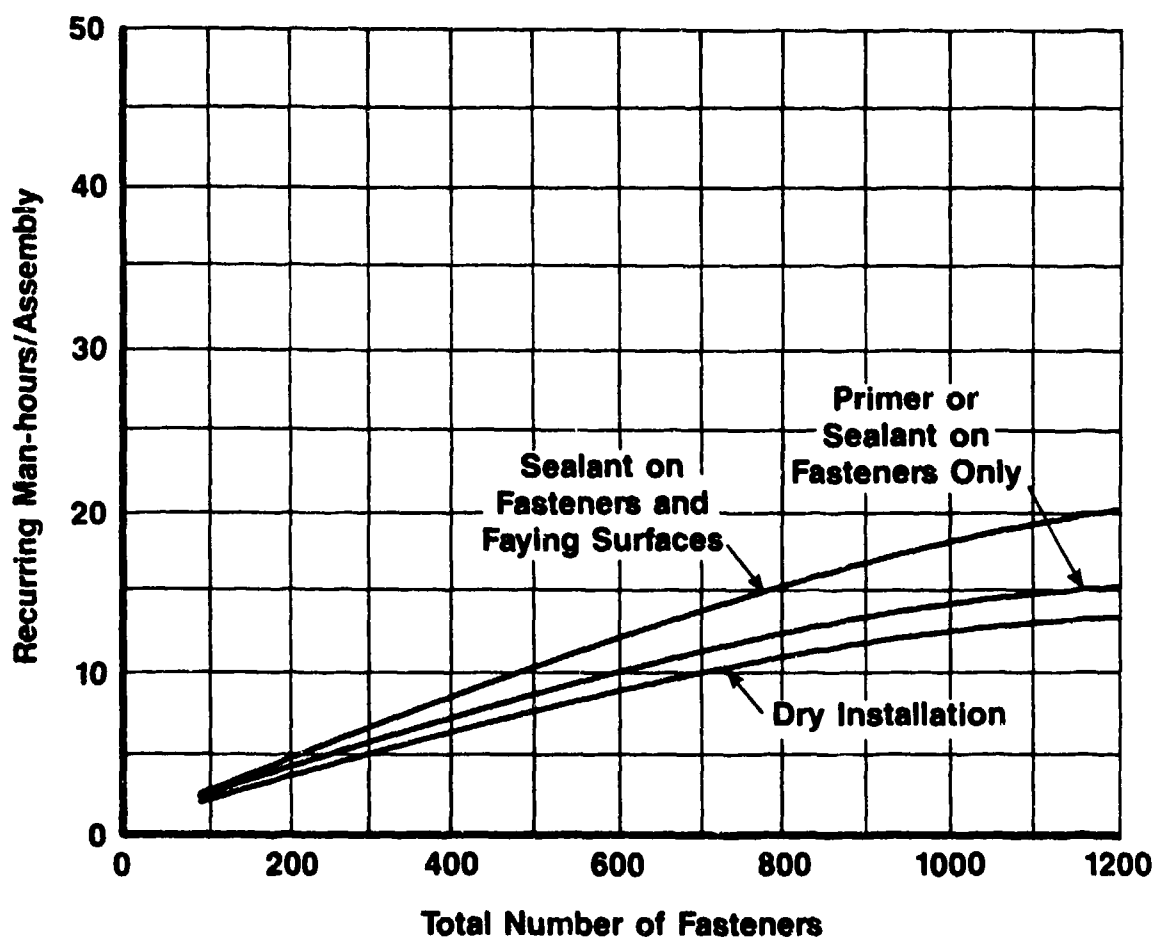
INSTALLATION COSTS FOR ALUMINUM RIVETS

- **Manual**



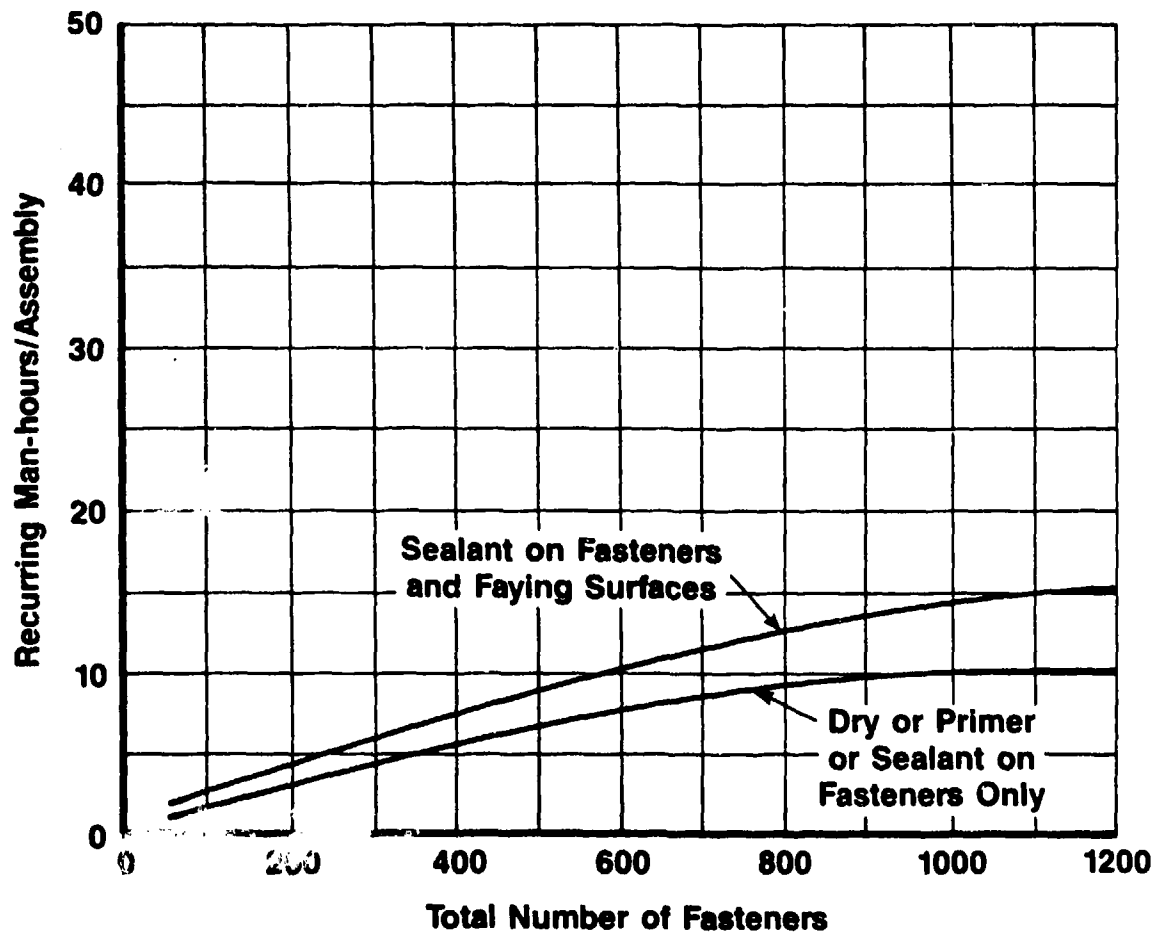
INSTALLATION COSTS FOR ALUMINUM RIVETS

- 80% Automatic
- 20% Manual

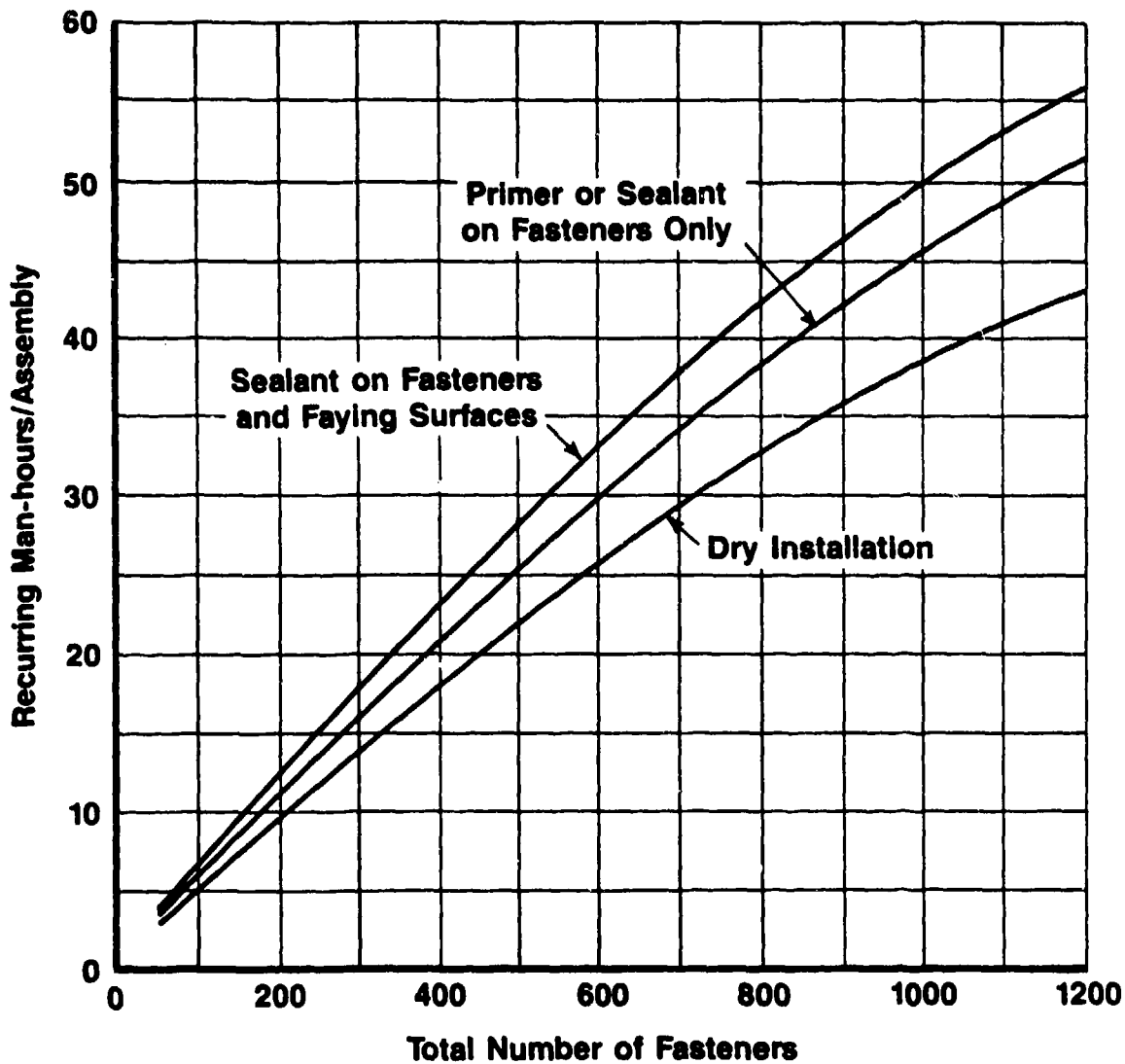


INSTALLATION COSTS FOR ALUMINUM RIVETS

- **Automatic**

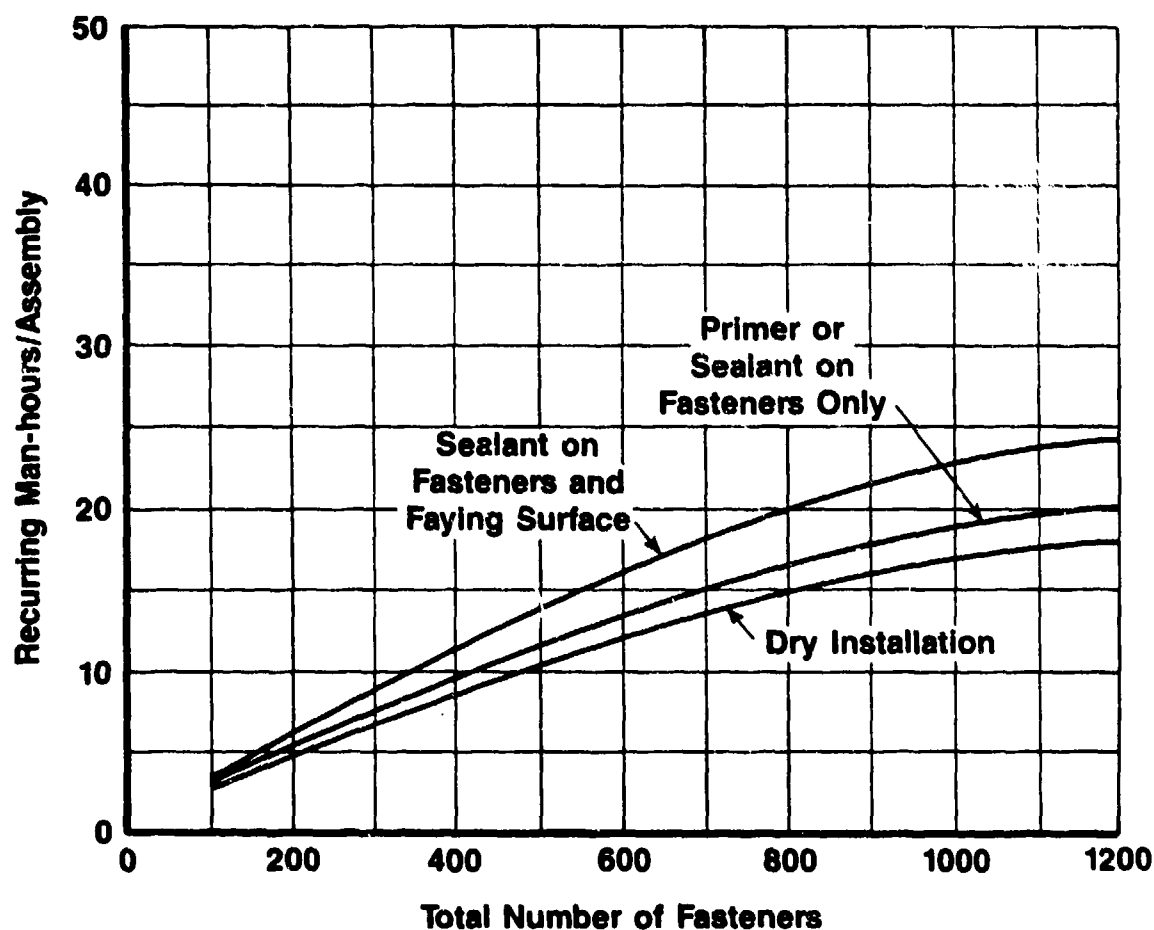


MANUAL INSTALLATION COST FOR TITANIUM RIVETS

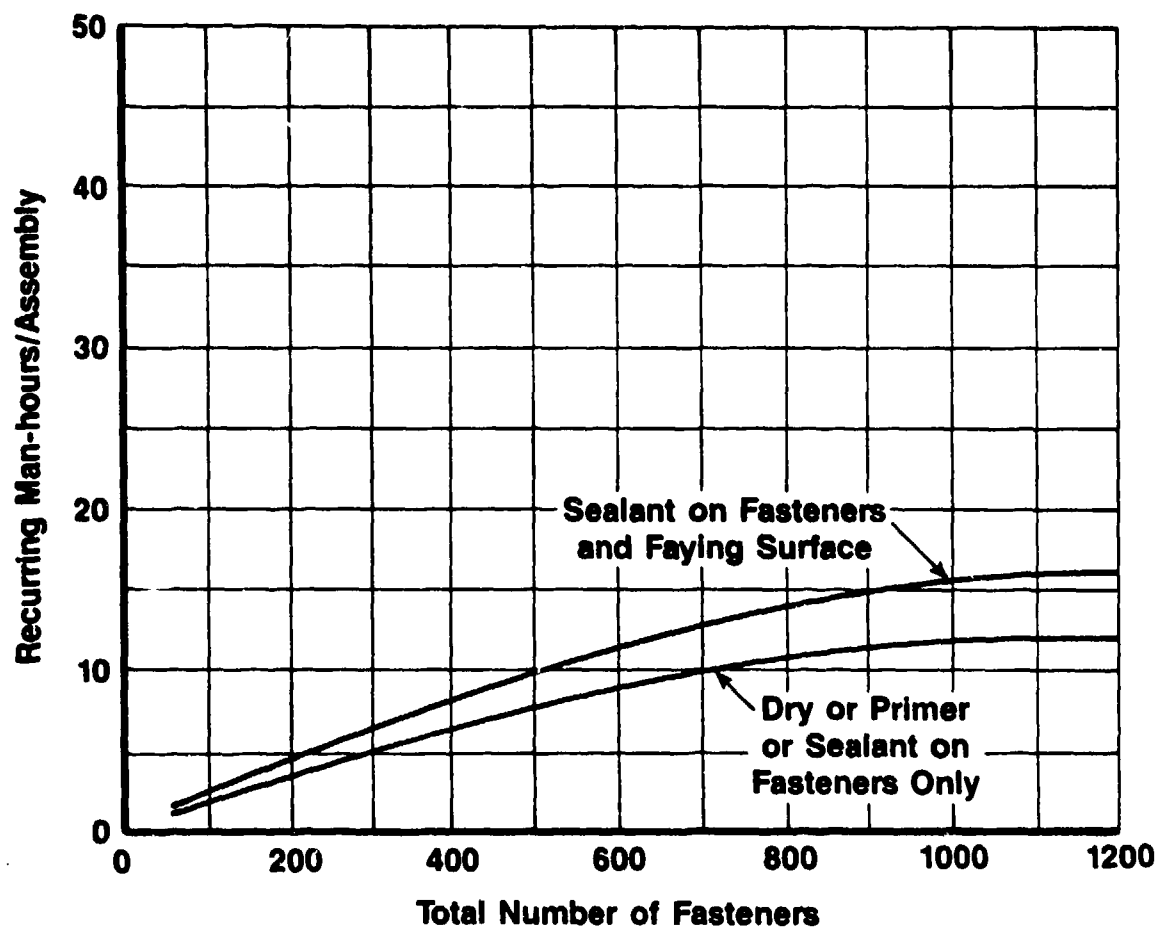


INSTALLATION COSTS FOR TITANIUM RIVETS

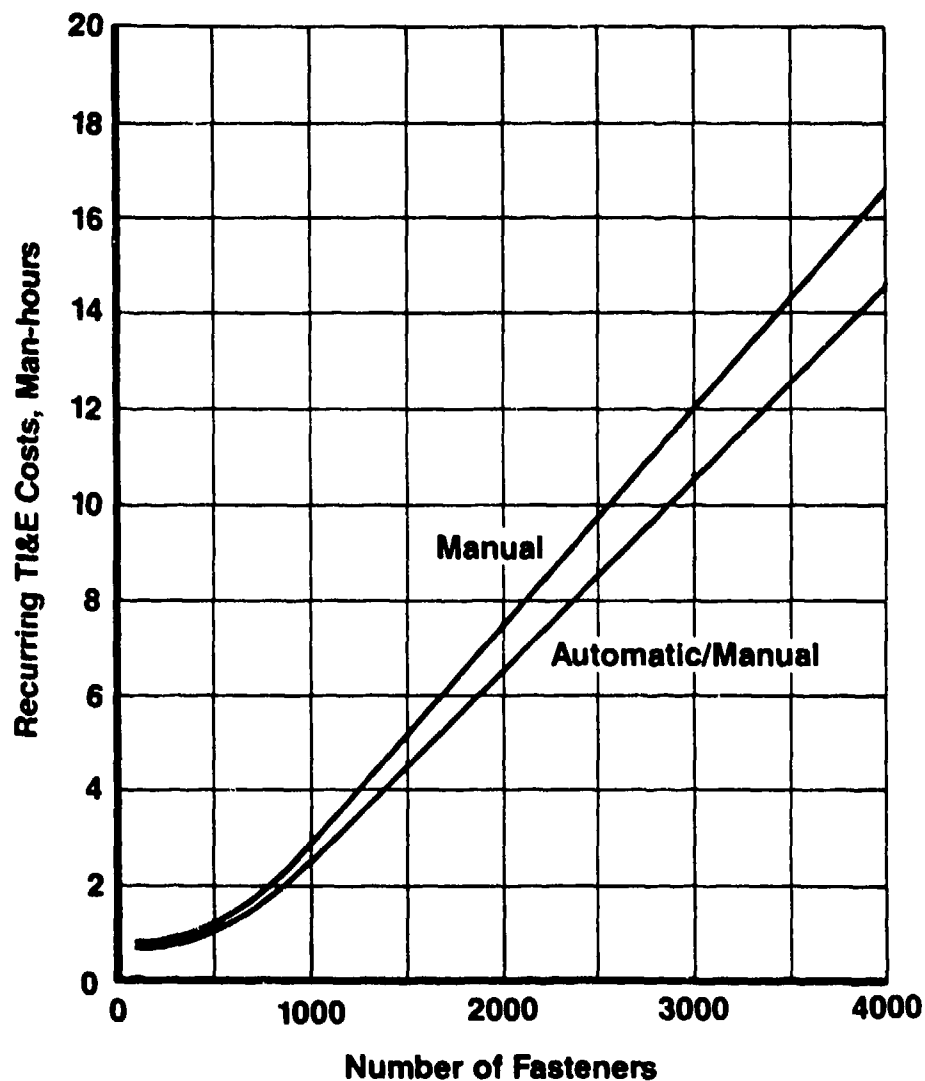
- 80% Automatic
- 20% Manual



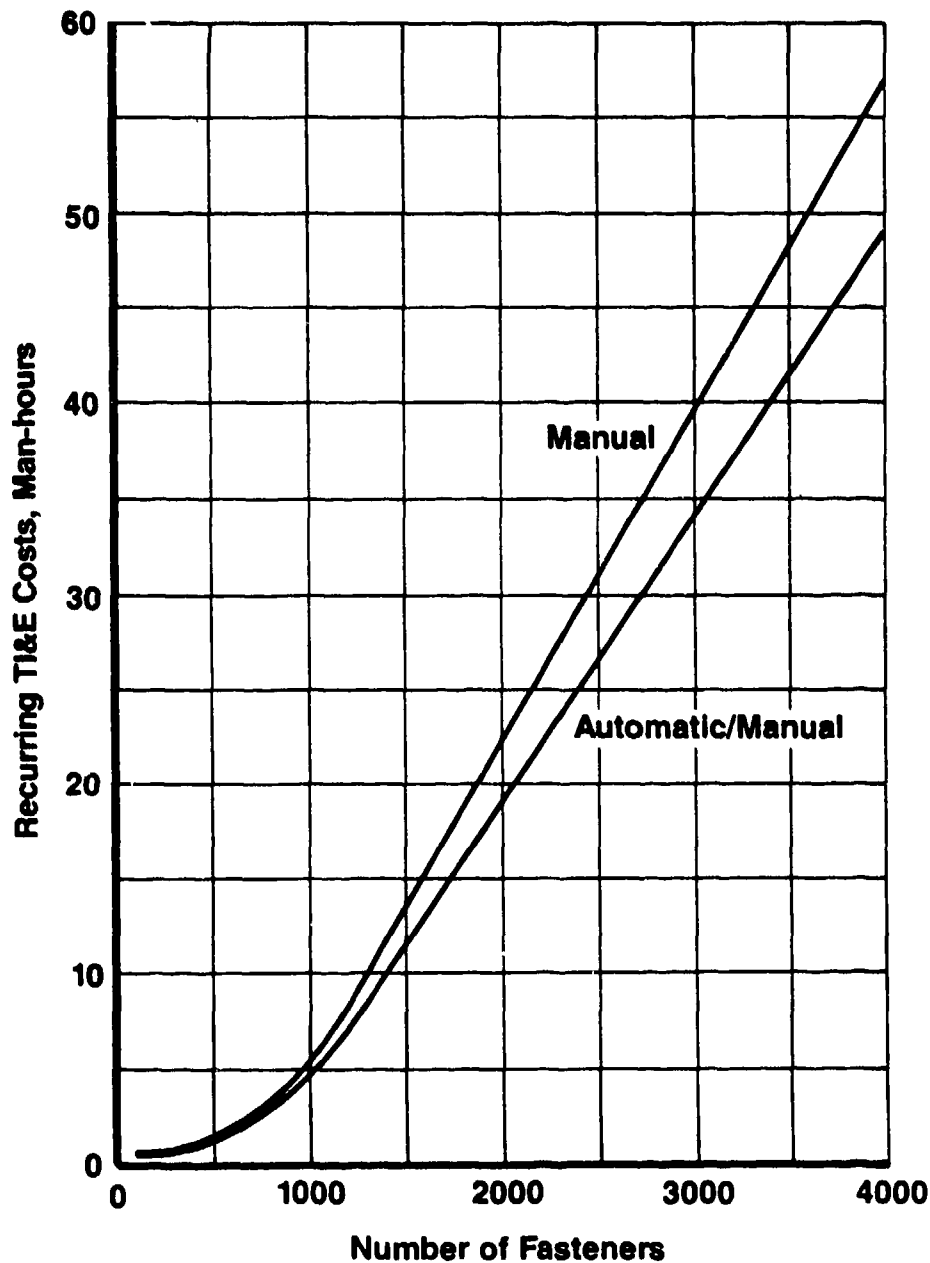
AUTOMATIC INSTALLATION COST FOR TITANIUM RIVETS



TEST, INSPECTION AND EVALUATION (TI&E) RECURRING MAN-HOURS FOR MECHANICALLY FASTENED ALUMINUM ASSEMBLIES

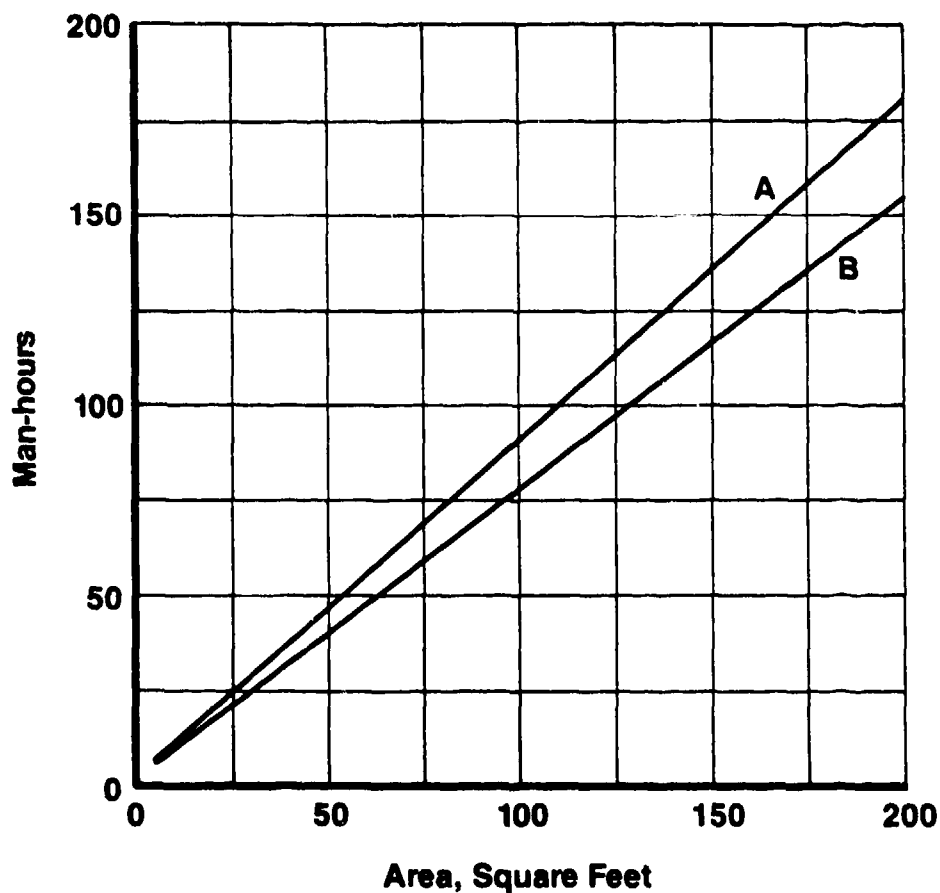


TEST, INSPECTION AND EVALUATION (TI&E) RECURRING MAN-HOURS FOR MECHANICALLY FASTENED TITANIUM ASSEMBLIES



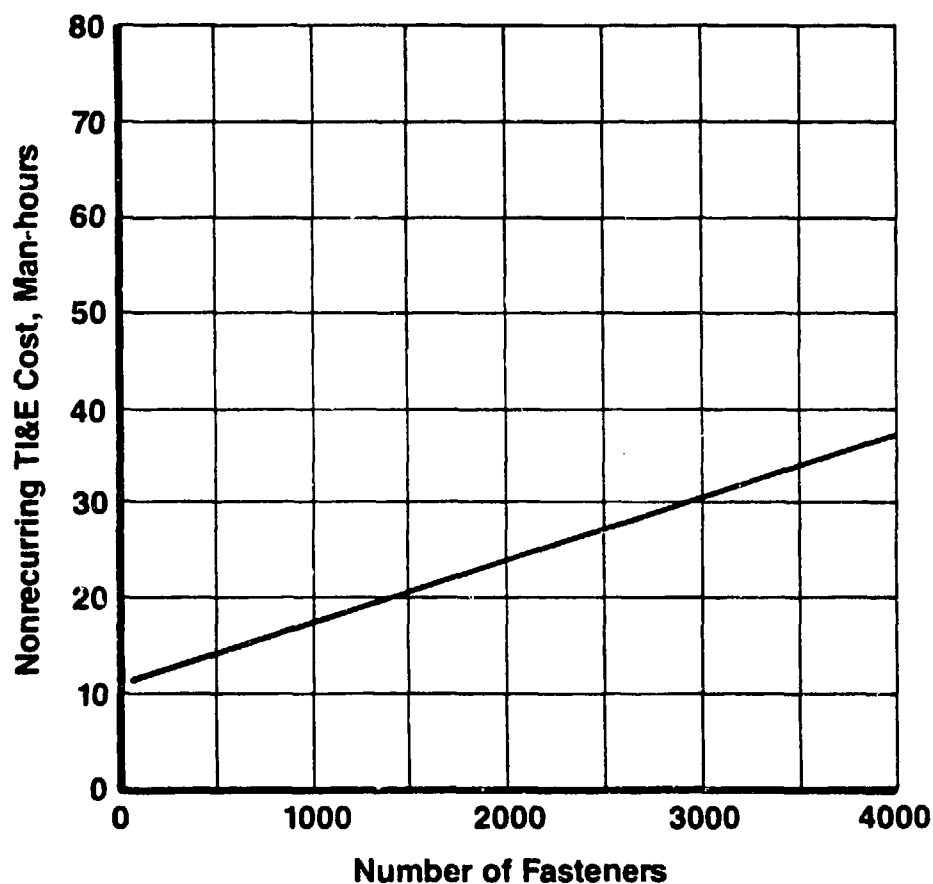
TEST, INSPECTION AND EVALUATION (TI&E) MECHANICALLY FASTENED ASSEMBLIES

Recurring Cost/Part For TI&E of DICE For Aluminum and Titanium Assemblies Using Manual or Combined Automatic/Manual Fastening Methods



- (A) Permissible to Seal and Verify Sealant on Fastener and Faying Surface
- (B) Permissible to Seal and Verify Sealant on Fastener Only

**TEST, INSPECTION AND EVALUATION (TI&E)
NONRECURRING TI&E MAN-HOURS FOR
ALUMINUM AND TITANIUM ASSEMBLIES
USING MANUAL OR COMBINED AUTOMATIC/
MANUAL FASTENING METHODS**



APPENDIX A

"Manufacturing Cost/Design Guide
for Aerospace Applications"

GROUND RULES
for
COMPOSITE STRUCTURES

4.1.1.* GROUND RULES FOR COMPOSITE STRUCTURES

The following general and detailed ground rules for the MC/DG Section on Composite Structures were developed to establish the scope of the data required and to provide guidance for MC/DG application. Ground rules are necessary to promote understanding and to ensure consistency, uniformity, and accuracy in generating and integrating data into the formats. The ground rules also assure that the data presented will represent current aerospace industry technology and man-hours.

4.1.1.1. General Ground Rules

The major categories of general ground rules are:

- (a) Advanced Composite Parts
- (b) Advanced Composite Materials
- (c) Manufacturing Technology
- (d) Tooling
- (e) Facilities/Equipment
- (f) Test, Inspection, and Evaluation
- (g) Interaction With Other Air Force Programs
- (h) Data Generation - Recurring Costs
- (i) Data Generation - Nonrecurring Costs
- (j) Data Compilation and Presentation.

(a) Advanced Composite Parts

1. AFWAL-TR-80-4115, although limited in scope to a small number of discrete composite parts, permits the designer to utilize the data to enable design/cost trade-off studies to be conducted on a limited number of parts, such as a composite fuselage shear panel. However, because of designer-indicated needs, the MC/DG will be expanded to include additional discrete parts and complete complex composite assemblies, such as:

- Complete fuselage sections
- Complete panels (wing-fuselage)

*Numbering refers to Work Breakdown Structure (WBS).

- Control surfaces
 - Typical wing and stabilizer torque-boxes
 - Speed-brakes
 - Substructures - beams, spars, ribs and bulkheads.
2. The Battelle-Columbus Division (BCD)-airframe industry team will select, from the above list, at least two representative composite assemblies from current aerospace vehicles to demonstrate the suitability and benefits of the MC/DG as an effective document for the technological transfer of composite structures, cost tracking, cost analysis, and cost-effectiveness comparisons.

(b) Advanced Composite Materials

1. In addition to the more common materials and adhesive systems covered in the previous MC/DG program (AFWAL-TR-80-4115), the following material types will be included:
- Graphite/epoxy
 - Graphite/polyimide
 - Graphite/bismaleimide
 - Kevlar/epoxy
 - Fiberglass/epoxy.

(c) Manufacturing Technology

1. The technology for manufacturing composite parts/assemblies is experiencing phenomenal changes, progressing from primarily a manual hand-layup operation to semi- and fully automated manufacturing operations. With the use of advanced composite structures expected to expand from less than 30 percent of the structural weight today, to as high as 60 to 65 percent for the next generation of aircraft, improved manufacturing technology will be imperative.
2. The following manufacturing methods will be studied and evaluated:
- Filament winding
 - Tape-laying
 - Braiding

- Pultrusion
 - Layup of broadgoods.
3. Where applicable, formats such as CED's and DICE, will be developed to include the man-hours for these fabrication processes.
 4. These methods will be closely coordinated with the DOD/NASA "Advanced Composites Fabrication Guide". Where this document does not contain this information and such data are necessary for developing the MC/DG data, the Air Force Project Engineer Manager will be informed. This will preclude duplication of this information and data and will avoid conflict or disagreement between data published in the respective documents.
 5. Team members will provide descriptions of manufacturing methods/processes, equipment, and tooling utilized in developing man-hour data for parts/assemblies analyzed.

(d) Tooling

1. The BCD/industry team will investigate tooling utilized in preparing all data developed. This will include:
 - Metallic vs. nonmetallic tooling material
 - Male vs. female tooling
 - Soft tooling (temporary/limited production) vs. hard tooling (permanent/high production).
2. Recommendations will be made on selecting tooling based on tool life, production quantity, and tooling materials.
3. Data contained in existing guides will be utilized in these analyses to determine the tooling cost.

(e) Facilities/Equipment

1. Facilities and equipment utilized for the manufacture of composites will be limited to production as opposed to prototype. It is intended to include the following equipment:
 - Autoclaves (or alternative methods of curing)
 - Tape-laying machines (semi-automated/fully automated)

- Filament winding machines
 - Pultrusion equipment (in-house vs. purchased item)
 - Braiding machines
 - Layup machines for broadgoods (semi-automated vs. automated).
2. Designers are limited to some extent by the capacity and fabricating methods, equipment, and facilities available.
 3. Team members will analyze the types and size range of equipment not presently available and predict future requirements from the above list.

(f) Test, Inspection, and Evaluation (TI&E)

1. Quality control expends significant effort in all phases of composite manufacturing from the monitoring of materials (shelf-life, environmental controls, resin content, etc.) to continuous monitoring of the entire fabrication process.
2. The costs of these functions are generally regarded as recurring and will be considered by the team members.
3. Previous MC/DG programs have highlighted and documented the factors (CDE, CED, DICE) that contribute to TI&E costs.

(g) Interaction with other Air Force Programs

1. The Advanced Composite Cost-Estimating Manual (ACCEM) and the Advanced Composite Fabrication Guide (ACFG) will be utilized extensively as aids in generating and, in some cases, verifying the in-house data reflecting the production experience and data developed by each team member.
2. The ACFG will be used as the basis for the manufacturing methods chosen for investigation on this program. For example, it will help in:
 - Developing standard operational sequences
 - Defining various tooling concepts.
3. The approach to data definition used in the Fabrication Cost-Estimating Technique (FACET) will be evaluated for potential appli-

cation to airframe discrete parts of the MC/DG data development phase.

4. The MC/DG data development team will maintain contact with other related CIM programs. These include:
 - Integrated Composites Center (ICC)
 - MC/DG Computerization (MCDS)
 - Group Technology Characterization System
 - ICAM Definition Methodology (IDEF)
 - ICAM Architecture
 - ICAM Human Factors.
5. The BCD/industry team acknowledges the benefits of interaction with various related programs and will continue to maintain an interchange of data and information.

(h) Data Generation - Recurring Costs

1. Recurring costs for manufacturing will cover the total man-hours required for detail part fabrication, including all hands-on direct factory operations required for converting the basic composite materials to a finished part or assembly.
2. Base-part costs will include all standard hours associated with each part, as defined by design, and will not include costs associated with design complexities.
3. Designer-influenced cost elements (DICE), requiring added operations, will be treated separately and not included in the part cost. This provides the building block approach to designers.
4. In addition to the base-part cost, costs associated with design complexities will be identified when these represent cost drivers.
5. All cost data shall be presented in man-hours.
6. Each company on the team will utilize its respective learning curves; but part costs will be determined at unit 200, and for a lot size of 25 parts.
7. Man-hour cost submitted by each company will be synthesized and normalized by BCD to reflect an industry team average.

8. Other recurring costs, such as those for tool design, production planning, tool manufacturing, and maintenance, will not be included.
9. For proprietary reasons, business-sensitive information supplied by member companies to BCD will not be presented, or disclosed to other team members, agencies, or to the public, without written approval by the team members, agencies, or to the public, without written approval by the team member company. ACCEM and ACFG data that are available throughout industry does not fall in this category.
10. TI&E recurring hours will not be included in fabrication man-hours, but will be displayed separately where applicable. However, TI&E man-hours may be expressed as a percentage of manufacturing hours.

(i) Data Generation - Nonrecurring Costs

1. Tool fabrication hours will include tool design hours, but will not include nonrecurring production planning (method sheets) or shop work order man-hours.
2. Only the cost of contract tooling required for the fabrication/assembly of the part/assembly will be included. The cost of perishable or standard tooling, e.g., cutters and drills, will not be included.
3. All nonrecurring cost data submitted by the member companies will be synthesized and normalized by BCD, and will be considered proprietary.

(j) Data Compilation and Presentation

1. The manufacturing cost (man-hours) data for the composite configurations studied, e.g., spars, ribs, panels, and assemblies, will be compiled using FACET.
2. In addition to FACET, the documents referred to earlier which compile actual composite assembly costs throughout the aerospace industry, will be utilized in data analysis.
3. "Data Entering and Summary Sheets," similar to those used in previous MC/DG programs, will be used for the compilation effort.

4. Data will be presented to designers in two forms:
 - Designer-oriented formats similar to previous MC/DG data development efforts, e.g.:
 - Cost-Driver Effects (CDE)
 - Cost-Estimating Data (CED)
 - Designer-Influenced Cost Effects (DICE).
 - Data Summary Sheets that display the normalized data in tabular form. These tables will be the primary data presentation form. They will provide the team with backup data for the formats, and will also be used for entering data into the computerized MC/DG data base.
5. A format selection aid will be provided to enable the designer to rapidly select the appropriate format.
6. A supplement to the current designer's work sheet may be required for applicability to the newly developed data and formats.
7. All formats (CDE, CED, and DICE) will specify the applicable operations code to identify the operation, fabrication method, and facilities used.
8. The formats will address, whenever appropriate, the various manufacturing processes involving manual, semi-automatic, and fully automatic operations.
9. All formats will be submitted by team members to their design engineers for recommendations and approval before finalization.

4.1.1.2. Detailed Ground Rules

The major categories of detailed ground rules are:

- (a) Structural Parts
- (b) Materials
- (c) Tolerances
- (d) Support Functions.

(a) Structural Parts

1. The composite parts selected for evaluation in this phase will include the following design features:
 - Laminate thickness transition
 - Precuring or metallic inserts
 - Lineal members (straight, contoured, cylindrical)
 - Edge trimming
 - Beaded webs, ribs, and spars
 - Sine-wave webs, ribs, and spars
 - Selective stiffening (skin/stiffeners and high modulus strip plates, etc.)
 - Mechanically fastened assembly techniques for separately cured and cocured secondary and primary structures
 - Integral construction
 - Tolerances (high and low range)
 - Sandwich construction (honeycomb and longitudinally corrugated cones).

(b) Materials

1. The composite materials utilized will be primarily determined by the design of the parts selected. Emphasis will be placed on the materials listed in the general ground rules (b), but the following common materials will be considered:
 - T300/5208
 - T300/934
 - AS-3501-6
2. All materials and forms (tape, broadgoods, etc.) used will be assumed to be readily available from commercial sources. With the exception of thermoplastics, no experimental type materials will be studied.

(c) Tolerances

1. Tolerances will be determined primarily from the engineering drawings of the parts selected. Special tolerances will be considered DICE.
2. Tolerances for base part configurations will be: ± 0.030 inch on lineal dimensions and ± 0.00025 inch on thickness per ply.
3. Tolerances for cocured assemblies will be ± 0.06 inch on part location.
4. Maximum tolerances for fit-up of cured details will be 0.030 inch per gap for mechanically fastened assemblies and 0.015 inch for bonded assemblies.

(d) Support Functions

1. Due to the diversity of the methods used for cost allocation by the aerospace industry, the following costs will not be provided by the team members:
 - Manufacture/Production Planning
 - Engineering Liaison/Support
 - Production/Tool Control
 - Quality Assurance Testing and Specification Preparation
 - Overhead and General Administration (G&A)
 - Profit or Fees.

APPENDIX B

"Manufacturing Cost/Design Guide
for Aerospace Applications"

GROUND RULES
for
MECHANICALLY FASTENED METALLIC ASSEMBLIES

4.2.1.* GROUND RULES FOR MECHANICALLY FASTENED METALLIC ASSEMBLIES

The following general and detailed ground rules for the MC/DG Section on Mechanically Fastened Metallic Assemblies were developed to establish the scope of the data required and to provide guidance to MC/DG application. Ground rules are necessary to promote understanding, and to ensure consistency, uniformity, and accuracy in generating and integrating data into the formats. The ground rules also assure that the data presented represent current aerospace industry technology and man-hours.

4.2.1.1. General Ground Rules

The major categories of general ground rules are:

- (a) Typical Mechanically Fastened Metallic Assemblies
- (b) Materials
- (c) Manufacturing Technologies/Processes
- (d) Tooling
- (e) Facilities/Equipment
- (f) Data Generation - Recurring Costs (including YI&E)
- (g) Data Generation Nonrecurring Costs
- (h) Support Function Modifiers
- (i) Test and Evaluation of Data.

(a) Typical Mechanically Fastened Metallic Assemblies

1. Parts selected will be representative of primary (basic) and secondary structures, with emphasis on primary structures.
2. Metallic assemblies will be defined as two or more metallic parts (sheet metal, extrusions, machined parts, etc.) joined with metallic fasteners (rivets, bolts, pins, etc.).
3. Typical mechanically fastened assemblies shall include, but not be limited to:
 - Fuselage skins and substructures
 - Lifting surface skins to substructure
 - Control surfaces

*Numbering refers to Work Breakdown Structure (WBS).

- Bulkhead assemblies
 - Integral fuel-tank structures
 - Built-up spar and beam assemblies
 - Removable doors and panels
 - Ducts.
4. A method of defining assemblies by their degree of complexity (simple, average, complex) will be devised and drawings provided to aid in their identification.
 5. The cost impact of "interchangeable" vs. replaceable assemblies will be assessed.
 6. Assemblies that are currently "in-production" and advanced designs will be evaluated.
 7. Consideration will include, but not be limited to metallic assemblies that provide "fuel sealing" as utilized in integral fuel-tank structures, such as a wing-box.

(b) Materials

1. Detail parts fabricated from the following materials will be included:
 - Aluminum alloys
 - Titanium alloys
 - CRES and PH steels.
2. Fasteners will be of the same materials.
3. Representative metallic assemblies may include the following detail parts:
 - Sheet metal
 - Castings
 - Machined parts
 - Machined forgings.

(c) Manufacturing Technologies/Processes

1. To provide a common basis for establishing cost data, manufacturing operation sheets or process sheets will be prepared for each

assembly by each team member. These data will be standardized by BCD to represent a realistic industry base to the degree feasible. The sheets shall provide, but not be limited to, the following information:

- All hands-on operations necessary
 - Project (contract) tooling required
 - Inspection operations
 - Standard man-hours required
 - Equipment required.
2. All "cost drivers" will be identified by source, i.e., engineering, tooling, equipment, etc.
 3. All work is to be completed in a production environment as opposed to a prototype or R&D environment.

(d) Tooling

1. All project (contract) tooling will be identified, including:
 - Assembly jigs/fixtures
 - Drill plates
 - Holding devices
 - Special handling devices.
2. Perishable (consumable) tools, such as drills, reamers, and cutters, will be listed in operation sheets, but not considered in cost data, unless they are specific cost drivers.
3. Special tooling for positioning parts, automatic or numerically controlled drilling, reaming, etc., for specific assemblies, shall be classified as project tooling.

(e) Facilities/Equipment

1. All cost estimates shall be based on the type of production environment normally associated with the airframe industry.
2. Equipment, either off-the-shelf or in-house developed, that is specifically designed to install fasteners, will be highlighted as special equipment.

3. The current availability of semi-automated or fully automated equipment will be indicated.
4. The importance of cost avoidance by using semi-automated or fully automated equipment to install fasteners will be indicated to designers.

(f) Data Generation - Recurring Costs

1. All cost (man-hours) data developed and presented on the manufacturing operation sheets will be transferred to "Data Summary Sheets" (similar to those used on previous MC/DG programs).
2. All data will be synthesized and normalized by BCD to obtain an industry average.
3. BCD will consider all submitted data company private and proprietary. These data will not be disclosed to other team members, agencies, or to the public without expressed written approval of the airframe company team member.
4. Recurring man-hours will be included in the total manufacturing direct man-hours needed to complete the assembly, as specified on the manufacturing operation sheets prepared by each team member.
5. No recurring tool fabrication, production planning, or tool design man-hours will be included.
6. All cost drivers and their source will be identified.
7. All team members will utilize their company's learning curves, which will be considered proprietary.
8. All data (man-hours) will be presented on designer-approved formats compatible with the MC/DG objectives and previous MC/DG programs. These formats are:
 - Cost Estimating Data (CED)
 - Cost-Driver Effects (CDE)
 - Designer-Influenced Cost Elements (DICE).
9. DICE will be treated separately to highlight them to designers.
10. As major assemblies are generally manufactured on a line-type basis (i.e., one at a time and not by lot), the man-hour data will be based in total runs of 200 assemblies.

11. For small assemblies, i.e., stringers-to-skins, set-up time will be defined as the total set-up time to fabricate/assemble the lot size of 25, amortized over the complete lot size, i.e., 1/25 of the total set-up time. The run-time will be the total time to complete one assembly. Thus, the total base-assembly man-hours will be the sum of the run-time plus 1/25 of the set-up time.
12. Test, inspection, and evaluation (TI&E) man-hours will be the total man-hours reflected on the operation sheets for inspection operations and will be presented separately and not included in the direct factory/manufacturing man-hours.
13. Specific dollar costs for material or hardware will not be displayed, but relative costs will be provided. These costs can be provided by designers on the "Designer's Worksheet."

(g) Data Generation - Nonrecurring Costs

1. Tool design, tool fabrication, and tool inspection man-hours required to manufacture contract or project tooling will be included, but will be listed separately from manufacturing man-hours.
2. Manufacturing/production planning man-hours will not be included.
3. Nonrecurring costs (man-hours) will be submitted by the team members and synthesized and normalized by BCD to obtain an industry average.
4. All nonrecurring costs (man-hours) submitted by the industry team members will be considered company private and not released by BCD to other team members, agencies, or to the public without the written approval of the team member.

(h) Support Function Modifiers

The following support function costs vary significantly between companies. They are considered company private, and will not be included in data provided by the team member companies to BCD. These are:

- Engineering Design Support
- Production/Tool Control

- Quality Assurance Testing and Specification Preparation
- Material/Purchasing Costs
- Manufacturing/Tool Planning
- Overhead or General Administration (G&A) Costs
- Profit or Fees.

The support costs may be added by the respective team member companies.

(i) Test and Evaluation of Data

1. Before finalization, all formats (CDE, CED, and DICE) will be submitted to design engineers at the team member companies for their evaluation, critique, and approval.
2. All data (CED, CDE, and DICE) will be tested and proven applicable to any aerospace mechanically fastened metallic assembly. Data will be demonstrated on a minimum of two aerospace assemblies from the list under heading (a) of these general ground rules.
3. Examples will be verified "step-by-step" to illustrate the steps necessary to conduct "trade-off" studies utilizing the formatted data (CED, CDE, and DICE).
4. All data will be integrated into the MC/DG User's Manual, together with the necessary procedures and examples illustrating their application to mechanically fastened metallic assemblies.

4.2.1.2. Detailed Ground Rules

The major categories of detailed ground rules are:

- (a) Mechanically Fastened Metallic Assemblies

- (b) Materials
- (c) Tolerances
- (d) Recurring Costs
- (e) Manufacturing Methods/Processes/Facilities
- (f) Tooling.

(a) Mechanically Fastened Metallic Assemblies

1. Assemblies selected will be representative of the full range of materials and fasteners currently in production within the aerospace industry.
2. Representative examples of simple, average, and complex assemblies will be illustrated and described.

(b) Materials

1. Fastener materials will include:
 - Aluminum
 - Titanium
 - Steel
 - Inconel.
2. Types of fasteners will include:
 - Conventional AN rivets (button head and flush counter-sunk)
 - AN-NAS bolts
 - Hi-Lok
 - Hi-Tique
 - Taper-Lok
 - Fuel sealing rivets/bolts.

(c) Tolerances

1. Tolerances will be "per blueprint" on parts selected for review.
2. Tolerances less than ± 0.030 inch will be considered DICE.

(d) Recurring Costs

1. All costs will be submitted in man-hours (except where material costs are considered cost drivers).
2. Standardized manufacturing/planning operation sheet man-hour data, supplied by the team members, will be transferred to "Data Summary Sheets" (similar to those used on previous MC/DG programs), synthesized and normalized by BCD.
3. Only recurring costs (man-hours) for those operations normally referred to as "inspection" and specifically appearing on the manufacturing/planning operation sheets will be treated as TI&E costs.
4. Other TI&E recurring or nonrecurring costs will be included, such as:
 - Receiving inspection
 - Testing and evaluation.
5. Specification preparation will not be included in TI&E costs.

(e) Manufacturing Methods/Processes/Facilities

1. All manufacturing methods/processes will be conducted in a "production-type environment" using standard aerospace methods, tools, and equipment.
2. The degree to which manual or conventional methods are used to install fasteners (hand tools, etc.) vs. the use of semi-automated or fully automated equipment (drivematic, etc.) will be documented.
3. Cost drivers arising because certain fasteners or the basic engineering design preclude fully utilizing semi-automatic or automated equipment will be highlighted.

(f) Tooling

1. Contract or project tooling designed for a specific assembly will be included as NRTC. No consumable (perishable) or standard tooling (drills, reamers, cutting tools, rivet sets, etc.) will be included.

2. NRTC's will include tool design, tool fabrication, and tool inspection costs (man-hours) for all contract or project tooling.
3. All tooling costs (man-hours) will be displayed separately.

APPENDIX C

"Manufacturing Cost/Design Guide
for Aerospace Applications"

GROUND RULES

for

SUPERPLASTIC FORMING/DIFFUSION BONDING (SPF/DB)

4.1.3.* GROUND RULES FOR SUPERPLASTIC FORMING/DIFFUSION BONDING (SPF/DB)

The following general and detailed ground rules for the MC/DG Section on Superplastic Forming/Diffusion Bonding (SPF/DB) were developed to establish the scope of the data required and to provide guidance for MC/DG application. These ground rules also apply to Superplastic Formed (SPF) and Diffusion Bonded (DB) components. Ground rules are necessary to promote understanding and to ensure consistency, uniformity, and accuracy in generating and integrating data into the formats. The ground rules also assure that the data presented will represent current aerospace industry technology and man-hours.

4.1.3.1. General Ground Rules

The major categories of general ground rules are:

- (a) Typical SPF/DB, SPF and DB Applications
- (b) Materials
- (c) Processes/Manufacturing Technology
- (d) Facilities/Equipment
- (e) Data Generation - Recurring Costs (including TI&E)
- (f) Data Generation - Nonrecurring Costs
- (g) Support Function Modifiers
- (h) Test and Evaluation of Data.

(a) Typical SPF/DB Applications

1. SPF/DB is in fact a combination of two manufacturing technologies or manufacturing processes, i.e., superplastic forming (SPF) and diffusion bonding (DB), each capable of producing complete finished parts or assemblies. When combined, they are referred to as the superplastic forming/diffusion bonding (SPF/DB) process. Representative parts and assemblies of each of the processes will be selected for review and evaluation.
2. Typical SPF parts - usually limited to single sheet parts such as bulkhead webs with deep draw beads, spars, or beams with complex forming requirements, ducts requiring deep draws that exceed conventional die forming methods.

*Numbering refers to Work Breakdown Structure (WBS).

3. Typical DB parts - usually comprise various sizes of plate, bar, or sheet titanium assembled in suitable tooling to simulate a forging when diffusion bonded (solid state welded) under pressure and heat. Large machined type parts, such as bulkheads, wing spars, and large fittings, are typical candidates, especially when prototype, limited production, or lead-time constraints make conventional forging costs noncompetitive.
4. Typical SPF/DB parts are in general limited to sheet material (two to four sheets) sandwiched together using a parting agent and provisions for evacuation in the areas to be formed similar to the single sheet SPF process. Parts selected will be multi-sheet (2-4) and contain sine-waves, truss core, "cookie-tin," and beaded sheets. Typical parts are canard components, forward/center/aft fuselage components (bulkheads, air induction structures, longerons, speed-brakes, frames, doors, keel beams, panels), wing structures (ribs, spars, beams, skins), and nacelle frames.

(b) Materials

1. Diffusion Bonding (DB) titanium sheet, bar, and plate stock.
2. Superplastic Forming (SPF) and Superplastic Forming/Diffusion Bonding (SPF/DB) titanium sheet stock.

(c) Processes/Manufacturing Technology

1. SPF/DB is a relatively new process, but has proven to be cost-effective. Team members will base all data on the latest manufacturing technology available.
2. A production, as opposed to a prototype or R&D environment, will be analyzed.
3. A manufacturing operation or process sheet will be prepared by each team member for each part selected and standardized by the team to the degree feasible to ensure that the results represent a common or realistic industry base.

(d) Facilities and Equipment

1. Only production type of facilities and equipment currently available to the aerospace industry will be considered.
2. Present limitations as to capacity and size of present equipment and facilities will be highlighted.
3. The degree to which automation of the process(es) is currently available will be highlighted.

(e) Data Generation - Recurring Costs

1. Recurring man-hours will be generated for the complete "hands-on" direct operation and defined in detailed operation/processes sheets prepared by each team member.
2. TI&E recurring man-hours will be highlighted for the corresponding manufacturing hours. They will be presented separately and not included in the direct factory/manufacturing man-hours.
3. No recurring tool, production planning, or tool design man-hours will be included.
4. Cost drivers will be identified.
5. Designer-influenced cost elements (DICE) will be treated as separate cost elements.
6. All data (man-hours) will be presented in designer approved formats compatible with past MC/DG programs, i.e.:
 - Cost-Estimating Data (CED)
 - Cost-Driver Effects (CDE)
 - Designer-Influenced Cost Elements (DICE)as published in AFML-TR-76-227.
7. The data will be based on a total quantity of 200 parts and a lot size of 25 parts.
8. Each team member will utilize their own learning curves, which will be considered proprietary.
9. Setup time (man-hours) is the total setup time required to complete the part, amortized over the lot size (25 parts) and added

to the total run-time to complete the part to obtain the base-part man-hours.

10. Expendable tooling (retorts) used only once in the manufacture of a part/assembly will be considered as a recurring cost but highlighted separately from direct labor manufacturing costs.

(f) Data Generation - Nonrecurring Costs

1. Tool design and tool fabrication costs of project or permanent tools will be included but listed separately.
2. Tool/Manufacturing planning costs will not be included.
3. Nonrecurring costs will be submitted by the team members, normalized by BCD, and treated as company private.

(g) Support Function Modifiers

Due to the diversity in allocation of costs of the following support functions, their costs will not be included in the data supplied by the team members to BCD.

- Manufacturing/Tool Planning
- Engineering Support
- Production/Tool Control
- Quality Assurance Testing and Specification Preparation
- Overhead or General Administrative (G&A) Costs
- Profit or Fees.

The above modifiers may be included later at the respective team member companies.

(h) Test and Evaluation of Data

1. All formats (CDE, CED, DICE) will be submitted to the design engineers of the team member companies for evaluation and approval before being finalized.
2. All data will be integrated into the MC/DG User's Manual and will include procedures and examples on the use of the SPF/DB data.

3. All formatted data (CDE, CED, DICE) will be tested on a minimum of two parts/assemblies, representative of the technologies, from "ongoing" aerospace programs.
4. Examples will be given to identify the steps necessary to conduct "trade-off" studies utilizing the formatted data (CDE, CED, DICE).

4.1.3.2. Detailed Ground Rules

The major categories of detailed ground rules are:

- (a) SPF/DB Designs
- (b) Materials
- (c) Tolerances
- (d) Recurring Costs
- (e) TI&E Costs
- (f) Manufacturing Methods - Facilities
- (g) Contract Tooling.

(a) SPF/DB Designs

1. Parts will be selected by the team members from "ongoing" aerospace "in-house" programs representative of the technologies (DB, SPF, and SPF/DB) and analyzed by the team to select the parts most representative of the technologies that conform to the general ground rules (a.4).
2. Whenever possible, parts selected will be representative of parts that are candidates for conventional assembly (mechanical assemblies, etc.) or conventional forgings.

(b) Materials

Titanium stock (base material) shall be selected based on the team members' consensus of opinion on the industry's most commonly used titanium for SPF/DB part(s) or list of specific alloys if available.

(c) Tolerances

1. DB parts used in lieu of forgings, etc. with subsequent machining operations:
 - ± 0.100 inch
2. SPF and SPF/DB parts considered finished parts:
 - ± 0.030 inch.

(d) Recurring Costs

1. All costs shall be submitted in man-hours for each format(s).
2. Man-hours will be submitted by team members based on the specific parts selected and operation sheets reflecting the manufacturing operations depicted.

(e) TI&E Costs

1. Only recurring costs (man-hours) for those operations normally referred to as "inspection" and specifically referred to on the operation sheets will be included.
2. Quality assurance cost (man-hours) for the following will not be included:
 - Receiving Inspection
 - Testing/Evaluation
 - Specifications.

(f) Manufacturing Methods - Facilities

1. Only manufacturing methods/processes considered "production types" will be evaluated. No prototype equipment or facilities will be used as the basis of establishing costs (man-hours).

(g) Contract Tooling

1. Nonrecurring costs for tooling (NRTC) will include the tool design, tool manufacturing, and tool inspection cost (man-hours) for the project or contract permanent tooling.
2. Expendable or consumed tooling (retorts, parting agents, inert gas, etc.) shall be considered recurring costs and depicted separately, not included in the direct manufacturing costs (man-hours).