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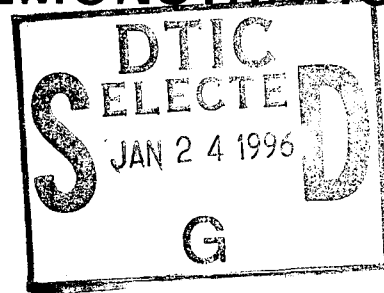
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AFWAL-TR-80-4115



ICAM MANUFACTURING COST/DESIGN GUIDE VOLUME II: APPENDICES TO DEMONSTRATION SECTIONS



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SEPTEMBER 1980

FINAL REPORT
SEPTEMBER 1977 — JULY 1979

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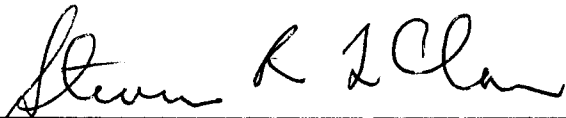
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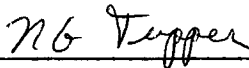
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This technical report has been reviewed and is approved for publication.



STEVEN R. LE CLAIR, CAPTAIN, USAF
Project Manager

FOR THE COMMANDER



NATHAN G. TUPPER
Chief
Computer Integrated Manufacturing Branch
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| 18. SUPPLEMENTARY NOTES <p style="text-align: right;">DTIC QUALITY INSPECTED 2</p> | | |
| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number) | | |
| Computer Aided Manufacturing | Trade Studies | Assemblies |
| Manufacturing Cost | Sheet Metal Parts | Mechanical Fastening |
| Design-to-Cost | Sheet Metal Forming | Part Count |
| Airframe Design | Aluminum Sheet | Advanced Composites |
| Fuselage Panels | Titanium Sheet | Graphite/Epoxy |
| Cost Drivers | Steel Sheet | Laminating |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) | | |
| <p>The purpose of the "Manufacturing Cost/Design Guide" (MC/DG) is to enable airframe designers to achieve lowest cost by conducting trade-offs between manufacturing cost and other design factors. When fully developed, the MC/DG will enable designers, at all levels of the design process, to perform quick, simple, cost-trade comparisons of manufacturing processes and structural performance/cost trade-offs on airframe components and subassemblies in metallic and composite materials. To accelerate technology transfer, potential cost saving opportunities offered by emerging materials and</p> | | |

manufacturing technologies will be indicated in the MC/DG.

The first program, reported in AFML-TR-76-227, developed a model of the MC/DG, the contents, cost drivers, data requirements and designer-oriented formats for conventional and some emerging manufacturing technologies, and also an implementation plan.

The second program (Contract No. F33615-77-C-5027) consisted of four phases in which manufacturing man-hour data and designer-oriented formats were developed for "Sheet-Metal Aerospace Discrete Parts", "First-Level Mechanically Fastened Assemblies", and "Advanced Composite Fabrication". Further, structural performance/manufacturing cost trade studies were conducted by designers in industry utilizing the manufacturing man-hour data developed in this program. Volume I of this report reviews the data development for each of these manufacturing technologies. A family of sheet-metal parts was studied. These represent typical stiffeners, stringers, doublers, frames, ribs, webs, skins, fairings, and brackets each produced by a number of manufacturing processes, such as brake forming, rubber press, Buffalo roll, etc. The materials studied were aluminum alloy, titanium alloy, and steel.

The data developed by the five participating aerospace companies were normalized and the data plotted in designer-oriented formats. Data have been developed for base parts and also discrete parts. The base part is an element in its simplest form and with designer-influenced cost elements (DICE) such as, in the case of sheet metal, joggles, cut-outs, and heat treatment, a discrete part is defined. Typical DICE analyzed for mechanically fastened assemblies are accessibility, material types joined, part and fastener counts, and sealing requirements. For composites, typical DICE are orientation and number of plies, overlaps, fiber mix, cut-outs, and quality requirements.

The data are presented in the series of formats showing cost-driver effects (CDE) and cost-estimating data (CED) and have been tested and evaluated using various fuselage designs in titanium, aluminum, and graphite/epoxy.

The demonstration sections for sheet-metal, mechanically fastened assemblies, and advanced composite fabrication are available to designers both in hard copy and also as a computerized data base. Interactive graphics systems will be necessary for future application in the design process. Volume III of this report discusses in detail the functional requirements of the computerized MC/DG.

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PREFACE

This technical report covers the work performed under Contract No. F33615-77-C-5027, from September 19, 1977, through July 19, 1979, by the Battelle's Columbus Laboratories (BCL)/Airframe Industry Team for the Computer Integrated Manufacturing Branch, Materials Laboratory (AFWAL/MLTC), Air Force Wright Aeronautical Laboratories, AFSC, Wright-Patterson Air Force Base, Ohio 45433. The airframe companies and program managers participating under a subcontract with BCL in this program are listed below.

1. USAF TECHNICAL DIRECTION

This program was administered under the technical direction of Capt. Dan L. Shunk, AFWAL/MLTC, and Mr. David Judson, AFWAL/MLTC, who was responsible for the MC/DG Computerization discussed in Volume III.

2. MC/DG COALITION

BCL was the prime contractor on the MC/DG Data Development Program. Mr. Bryan R. Noton, Manager, Design/Manufacturing Interaction Project Office, BCL, was the Program Manager. BCL was supported by the following subcontractors:

| <u>Airframe Company Subcontractors</u> | <u>Program Managers</u> |
|--|---|
| General Dynamics Corporation, Fort Worth Division | Ben E. Kaminski, Phase I Phillip M. Bunting, Phases II and III |
| Grumman Aerospace Corporation | Vincent T. Padden |
| Lockheed-California Company | Anthony J. Pillera |
| Northrop Corporation, Aircraft Group | John R. Hendel |
| Rockwell International Corporation, Los Angeles Division | Ralph A. Anderson |
| In Critique Mode: Boeing Commercial Airplane Company | David Weiss, Phases I and II Peter H. Bain, Phase III |

3. THE TEAM APPROACH

The team organization chart, indicating staff at BCL and at each team member company participating in this program, is shown on page iii.

Important advantages are evident in the development of manufacturing man-hour data by a team of major aerospace companies. The principal advantages are as follows:

- Provides a cross-section of small and large aircraft for the entire industry; both military and commercial.
- Present team members have large interface with all levels of designers. The MC/DG will, therefore, be transitioned more rapidly by industry to the design process.
- Team draws on each company's expertise making results more viable (expertise and installed manufacturing facilities vary across industry).
- Team has an extensive source of available data and provides a broad base from which to collect and develop data.
- Team provides the required base for deriving average industry data (which cannot be achieved without the team approach).
- Team can verify and thus provide confidence to data and formats for designer use, rather than a parochial point of view of a single company.
- Team has established ground rules and methodologies to develop manufacturing man-hour data and designer-oriented formats.
- Team provides a broad base for emerging technologies and utilization of Air Force manufacturing technology (MT) program results.

**TEAM ORGANIZATION ON
"MANUFACTURING COST/DESIGN
GUIDE" (MC/DG) PROGRAM**
CONTRACT NO: F33615-77-C-5027

| |
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| Dr. Frederick J. Milford Associate Director for Research |

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| MANUFACTURING COST/DESIGN GUIDE (MC/DG) PROGRAM |
| Bryan R. Noton, Program Manager Design/Manufacturing Interaction Project Office |
| Linda J. Maurer, Program Office Secretary |

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| AIR FORCE MATERIALS LABORATORY INTEGRATED COMPUTER-AIDED MANUFACTURING PROGRAM, AFML/LTC |
| Capt. Dan L. Shunk Project Manager |
| Mr. David Judson |

| |
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| BOEING COMMERCIAL AIRPLANE COMPANY |
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| STAFF |
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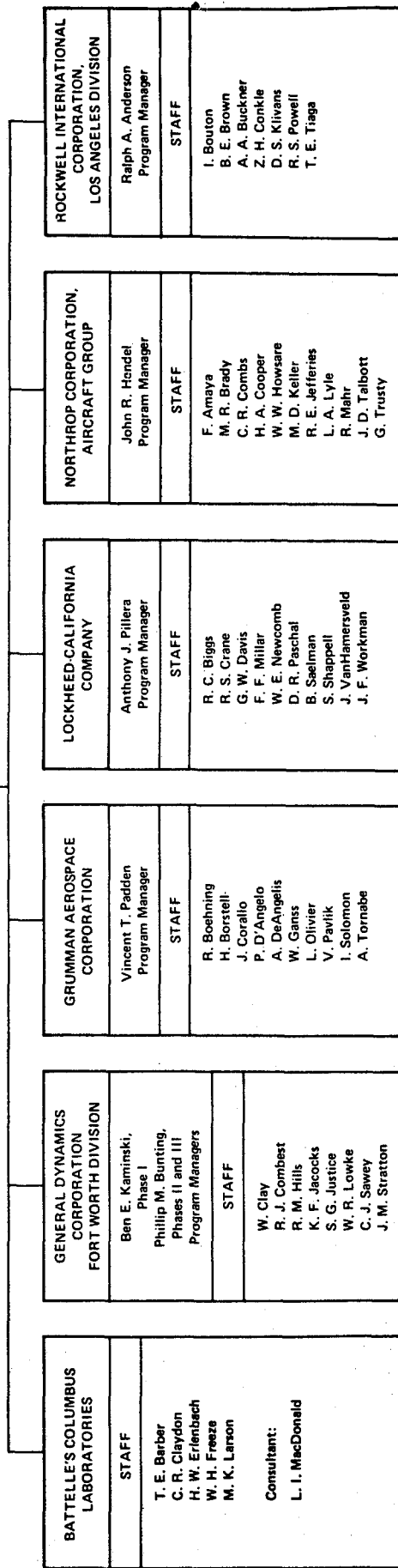


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APPENDIX A

GROUND RULES FOR SHEET-METAL DEMONSTRATION SECTION

General and Detailed Ground Rules for the Sheet-Metal Aerospace Discrete Parts Demonstration Section were developed by the team. Ground rules are necessary and important as they promote understanding, ensure consistency, uniformity, and accuracy in generating and integrating data into the formats.

1. GENERAL GROUND RULES

The general ground rules are categorized under the following major groupings:

- (a) Sheet-Metal Discrete Parts
- (b) Materials
- (c) Manufacturing Methods
- (d) Facilities
- (e) Data Generation - Recurring Costs
- (f) Data Generation - Non-Recurring Costs
- (g) Support Function Modifiers.

(a) Sheet-Metal Discrete Parts

- (1) The sheet-metal aerospace discrete parts selected are representative of common structural parts required for both small and large aircraft. The parts have been selected such that a base part forms the foundation which the designer can modify as required to achieve the desired discrete part or structural configuration. The discrete parts include stringers, longerons, frames, and panels representing elements of major airframe structural subassemblies.
- (2) The discrete parts were selected, where possible, to develop data for more than one manufacturing method. The data thereby enables the designer, using the MC/DG, to determine the most cost-competitive manufacturing method in trade studies.

- (3) The selected discrete parts were defined and dimensioned to adequately display the effect on part cost of DICE, e.g., heat treatment and lightening holes. Facility limitations were used in determining the dimension ranges for the discrete part considered.
- (4) Support function modifiers were excluded but can be handled in the preferred way by the aerospace company using the MC/DG.

(b) Materials

- (1) The alloys selected for the discrete parts were representative of the range of those more commonly used in the industry to enable a uniform data base to be established. The materials included were:
 - Aluminum - 2024 sheet
 - Titanium - 6Al-4V sheet
 - Steel - PH15-7Mo sheet.
- (2) Raw material costs for the parts were not included in the MC/DG formats but can be treated by the user at his discretion. However, the designer must be alerted and directed to include material costs wherever material costs are a cost driver such as with certain emerging materials.
- (3) Material cost of non-recurring tooling was not generally included, except when this cost impacts a design decision, for example, for manufacturing certain discrete parts in titanium and steel.

(c) Manufacturing Methods

- (1) Only conventional manufacturing methods required to produce the sheet-metal parts in the configurations selected were considered. No emerging manufacturing methods were evaluated.
- (2) A production, in contrast to a prototype, environment was assumed for the sheet-metal aerospace discrete parts.

- (3) To generate an effective data base for each selected part, a factory operational sequence for each applicable manufacturing method was established reflecting the most economical means of fabrication. This standardized sequence was used by each team member to determine the part cost (man-hours).
- (4) Tool families required to manufacture the various parts were identified on the data collection forms.

(d) Facilities

- (1) Only standard manufacturing facilities, available to the airframe industry, were considered.

(e) Data Generation - Recurring Costs

- (1) Recurring and non-recurring man-hour data were generated for the complete process of parts fabrication and included all hands-on-factory direct labor operations from raw stock blank preparation through forming, heat treatment, priming, etc., to storage of the part in readiness for assembly into the airframe.
- (2) The base part cost (man-hours) was generated for each part. The base part cost represented the sum of all standard hours associated with each part.
- (3) DICE, requiring added operations, were treated as separate cost elements and, therefore, not included in the base part cost.
- (4) The quantity for which the base part cost was determined was unit 200 and was based on team member learning curves.
- (5) Cost data were presented in man-hours.
- (6) To demonstrate the cost impact of setup costs, lot releases of 5, 10, 25, and 50 parts were evaluated. However, the values plotted on the MC/DG formats were only for lot size 25.
- (7) Setup time (man-hours) is the total setup time required to complete the part. The setup time was amortized over the lot sizes and added to run times to obtain the base part cost (man-hours).

- (8) Recurring tooling costs (tool maintenance, planning, etc.) were not included.
- (9) The data submitted to BCL were the base part cost (man-hours) plus the costs (man-hours) of DICE associated with the discrete part design.
- (10) In developing cost data for parts, each participating company utilized its own proprietary learning curves.
- (11) The part cost (man-hours), as derived by each airframe company, was normalized by BCL to reflect an industry team average value for each sheet-metal discrete part and range of dimensions.
- (12) For proprietary reasons, realization factors (including PF&D), standard hours, and other business sensitive information employed at team member companies are not included in the analysis, or on the data sheets or MC/DG formats.
- (13) No data provided by any team member are disclosed to other team members, agencies, or to the public without the expressed approval of the team member.

(f) Data Generation - Non-Recurring Costs

- (1) Tool fabrication costs were generated for each part type. In addition, tool design and tool planning costs were evaluated with respect to their impact, to determine whether they should be included or omitted for the three material types.
- (2) The cost of production tooling, if included, was restricted to contract or project tools only, for presentation in the MC/DG.
- (3) Non-recurring tooling costs (NRTC) generated by the team companies were normalized by BCL for presentation in the MC/DG.

(g) Support Function Modifiers

- (1) Additional effort other than factory labor, such as quality control and assurance and manufacturing

engineering, was excluded from the part cost data supplied to BCL. These modifiers may be included later by the MC/DG users at airframe companies.

2. DETAILED GROUND RULES

The detailed ground rules are categorized under the following major groupings:

- (a) Materials
- (b) Gages (Thicknesses)
- (c) Tolerances
- (d) Discrete Parts
- (e) Manufacturing Methods
- (f) Facilities
- (g) Contract Tooling.

(a) Materials

- (1) The materials selected for sheet-metal discrete parts are:
 - Aluminum - 2024
 - Titanium (annealed) - 6Al-4V
 - Steel (annealed) - PH15-7Mo.
- (2) Treatment required for any of these materials to increase physical properties or to improve formability are indicated on the part sketches, data collection forms, and formats.

(b) Gages (Thicknesses)

- (1) Part thickness in each material type was:
 - Aluminum: 0.063 inch
 - Titanium: 0.040 inch
 - Steel: 0.032 inch.

(c) Tolerances

- (1) Parts were assumed to be formed using standard bend radii as dictated by the material type and thickness.

- (2) Parts were assumed to be manufactured to a tolerance of ± 0.030 inch. The cost impact of tighter or more relaxed tolerances was addressed as a design complexity.

(d) Discrete Parts

- (1) Drawings of the sheet-metal aerospace discrete parts showing configurations, dimensions, joggles, holes, trim, heat treatment, etc., were prepared so that each team member may estimate base standard hours in a consistent manner.
- (2) The cross-sectional dimensions of the lineal shapes corresponded to a maximum envelope of 6 inches diameter.
- (3) The operational sequence necessary to produce each part, as required by the detail drawings, included every operation required to fabricate the part by the manufacturing method being evaluated, i.e., from the blank to completion ready for the storeroom and assembly into the airframe.
- (4) To facilitate trade-off studies, the discrete parts and MC/DG formats indicate any thermal and/or chemical processing required such as heat treatment and anodizing, respectively, and also painting, prior to assembly, as specified on the detail drawing.

(e) Manufacturing Methods

- (1) Forming methods used to fabricate the respective parts were specified on Part Size Matrices accompanying each drawing and on the Data Collection Forms.
- (2) Where more than one manufacturing technology were candidates to fabricate a discrete part, data were generated for each method to reveal the comparative cost relationships to the designer.

(f) Facilities

- (1) The types of forming equipment utilized in the fabrication of the parts were those listed in the Part Size Matrix accompanying each discrete part drawing.

(g) Contract Tooling

- (1) Because of nonuniformity of tool nomenclature, each team member company indicated, on the Data Collection Forms, the tool family required to fabricate each discrete part. The nomenclature shown on the forms were supplemented with information providing a complete tool description, i.e., Drill Press Fixture (DPF).
- (2) Tools included were those required to manufacture the tools, as well as those to make and check the parts, i.e., production check tools.
- (3) The average hours per tool type, individual tool estimate, etc., were determined in accordance with each team member's standard procedures for determining cost.

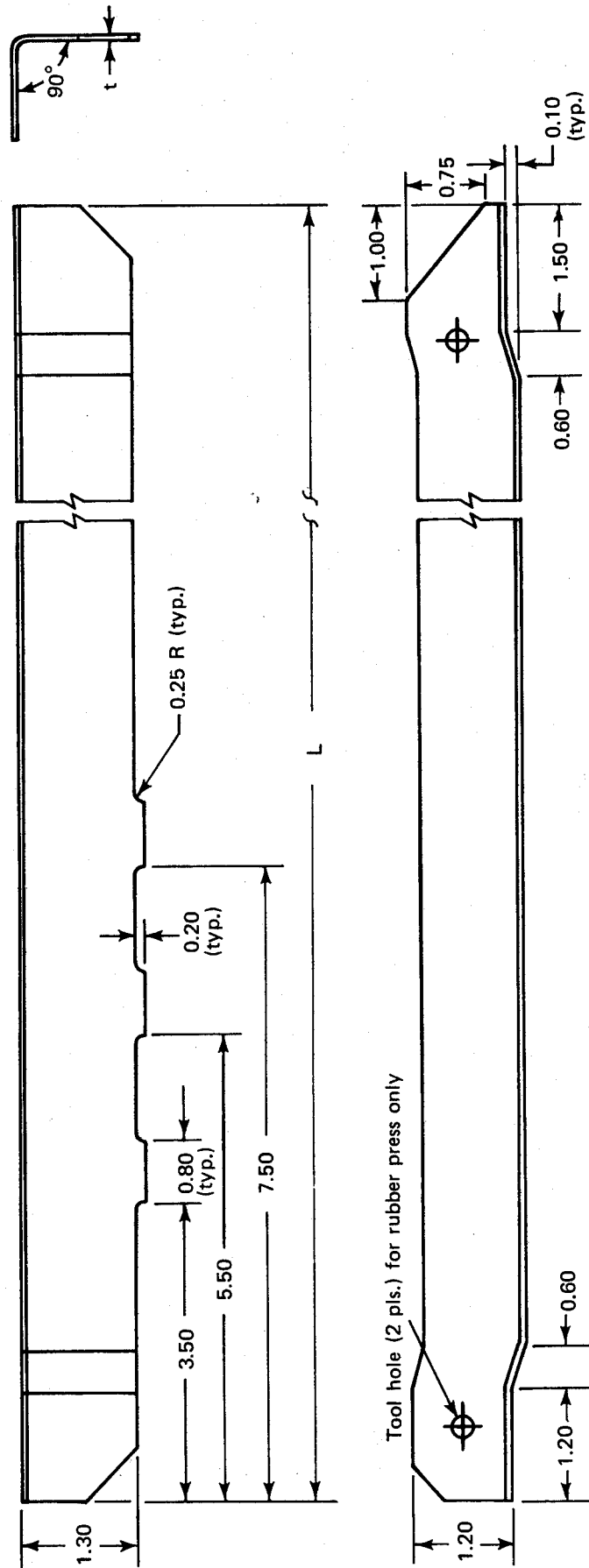
APPENDIX B

EXAMPLES OF SHEET-METAL AEROSPACE DISCRETE PARTS
ANALYZED TO DEVELOP DEMONSTRATION SECTION

TABLE B-1. EXAMPLES OF SHEET-METAL AEROSPACE
DISCRETE PARTS

| Part Code | Material | Description | Page No. |
|------------|----------|--|----------|
| MC/DG-A-1A | Aluminum | Constant Section, Straight Angle | 9 |
| MC/DG-A-2A | Aluminum | Constant Section, Straight Channel | 10 |
| MC/DG-A-4B | Aluminum | Constant Section, Curved Lipped Zee | 11 |
| MC/DG-A-5B | Aluminum | Constant Section, Curved "J" | 12 |
| MC/DG-A-9 | Aluminum | Constant Thickness, Non-Circular Curvature Skin | 13 |
| MC/DG-A-11 | Aluminum | Compound Curvature Fairing | 14 |
| MC/DG-A-12 | Aluminum | Rib | 15 |
| MC/DG-A-13 | Aluminum | Flat Beaded Panel | 16 |
| MC/DG-S-1B | Steel | Constant Section, Curved Angle | 17 |
| MC/DG-S-2B | Steel | Constant Section, Curved Channel | 18 |
| MC/DG-T-3A | Titanium | Constant Section, Straight Zee | 19 |
| MC/DG-T-5 | Titanium | Frame | 20 |

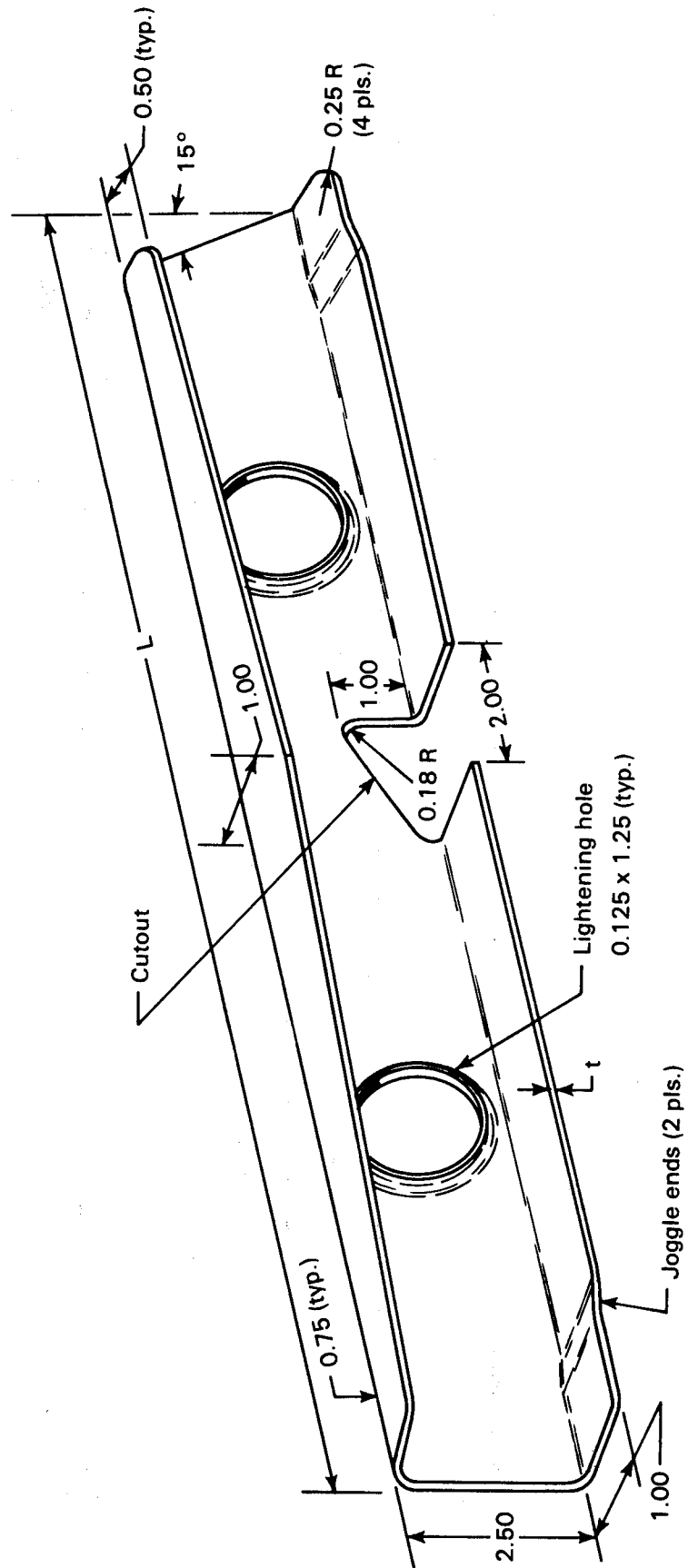
ALUMINUM ANGLE CONSTANT SECTION STRAIGHT



MC/DG-A-1A

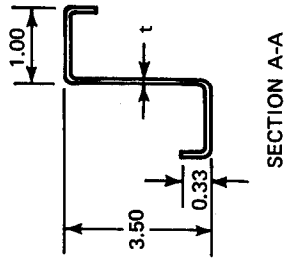
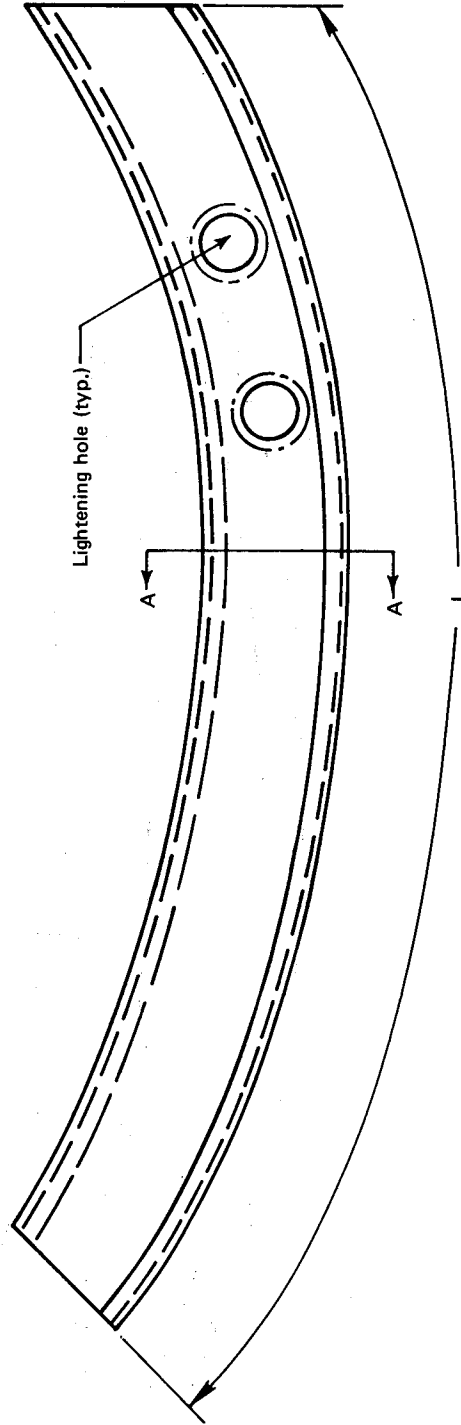
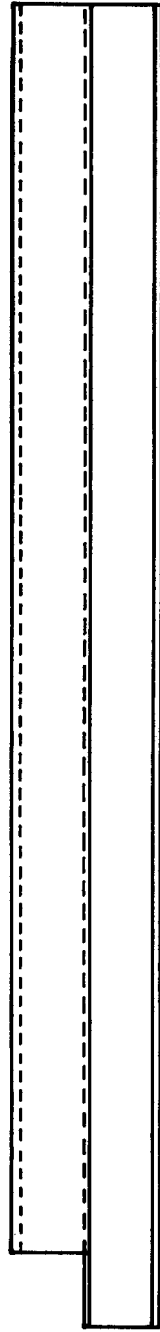
ALUMINUM CHANNEL

CONSTANT SECTION STRAIGHT



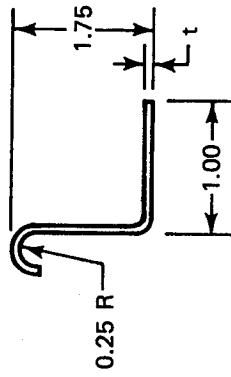
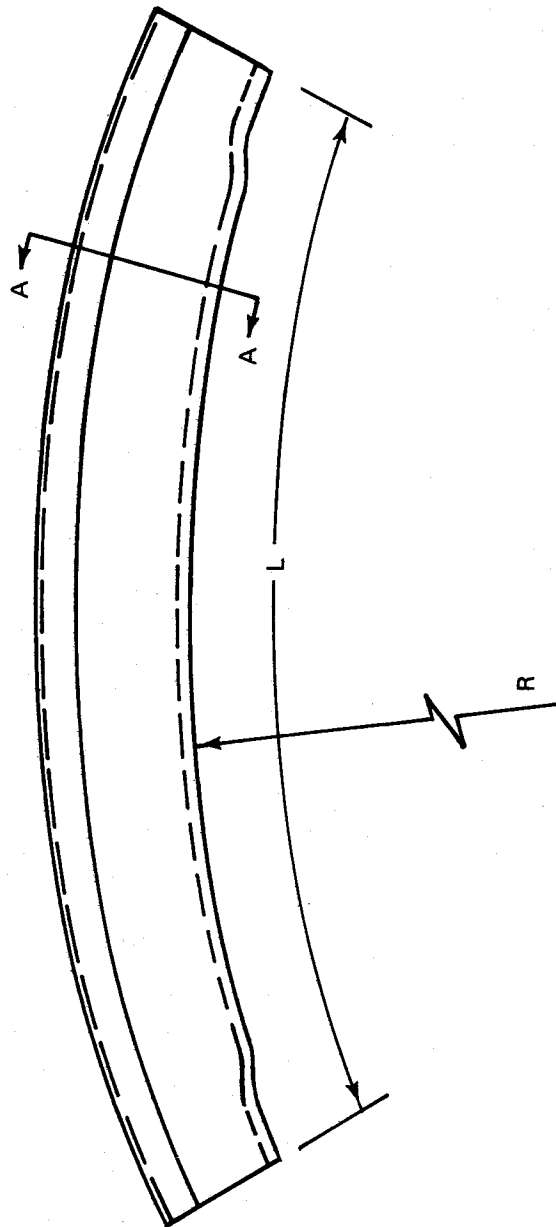
MC/DG-A-2A

ALUMINUM "Z" SECTION—LIPPED FLANGES
CONSTANT SECTION
CURVED



MC/DG-A-4B

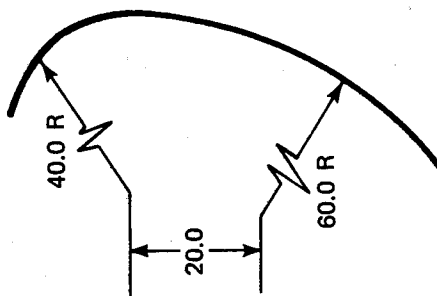
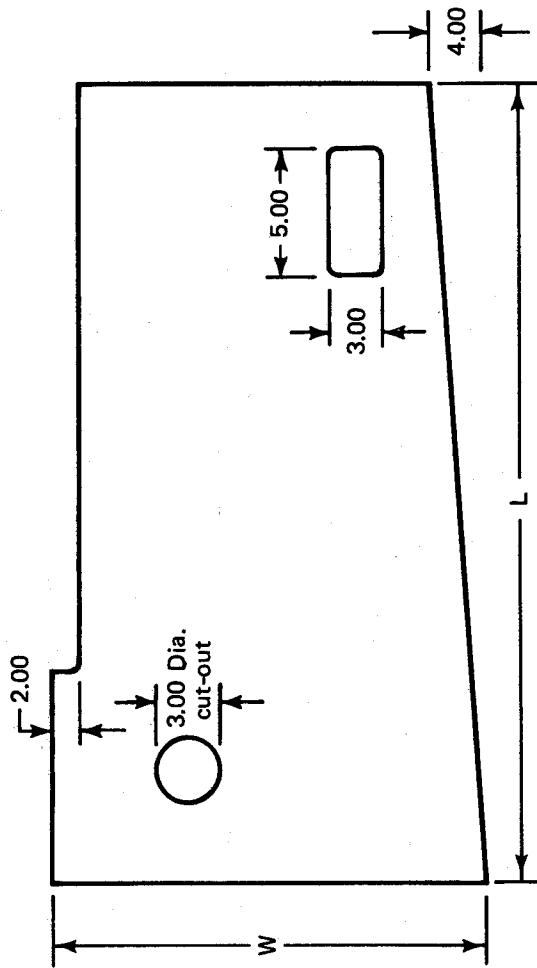
ALUMINUM "J" SECTION
CONSTANT SECTION
CURVED



SECTION A-A

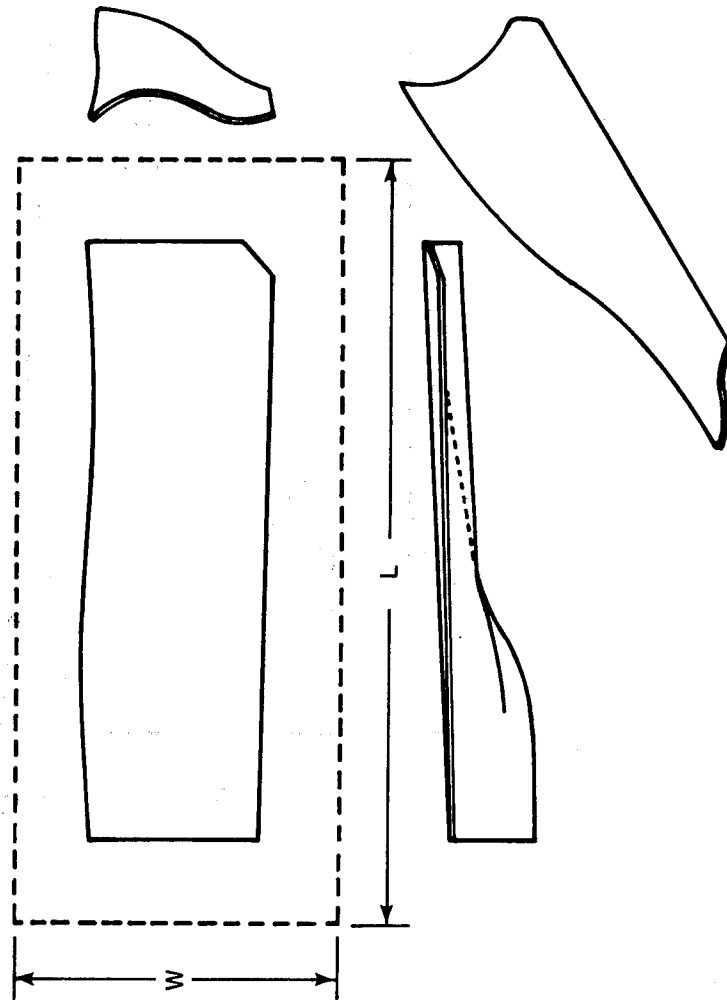
MC/DG-A-5B

ALUMINUM SKIN PANEL
CONSTANT THICKNESS
SINGLE CURVATURE—NONCIRCULAR



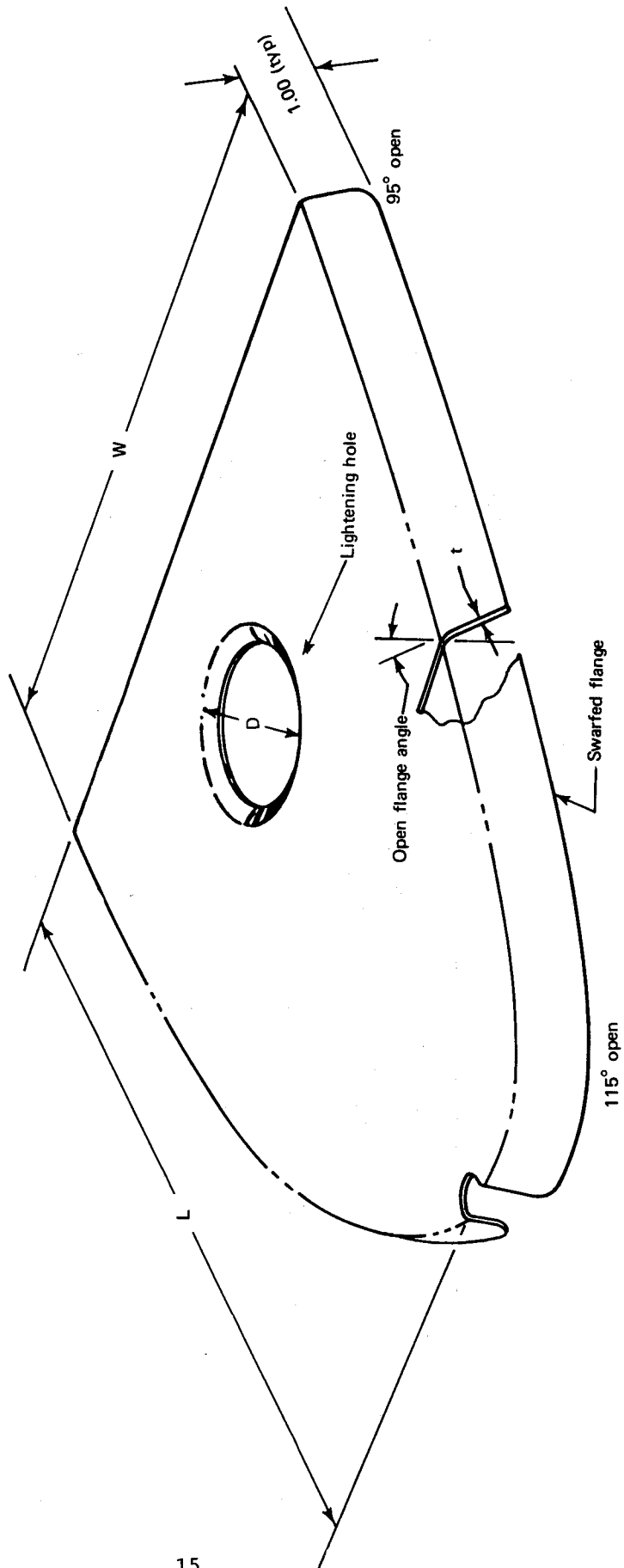
MC/DG-A-9

ALUMINUM FAIRING COMPOUND CURVATURE



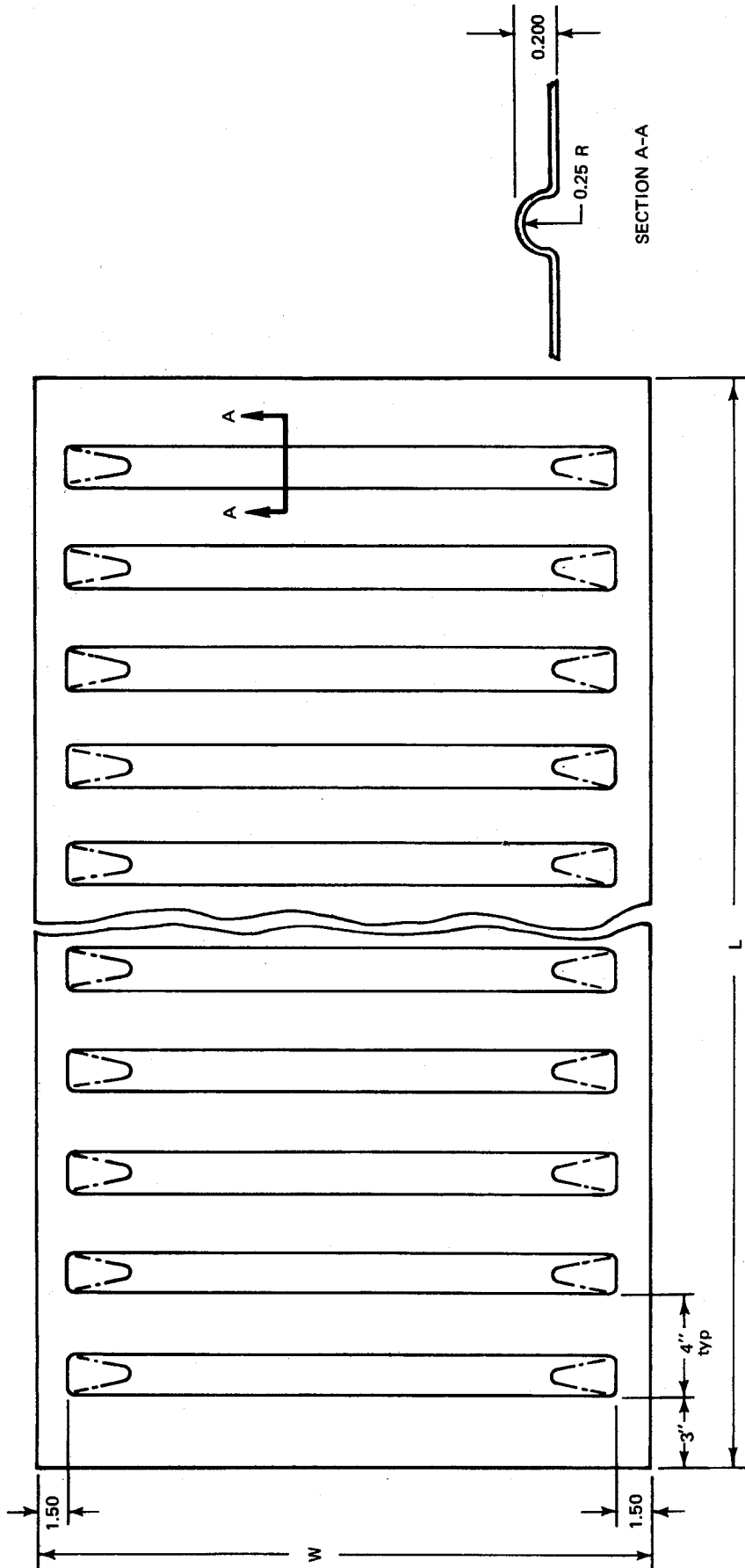
MC/DG-A-11

ALUMINUM RIB



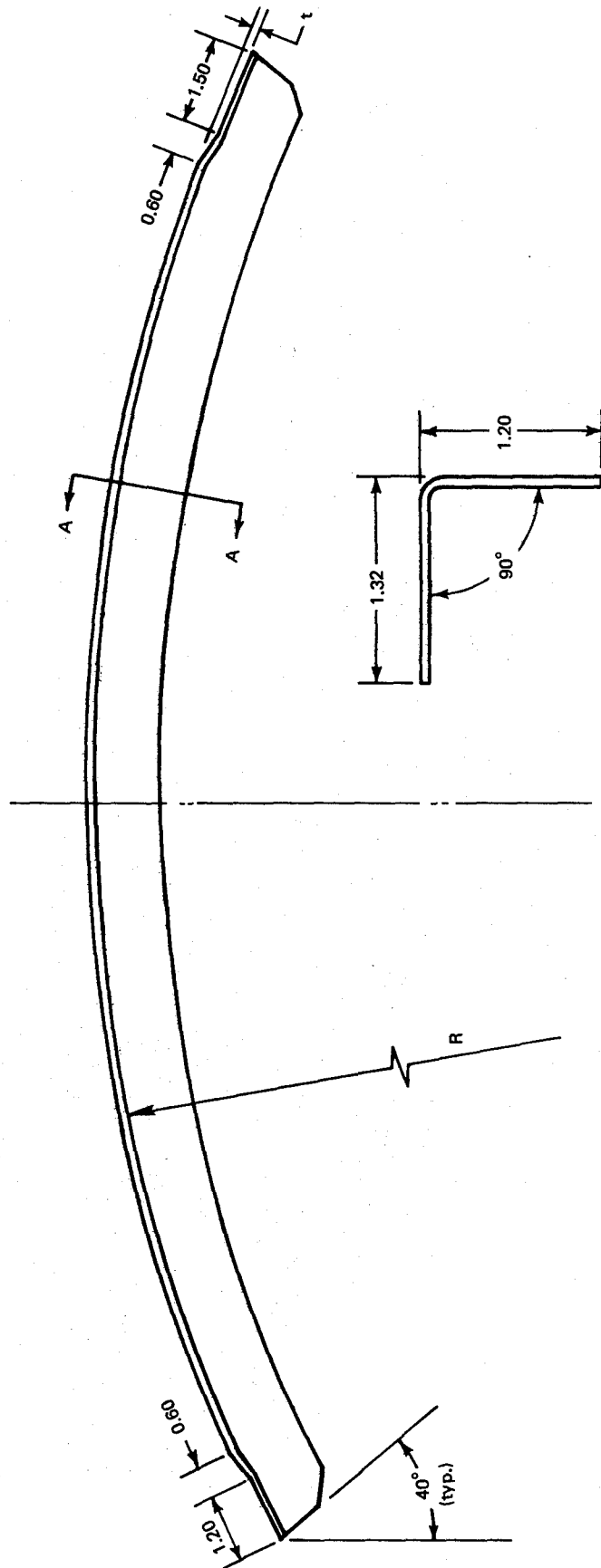
MC/DG-A-12

BEADED PANEL FLAT



MC/DG-A-13

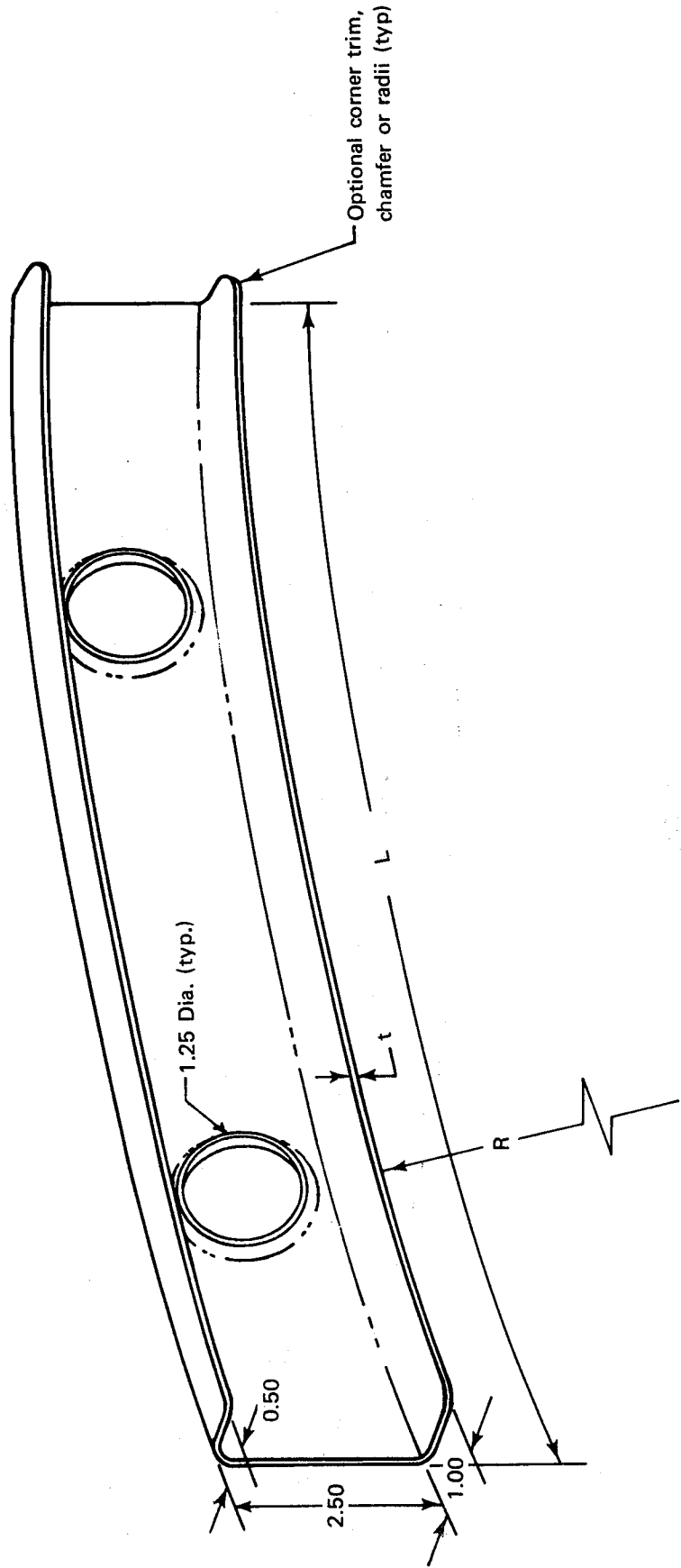
**STEEL ANGLE
CONSTANT SECTION
CURVED**



SECTION A-A

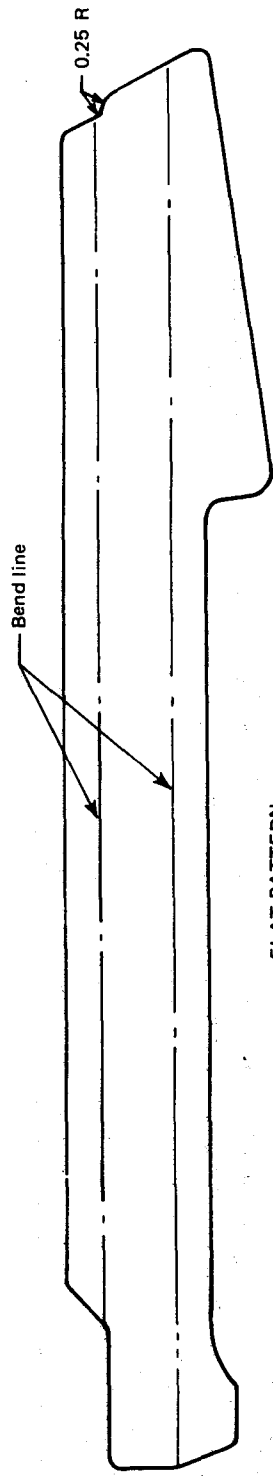
MC/DG-S-1B

**STEEL CHANNEL
CONSTANT SECTION
CURVED**

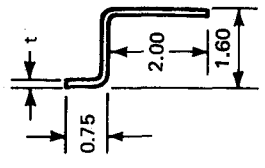
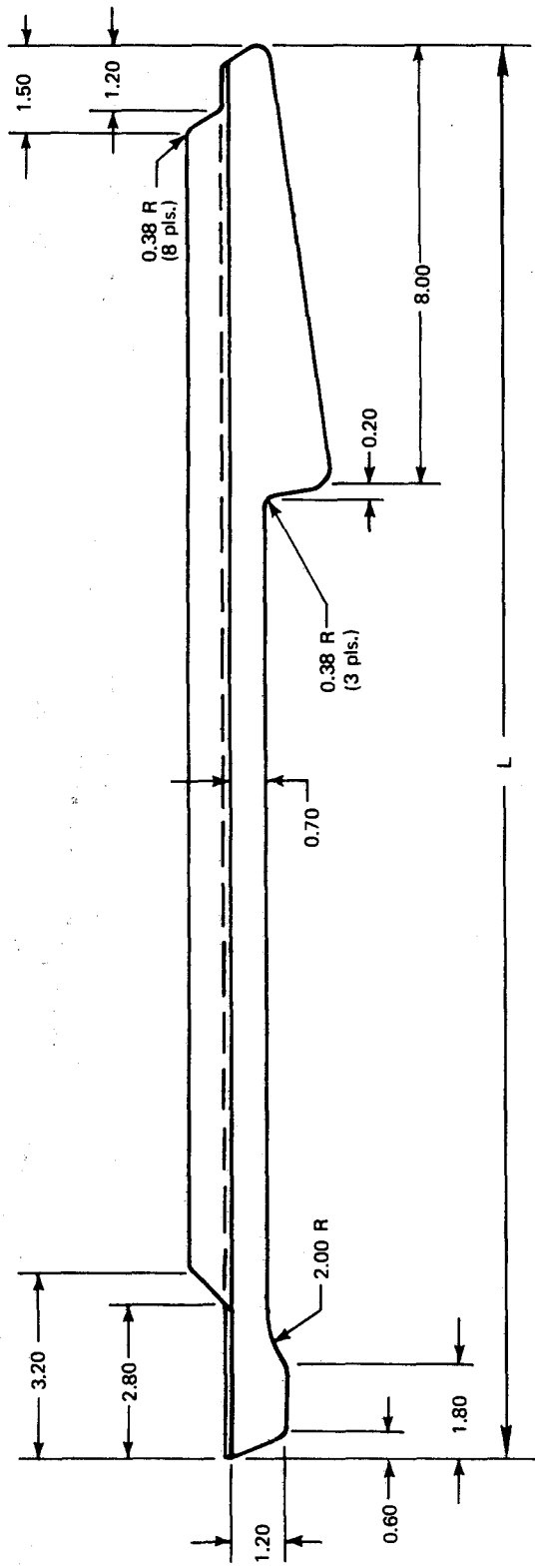


MC/DG-S-2B

**TITANIUM "Z" SECTION
CONSTANT THICKNESS
STRAIGHT**

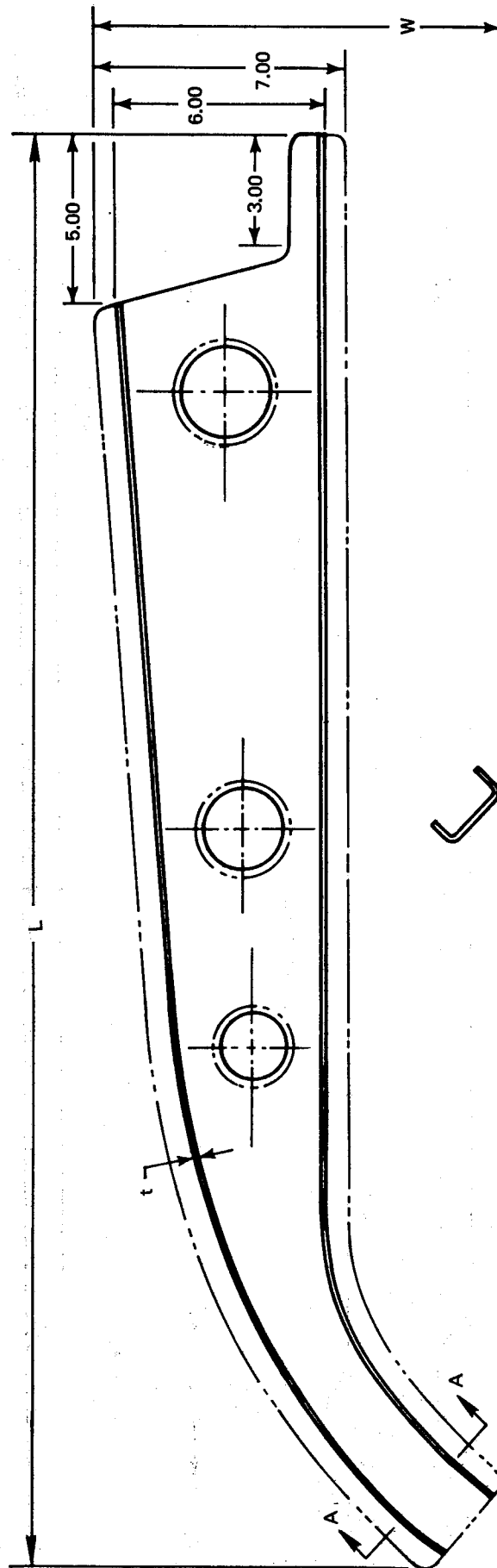


FLAT PATTERN



MC/DG-T-3A

TITANIUM FRAME



SECTION A-A

MC/DG-T-5

APPENDIX C

GLOSSARY FOR SHEET-METAL DEMONSTRATION SECTION

A Glossary and a series of General and Detailed Ground Rules have been developed by the team for each demonstration section of the MC/DG. The glossary and ground rules are necessary and very important as they promote understanding, ensure consistency, uniformity, and accuracy in generating and integrating data into the formats.

1. GLOSSARY

Aging: A change in a material property or properties with time (see Quench Aging and Strain Aging).

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.

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 a 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.

Blanking: The act of cutting a blank.

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.

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.

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.

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

Designed Tools: Tools of such 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 units, 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.

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 sometimes loosely used to describe a wide variety of press forming operations which are actually stretch forming operations or a combination of stretching and drawing.

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

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.

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.

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

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.

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.

Non-Designed Tools: Tools of such simple or standard configuration that no design work is required.

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

Normalized Part Cost: The base part cost and cost of complexities submitted to BCL by the team members are normalized or averaged by BCL for integration into the MC/DG formats.

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

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.

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

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

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

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.

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 endwheel 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.

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.

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

Run Time: Base standard hours for the repetitive elements comprising the job or 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 tear-down or clean-up efforts to return the areas and equipment to that condition necessary to undertake a different operation normally assigned to the work place or equipment.

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.

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.

Standard Hours: The industrial engineering base standard hours (IEBSH) to perform a specific factory task, operation, or work elements. 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.

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, an 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 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 effort, but are often charged as direct labor to the cost of producing the part. This depends on individual company policy.

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.

Trimming: The removal of excess metal from around the formed part after drawing.

APPENDIX D

GROUND RULES FOR MECHANICALLY-FASTENED ASSEMBLIES DEMONSTRATION SECTION

The following ground rules for the First-Level Mechanically-Fastened Assemblies (MFA) Demonstration Section were developed by the team. Ground rules are necessary and important as they promote understanding, consistency, uniformity, and accuracy in generating and integrating data into the formats.

1. GENERAL GROUND RULES

The general ground rules are categorized under the following major groupings:

- (a) First-Level Mechanically-Fastened Assemblies (MFA)
- (b) Materials
- (c) Assembly Methods
- (d) Facilities
- (e) Data Generation - Recurring Costs
- (f) Data Generation - Non-Recurring Costs
- (g) Test and Evaluation of Data
- (h) Support Function Modifiers.

(a) First-Level Mechanically-Fastened Assemblies (MFA)

- (1) The MFA were selected to provide, where possible, data for more than one manufacturing assembly method to enable the designer to select the most cost-competitive method in trade studies by making cost comparisons.
- (2) The assemblies selected are representative of common first-level structural assemblies required in both small and large aircraft. The majority of discrete parts utilized in these assemblies were selected from the Demonstration Section for "Sheet-Metal Aerospace Discrete Parts", to form the foundation so that the designer can modify the part, as required, to achieve

the desired structural foundation and configuration. The assemblies selected were an avionics bay panel, a fuselage panel with a cut-out, and a fuselage door assembly.

- (3) Drawings were developed defining the selected assemblies in the required detail to conduct the cost estimating analysis.

(b) Materials

- (1) The materials selected for the assemblies are:
 - Aluminum - 2024
 - Titanium - 6Al-4V.
- (2) Raw materials and fastener costs are not included in the MC/DG formats for MFA but were addressed in the Fuselage Shear-Panel Trade Studies.
- (3) The material cost for the tooling was not included.

(c) Assembly Methods

- (1) Only conventional methods of assembly were evaluated to assemble the parts.
- (2) A production environment was assumed for the selected assemblies.
- (3) To generate an effective manufacturing man-hour data base for each selected assembly, the operational sequence for the applicable manufacturing technologies were established reflecting the most economical procedure. The operational sequence was standardized then used by each team member, as the standard, to determine the base assembly cost. The operational sequences are indicated in Appendix E.
- (4) Non-recurring tooling costs (NRTC) for the manufacture of the various assemblies were provided on the Data Collection Forms.

(d) Facilities

- (1) Only conventional or standard manufacturing facilities available in the airframe industry were considered.

(e) Data Generation - Recurring Costs

- (1) Recurring man-hour data were generated for the complete assembly process to include all hands-on-factory direct labor operations from initial preparation for jig loading, drilling, and fastener installation, to storage for the next assembly phase.
- (2) A base cost was generated for each assembly type. This base part was configuration IIA-1-size A (24 in x 36 in) avionics panel assembly with 100 percent automatic installation of fasteners common to skin and sub-structure.
- (3) Designer-influenced cost elements (DICE) were treated as separate cost elements over and above the base assembly cost.
- (4) The quantity for which the base assembly cost was determined was unit 200.
- (5) Man-hours associated with DICE and other cost drivers were identified.
- (6) The data were represented in man-hours.
- (7) Assembly time consists of the direct man-hours to set up and complete the assembly operation.
- (8) Recurring tooling costs (tool maintenance, planning, etc.) were not included.
- (9) In developing cost data for assemblies, the participating companies used common, but proprietary, learning curves.
- (10) The assembly man-hours, as derived by each airframe company, were normalized by BCL to reflect an industry team average value for each assembly.
- (11) For proprietary reasons, realization factors, including personal fatigue and delay (PF&D), individual company standards, and other business-sensitive information employed at team member companies were not included in the analysis or on the data sheets or MC/DG formats.

(f) Data Generation - Non-Recurring Costs

- (1) Tool fabrication man-hours were developed for each assembly type. Tool design and tool planning man-hours were not included.
- (2) The cost of production assembly tooling was restricted to contract or project tools only.
- (3) Non-recurring tooling costs (NRTC) generated by the team companies were normalized by BCL for presentation in the MC/DG formats for MFA.

(g) Test and Evaluation of Data

- (1) Test and confirmation of the formats and integrated data were accomplished by two team members. Each of the remaining three team members were provided with the data inserted on the MC/DG formats. In order to gain confidence and ensure the validity of the formatted data, the selected configurations were submitted to cost-estimators in other team companies. These data were then compared to the formatted data generated and evaluated to assess its credibility. Any anomalies were resolved and modifications incorporated, if appropriate.

(h) Support Function Modifiers

- (1) Additional efforts other than factory labor, such as quality control and assurance, manufacturing engineering, and planning, were excluded from the assembly man-hour data supplied to BCL. These modifiers may be included later by MC/DG airframe company users.

2. DETAILED GROUND RULES

- (1) Manufacturing assembly methods evaluated:
 - Manual installation--impact of squeeze
 - Automatic installation--manual positioning

- (2) Fastener types evaluated:
 - Upset rivets
 - Aluminum panel--AD rivets
 - Titanium panels--bitmetallic titanium rivets
 - Pins
 - Titanium
 - Collar
 - Aluminum panel--aluminum collar
 - Titanium panel--Cres collar
- (3) Flush fasteners were countersunk:
 - No dimpling (skin gages selected were sufficiently thick to make dimpling unnecessary)
- (4) Hole preparation accomplished by combination of drill and countersink
- (5) Tolerances--location and hole sizes corresponded to individual company standards
- (6) No shimming, fitup, or trimming of assembly
- (7) Rivet heads were as driven with no shaving required
- (8) No sealing required in baseline assemblies
- (9) No mastered hard points or interchangeability requirements
- (10) Manual assemblies were assumed to be deburred at mating surfaces
- (11) No finishing, e.g., paint or prime, required after driving fasteners
- (12) All assemblies were evaluated in aluminum and titanium materials.

APPENDIX E

MANUFACTURING OPERATIONAL SEQUENCES FOR MECHANICALLY-FASTENED ASSEMBLIES

1. AVIONICS BAY PANEL (MANUAL RIVETING)

- (1) Load, locate, index, and secure frames and longerons in Assembly Fixture (ASFX).
- (2) Locate clips to frames and longerons per drawing. Drill four 5/32 inch (0.161) diameter holes from clip through frames and longerons at each clip (temporarily fasten).
- (3) Load, locate, index, and secure skin into ASFX. Load and index Assembly Template (ASTP) to ASFX.
- (4) Hand drill (X) pilot holes from ASTP through skin, frames, and longerons at predetermined locations and temporary fasten.
- (5) Drill/Countersink (Spacematic) all holes full size 5/32 inch (0.161) diameter holes per drawing. Note: Temporary fasteners removed as necessary.
- (6) Remove skin, longerons, frames, and clips from ASFX.
- (7) Deburr all holes complete.
- (8) Load, locate, index, and secure frames and longerons in ASFX.
- (9) Locate clips to longerons and frames, clamp, and hand rivet.
- (10) Load, locate, index, and secure (cleco) skin into ASFX.
- (11) Hand rivet all holes common to skin, frames, and longerons.
- (12) Obtain okay to remove assembly from ASFX.
- (13) Clean and touch-up assembly as required.
- (14) Identify (rubber stamp).
- (15) Prepare assembly for storage and forward to stock.

2. AVIONICS BAY PANEL (AUTOMATIC RIVETING)

- (1) Load, locate, index, and secure frames and longerons into ASFX.
- (2) Locate clips to frames and longerons per drawing. Drill 5/32 inch (0.161) diameter holes common to clips, frames, and longerons (temporarily fasten).
- (3) Load, locate, index, and secure skin into ASFX. Load and index ASTP and ASFX.

- (4) Drill #30 (0.128 inch) diameter holes in predetermined locations in order to secure skin to substructure for later installations (install temporary fasteners).
- (5) Complete spray-dot application skin of fastener locations for later automated installation of fasteners.
- (6) Remove ASTP from ASFX and store.
- (7) Remove skin from ASFX and store.
- (8) Remove clips and deburr holes common to clips, frames, and longerons.
- (9) Relocate clips to substructure and install fasteners common to clips, frames, and longerons per drawing.
- (10) Relocate skin to ASFX and re-index to ASFX and install temporary fasteners common to skin and substructure.
- (11) Obtain okay to remove from ASFX.
- (12) Remove assembly from ASFX and load into holding fixture for transportation to automatic riveting area. Note: Holding fixture is used to support assembly during automatic riveting installation.
- (13) Transport subassembly to automatic riveter.
- (14) Complete installation of fasteners common to skin and substructure at spray-dot locations. Note: Remove temporary fasteners common to skin and install drawing type fasteners utilizing automatic riveting.
- (15) Clean and touch up assembly as required.
- (16) Identify (rubber stamp).
- (17) Prepare assembly for storage and next assembly.

3. FUSELAGE PANEL (MANUAL RIVETING)

- (1) Load, locate, index, and secure frames into ASFX.
- (2) Load, locate, index, and secure stringers into ASFX. Note: Insure proper location of stringers relative to frames, and all details relative to moldline controls.
- (3) Load, locate, and secure two clips common to center stringers and middle frames. Drill #30 (0.128 inch) diameter pilot holes common to clips, stringers, and frames. Install temporary fasteners.
- (4) Load, locate, index, and secure skin into ASFX. Check location relative to substructure and moldline.

- (5) Back drill #30 (0.128 inch) index holes, common to stringers and skin and frames and skin, from predetermined pilot holes in frames and stringers. Install temporary fasteners.
- (6) Load, locate, index, and secure Spacematic Templates (SPMT) to index locations common to stringers only.
- (7) Drill/countersink all rivet locations common to skin and stringers only (except in cutout/doubler area). Install temporary fasteners.
- (8) Remove SPMT's and store.
- (9) Load, locate, index, and secure SPMT's common to skin and frames only.
- (10) Drill/countersink all rivet locations common to skin and frames only and drill/countersink all HiLOK locations common to skin, frame, and stringer intersections only. Note: Not in cutout/doubler area, install temporary fasteners.).
- (11) Remove SPMT's and store.
- (12) Load, locate, index, and secure doubler common to skin and stringer in cutout area.
- (13) Back drill #30 (0.128 inch) index holes, common to skin, stringer, and doubler, from pilot holes in doubler.
- (14) Load, locate, index, and secure SPMT to cutout/doubler area.
- (15) Drill/countersink all rivet locations common to skin, stringers, and doubler. Install temporary fasteners.
- (16) Remove SPMT and store.
- (17) Drill full size holes common to two clips, frames, and stringers.
- (18) Disassemble assembly. Clean and deburr all hole locations common to skin, stringer, frames, clips, and doubler.
- (19) Relocate all details into ASFX and install temporary fasteners.
- (20) Install HiLOKS permanently at all skin frame and stringer intersections per drawing.
- (21) Install all rivets common to skin, frames, and stringers per drawing.
- (22) Install all rivets common to skin, stringer, and doubler per drawing.
- (23) Obtain "AUTHORIZATION TO REMOVE" assembly from ASFX.
- (24) Clean and touch-up assembly as required.
- (25) Identify (rubber stamp).
- (26) Prepare assembly for storage and next assembly.

4. FUSELAGE PANEL (AUTOMATIC RIVETING)

- (1) Load, locate, index, and secure frames into ASFX.
- (2) Load, locate, index, and secure stringers into ASFX. Note: Ensure proper location of stringers relative to frames, and all details relative to moldline controls.
- (3) Load, locate, and secure two clips common to center stringers and middle frames. Drill #30 (0.128 inch) diameter pilot holes common to clips, stringers, and frames. Install temporary fasteners.
- (4) Load, locate, index, and secure skin into ASFX. Check location relative to substructure and moldline.
- (5) Back drill two fastener locations through skin at each intersection of a frame and stringer and install temporary fasteners.
- (6) At each stringer and frame intersection, drill/ream one each 3/16 inch (0.187/0.190) diameter hole common to frame joggle, stringers, and skin and countersink for HiLOK. Install temporary fasteners. Also, drill/ream one each 3/16 inch (0.190/0.199) diameter hole common to frame and skin only and countersink for AD rivet.
- (7) Load, locate, index, and secure doubler common to skin and stringer at cutout location.
- (8) Drill #30 (0.128 inch) diameter holes at pre-piloted locations and install temporary fasteners.
- (9) Disassemble skin and substructure and deburr all details at all hole locations.
- (10) Reassemble all details into ASFX. Check for proper location of details.
- (11) Install permanent fasteners (HiLOKS and AD rivets) at stringer and frame intersections.
- (12) Install temporary fasteners common to doubler, stringers, and skin.
- (13) Install permanent fasteners common to two clips and frames.
- (14) Load, locate, index, and secure ASTP into ASFX.
- (15) Complete spray-dot application to skin area for automatic rivet installation locations.
- (16) Remove and store ASTP.
- (17) Obtain "AUTHORIZATION TO REMOVE" assembly.
- (18) Remove assembly from ASFX and load into holding fixture for transportation to automatic riveting area. Note: Holding fixture also used to support assembly during automatic rivet installation.

- (19) Automatically install all remaining fasteners, per spray-dot location, common to skin, frames, stringers, and doubler per drawing.
- (20) Remove assembly from holding fixture.
- (21) Clean and touch-up assembly, as required.
- (22) Identify (rubber stamp).
- (23) Prepare assembly for storage and next assembly.

5. FUSELAGE DOOR (MANUAL RIVETING)

- (1) Load, locate, index, and secure frames, intercostals, and edge members into ASFX.
- (2) Locate clips, gussets common to frame, intercostals, and edge members per drawing. Drill 5/32 inch (0.161) diameter holes, common to clips, gussets, frames, intercostals, and edge members per drawing and temporarily fasten.
- (3) Load, locate, index, and secure skin into ASFX. Load and index ASTP to ASFX.
- (4) Hand drill (X) pilot holes from ASTP through skin, frames, and edge members at predetermined locations and temporarily fasten.
- (5) Drill/countersink (Spacematic) all holes full size 5/32 inch (0.161) diameter per drawing (Note: Remove temporary fasteners as necessary).
- (6) Remove skin, clips, gussets, frames, and edge members from ASFX.
- (7) Deburr all holes complete.
- (8) Load, locate, index, and secure frames and edge members into ASFX.
- (9) Locate and clip gussets to frames and edge members and hand rivet.
- (10) Load, locate, index, and secure (cleco) skin into ASFX.
- (11) Hand rivet all holes common to skin, frames, and edge members.
- (12) Obtain okay to remove assembly from ASFX.
- (13) Clean and touch up assembly as required.
- (14) Identify (rubber stamp).
- (15) Prepare assembly for storage and forward to stock.

6. FUSELAGE DOOR (AUTOMATIC RIVETING)

- (1) Load, locate, index, and secure frames, intercostals, and edge members into ASFX.
- (2) Locate clips and gussets common to frames, intercostals, and edge members per drawing. Drill 5/32 inch (0.161) diameter holes common to clips, gussets, frames, intercostals, and edge members per drawing. Temporarily fasten.
- (3) Load, locate, index, and secure skin into ASFX. Load and index ASTP to ASFX.
- (4) Drill #30 (0.128 inch) diameter holes at predetermined locations in order to secure skin to substructure for later installations. Install temporary fasteners.
- (5) Complete spray-dot application to skin of fastener locations for later automated installation of fasteners.
- (6) Remove ASTP from ASFX and store.
- (7) Remove skin from ASFX and store properly.
- (8) Remove clips and gussets and deburr holes common to clips, gussets, intercostals, frames, and edge members.
- (9) Relocate clips and gussets to substructure and install fasteners common to clips, gussets, intercostals, frames, and edge members per drawing.
- (10) Relocate and reindex skin to ASFX and install temporary fasteners common to skin and substructure.
- (11) Obtain "AUTHORIZATION TO REMOVE" from ASFX.
- (12) Remove assembly from ASFX and load into Holding Fixture (HOFX) for transportation to automatic riveting area. Note: HOFX is used to support assembly during automatic riveting installation.
- (13) Transport subassembly to automatic riveter.
- (14) Complete installation of fasteners common to skin and substructure at spray-dot locations. Note: Remove temporary fasteners common to skin and install drawing type fasteners utilizing automatic riveter.
- (15) Clean and touch up as required.
- (16) Identify (rubber stamp).
- (17) Prepare assembly for storage and next assembly.

APPENDIX F

GROUND RULES FOR ADVANCED COMPOSITES FABRICATION DEMONSTRATION SECTION

Ground rules were developed by the team for each phase of the MC/DG program. Ground rules were essential, as they provided a common base for promoting understanding, consistency, uniformity, and accuracy in generating and integrating data into the formats and also for inter-relating the various phases of the MC/DG development.

1. GENERAL GROUND RULES

The general ground rules were categorized under the following major groupings:

- (a) Advanced Composite Discrete Parts
- (b) Composite Material Types
- (c) Manufacturing Technology
- (d) Facilities
- (e) Data Generation - Recurring Costs
- (f) Data Generation - Non-Recurring Costs
- (g) Support Function Modifiers.

The Advanced Composites Fabrication Guide (ACFG) glossary was used as a basis for terminology. The Advanced Composites Design Guide (ACDG), Advanced Composites Cost Estimating Manual (ACCEM), and the ACFG were utilized in the development of the MC/DG section, "Advanced Composites Fabrication".

(a) Advanced Composite Discrete Parts

- (1) The selected base parts were representative of common structural shapes that were required in both small and large aircraft. They were selected such that a base part formed the foundation to which a designer could modify the part as required to achieve the desired structural configuration. Some of these structural shapes were applicable to the Phase III trade study.

- (2) The selected discrete parts were defined and dimensioned to adequately display the effect on part manufacturing cost of designer-influenced cost elements (DICE).
- (3) Support function modifiers, e.g., quality assurance, manufacturing, etc., were excluded, but could be treated by the MC/DG user at his discretion.

(b) Composite Material Types

- (1) Composite materials were selected from those commonly used in the aerospace industry. This enabled a uniform data base to be established and enabled wide application of the manufacturing cost formats developed. The materials processing used was in accordance with the technical recommendations of the material suppliers, e.g., cure cycle and bleeder-ply ratios, except as noted in the detailed ground rules. The ACFG was utilized whenever applicable. Typical candidate material systems are:
 - AS/3501-6
 - 5208/T300
 - 934/T300.
- (2) As the cost of composite materials is constantly being reduced with increased usage, raw material costs were not included in the MC/DG formats. However, as raw material costs for composites have a large impact on the cost-effectiveness of these structures, current and projected prices must be included by the MC/DG user company.
- (3) Material cost of non-recurring tooling was not included.
- (4) Honeycomb sandwich structures were not considered in this phase of the program.

(c) Manufacturing Technologies

- (1) Only conventional manufacturing technologies, such as covered in the ACFG, were considered. No emerging manufacturing methods, such as robotics, were considered in Phase II(b).

- (2) A production environment, in contrast to a prototype, was assumed for the advanced composite parts. Two hundred units were considered.
- (3) To generate an effective data base for each selected part, a factory operational sequence for the selected manufacturing method and processes was established. This standardized sequence was used by each assigned team member to determine the base part cost using the ACCEM, wherever possible.
- (4) Unidirectional strip plies were to be internal.

(d) Facilities

- (1) For Phase II(b), only standard manufacturing facilities, currently available (1978-1979) to the airframe industry, were considered. However, it was recognized that if composites are to be more widely competitive with aluminum structures, automated equipment is necessary and development/implementation should be pursued by the industry on an expedited basis.

(e) Data Generation - Recurring Costs

- (1) Recurring man-hour data were generated for the complete process of parts fabrication to include all hands-on-factory direct operations from conversion of the raw material to a finished part.
- (2) The base part cost was generated for each part type. The base part cost represented the sum of all standard hours associated with each part as specified in these ground rules.
- (3) Designer-influenced cost elements (DICE), requiring added operations, were treated as separate cost elements and not included in the base part cost.
- (4) In addition to the base part cost data, costs associated with design complexities and the resulting cost drivers were identified.

- (5) Cost data were represented in man-hours.
- (6) Recurring tooling costs (tool maintenance, planning, etc.) are not included.
- (7) The data submitted to BCL were the base part cost and the costs of designer-influenced cost elements (DICE) provided separately.
- (8) In developing cost data for parts, individual team company learning curves were used. Unit part costs were evaluated at unit 200.
- (9) The part cost, as derived by each airframe company, was normalized by BCL to reflect an industry team average value for each part.
- (10) For proprietary reasons, business-sensitive information employed at team member companies is not presented in the MC/DG.
- (11) No data provided by any airframe company team member were disclosed to other team members, agencies, or to the public without the expressed approval of the team member.
- (12) A pilot data collection run was accomplished and coordinated with the team members and BCL prior to completing the data generation task.
- (13) Recurring costs included pattern trim, layup, debulking, cure, and trim of composite parts, unless otherwise specified.

(f) Data Generation - Non-Recurring Costs

- (1) Tool fabrication costs were generated for each part type and assembly. The cost of tool design or support of tool fabrication and development of shop work orders (methods sheets) was not included.
- (2) The costs of production contract tooling associated directly with the detailed fabrication of the parts and assemblies were the only tooling costs to be included.

- (3) Non-recurring costs generated by the team member companies were normalized by BCL for presentation in the MC/DG.
- (4) Soft tools, such as rubber bags, bladders, and mandrels, were limited to 50 curing cycles. For 200 parts, the soft tool man-hours were factored by 4.

(g) Support Function Modifiers

- (1) Additional effort other than factory labor, such as quality control and assurance and manufacturing engineering, was excluded from the part cost data supplied to BCL. These modifiers may be included later by the MC/DG users at airframe companies.
- (2) Quality control (QC) of composite structures was a cost driver and should be considered separately by each airframe company using the MC/DG. This was because of the wide variation in individual company QC methods and methods of accounting.

2. DETAILED GROUND RULES

Detailed ground rules were prepared by the team to define the part shapes and manufacturing processes for which cost data were prepared and to provide for the uniformity in the costing methodology between companies. The parts and methods defined by these detailed ground rules were chosen to provide a common ground for cost data development, but the use of the MC/DG was not restricted to these exact part definitions.

The detailed ground rules were categorized under the following major groupings:

- (a) Material
- (b) Base Part Drawings and Sketches Used to Develop Cost Data for Formats
- (c) Tolerances
- (d) Estimating Method.

(a) Material

- (1) The material system to be used was AS/3501-6 with a resin content of 34 percent \pm 3 percent.

- (2) 12-inch wide unidirectional tape was used on all parts.
- (3) Ply thickness, T, ranged from 0.005 inch to 0.007 inch.

(b) Sketches of Parts Used to Develop Cost Data

- (1) See following two pages.

(c) Tolerances

- (1) Tolerances for the base part configurations were considered to be: ± 0.03 inch on lineal dimensions and ± 0.00025 inch on thickness per ply.
- (2) Tolerance for the cocured assembly was ± 0.06 inch on part location.
- (3) A minimum of 0.25 inch was used on all interior radii.
- (4) Fit-up maximum tolerances for cured details were 0.030 inch gap for "Mechanically-Fastened Assembly" and 0.15 inch for "Bonding".

(d) Estimating Method

- (1) The ACCEM was used as the base, with each team member company applying its own learning curves.

FIGURE F-1. COMPOSITE LINEAL SHAPES ANALYZED TO DEVELOP FORMATS

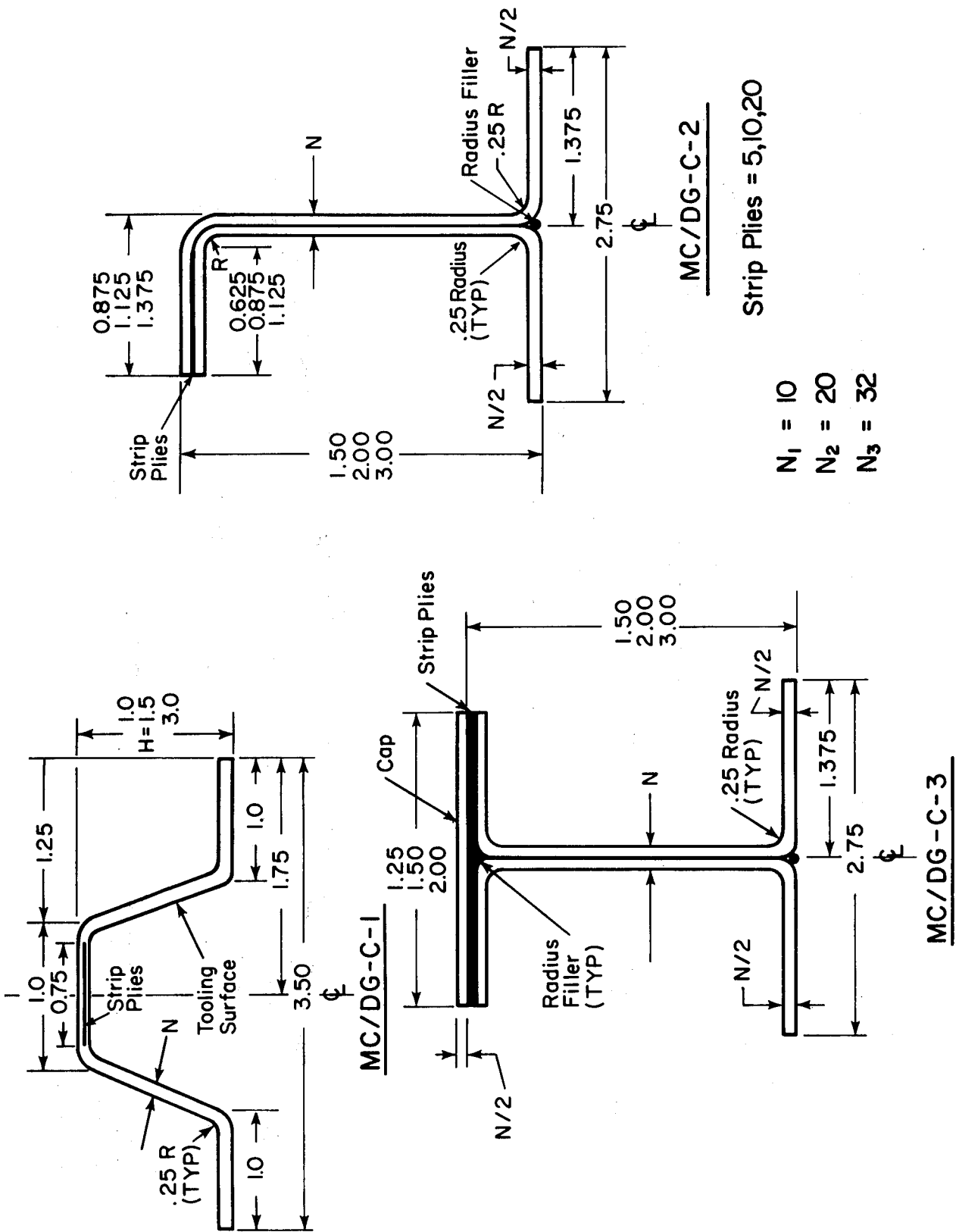
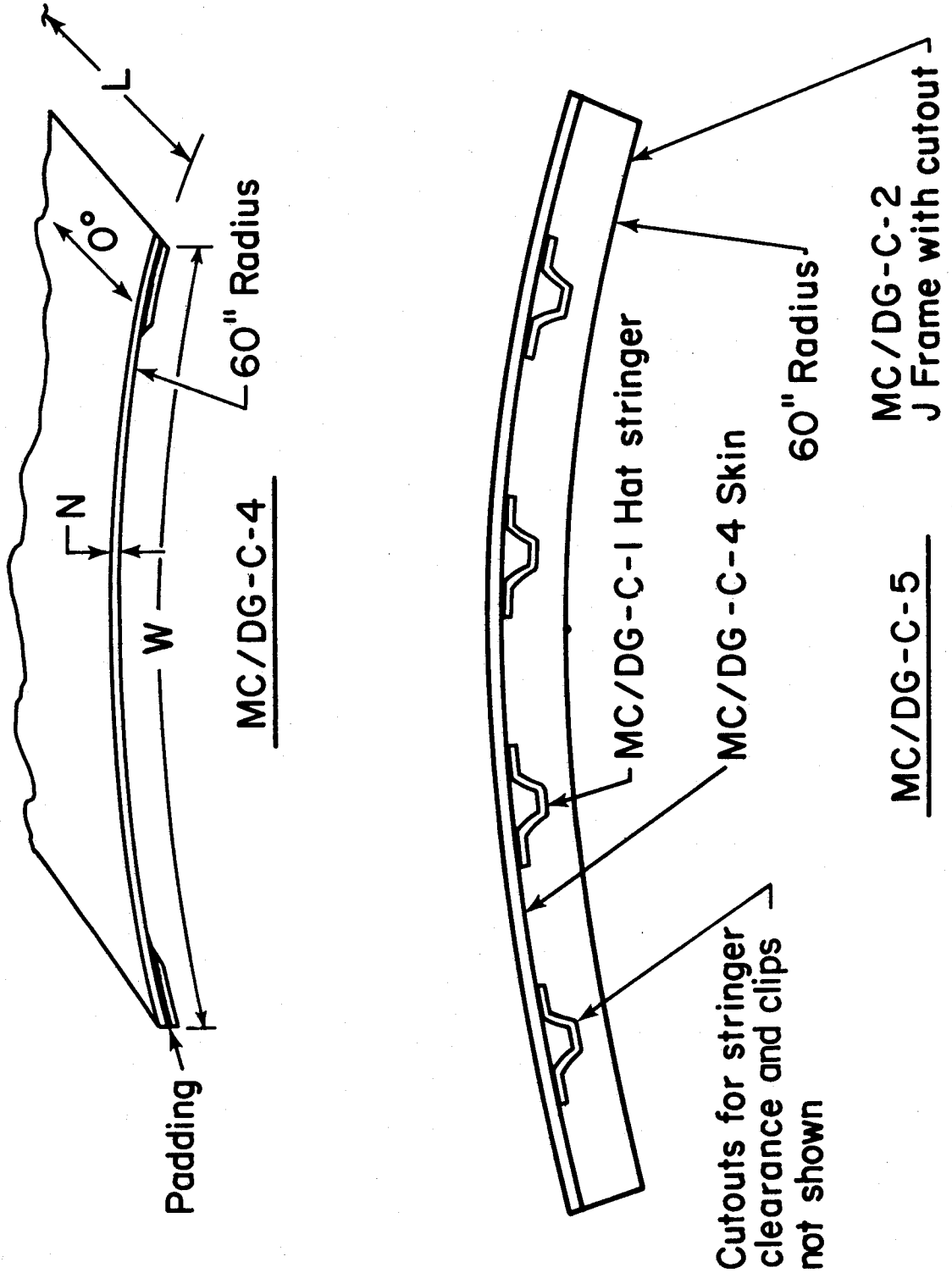


FIGURE F-2. COMPOSITE PANELS ANALYZED TO DEVELOP MC/DG FORMATS



APPENDIX G

ALUMINUM FUSELAGE PANEL MANUFACTURING COST/DESIGN TRADE STUDY

A series of fuselage shear panels were analyzed with regard to weight and manufacturing cost by three airframe industry team members utilizing the manufacturing man-hour data presented on design-oriented formats in the three demonstration sections described earlier in this report, i.e., "Sheet-Metal Aerospace Discrete Parts", "Mechanically Fastened Assemblies", and "Advanced Composites Fabrication".

The primary objectives of the fuselage shear panel trade studies were to:

- Demonstrate the use of the MC/DG in an industrial environment designing typical airframe structures
- Determine whether the manufacturing cost (man-hour) formats, providing CDE and CED information, meet the format design criteria established for their development
- Determine whether the CDE and CED formats provide the accuracy required by designers in conducting comparisons of airframe configurations utilizing both metallic and composite materials.

Fuselage panel designs were studied in the following structural materials by the design departments in each of the three companies:

- Aluminum alloy - by General Dynamics Corporation, Fort Worth Division
- Titanium alloy - by Lockheed-California Company
- Graphite/epoxy - by Rockwell International, Los Angeles Division.

The fuselage panel trade studies were critically reviewed by:

- Boeing Commercial Airplane Company
- Northrop Corporation, Aircraft Group.

Aluminum Fuselage Shear Panel Trade Study

This appendix presents the methodology and results of the trade study conducted on the aluminum fuselage panel. The approach used can be summarized in five steps. First, a basic panel was defined. Next, structural concepts were developed as candidate for the panel designs. Third, the ground rules and assumptions for the study were specified. Fourth, the MC/DG data display formats were utilized to obtain the cost of the concepts. Finally, conclusions were drawn concerning the effectiveness of the MC/DG in conducting this trade study.

The panel chosen for this trade study is from the fuselage of the Air Force F-16 aircraft. Figure G-1 shows the location of the panel on this aircraft. The panel concepts selected for evaluation are illustrated in Figures G-2 and G-3. Figure G-2 shows concepts having single curvature, while Figure G-3 shows a compound curvature concept. The aluminum alloy selected was 2024 aluminum. Skins and brake formed discrete parts were in the T-3 condition. The parts formed on the rubber press were in the "O" or "W" condition and solution heat-treated to a final condition of T-42. The brake formed parts were straight channels and Z-sections. Curved channels and Z-sections were formed on the rubber press. All skins were Farnham rolled. Further ground rules and manufacturing assumptions are shown in Figure G-4.

The design/analysis assumptions were:

- Shear buckling permitted
- No inter-fastener buckling
- No frame or stringer buckling
- No crippling of stringers in compression.

Details of the concepts are given in Figures G-5 through G-9.

The weight of each concept was determined using conventional methods of calculation. The MC/DG was utilized to determine the manufacturing cost of each concept. These results provided the cost per pound for each concept. Table G-1 lists the cost, weight, and cost per pound of the single curvature concepts. The compound curvature concept was similar to one of the single curvature concepts, and as expected, the MC/DG showed the compound curvature concept to be more expensive (Table G-2). Table G-3

FIGURE G-1. LOCATION OF ALUMINUM CONCEPTUAL PANEL ON F-16 FUSELAGE

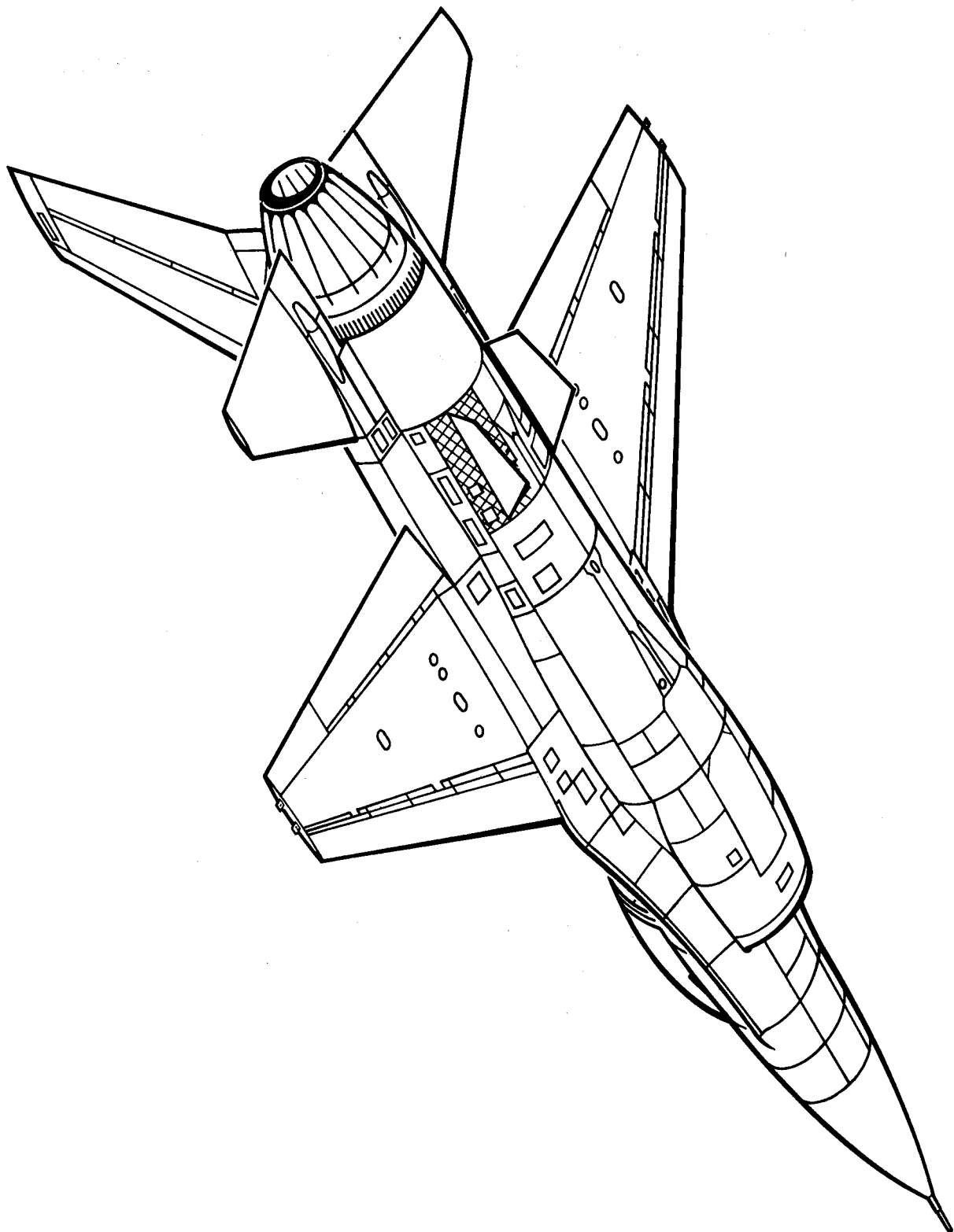
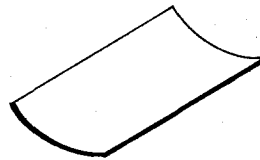


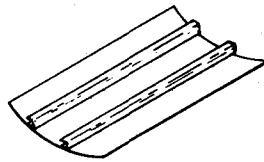
FIGURE G-2. CONCEPTS SELECTED FOR EVALUATION IN ALUMINUM FUSELAGE SHEAR-PANEL TRADE-STUDY

SINGLE CURVATURE

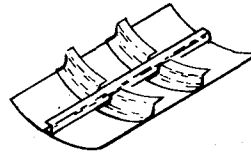
- **UNSTIFFENED SKIN**



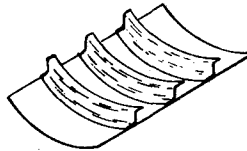
- **2 STRINGERS**



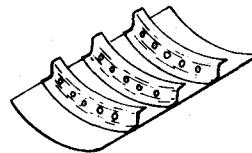
- **1 STRINGER, 2 FRAMES**



- **3 FRAMES**



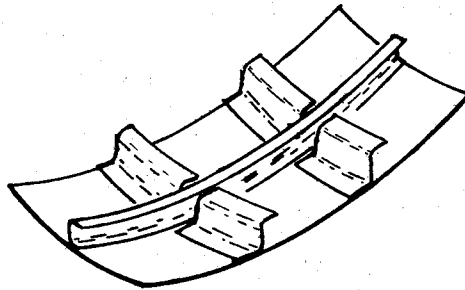
- **3 FRAMES WITH CUTOUTS**



**FIGURE G-3. CONCEPTS SELECTED FOR EVALUATION IN
ALUMINUM FUSELAGE SHEAR-PANEL TRADE-STUDY**

COMPOUND CURVATURE-TAPERED

- **1 STRINGER, 2 FRAMES**



**FIGURE G-4. FABRICATION/ASSEMBLY GROUND RULES
AND ASSUMPTIONS**

FABRICATION/ASSEMBLY GROUND RULES AND ASSUMPTIONS

- NO HEAT TREATMENT
- 3.5t BEND RADII
- ZEE FRAMES
- CHANNEL STRINGERS
- JOGGLE FRAMES AT STRINGERS
- CLIPS AT FRAME/STRINGER JOINTS
- SEALANT ON FAYING SURFACE AND FASTENERS
- RIVETS INSTALLED AUTOMATICALLY
(80% AUTO/20% MANUAL ON CLIPS)

**FIGURE G-5. THE F-16 SIMPLIFIED ENGINE ACCESS COVER (16B6530)
CONCEPT IA**

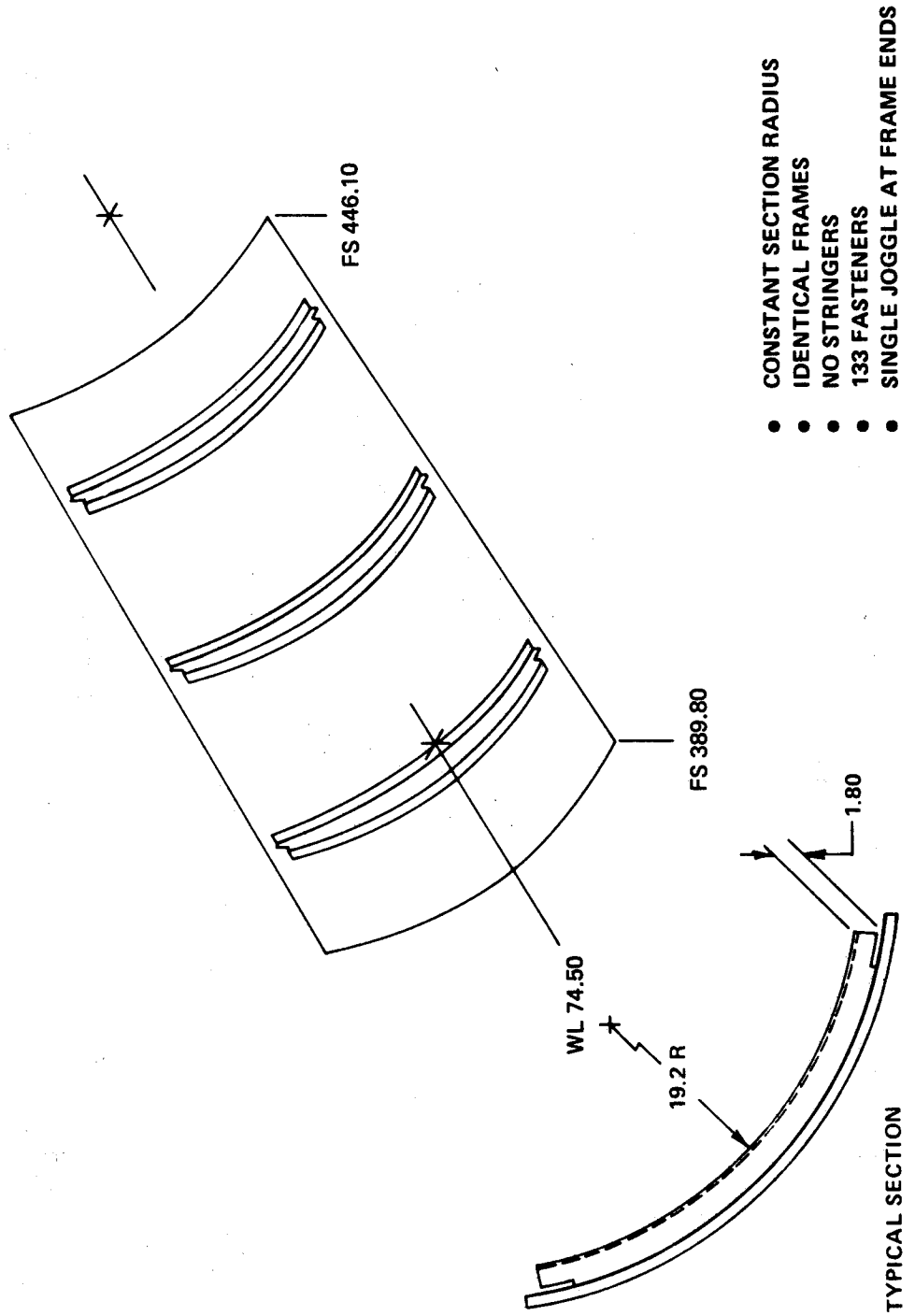


FIGURE G-6. THE F-16 SIMPLIFIED ENGINE ACCESS COVER (16B6530)

CONCEPT IB

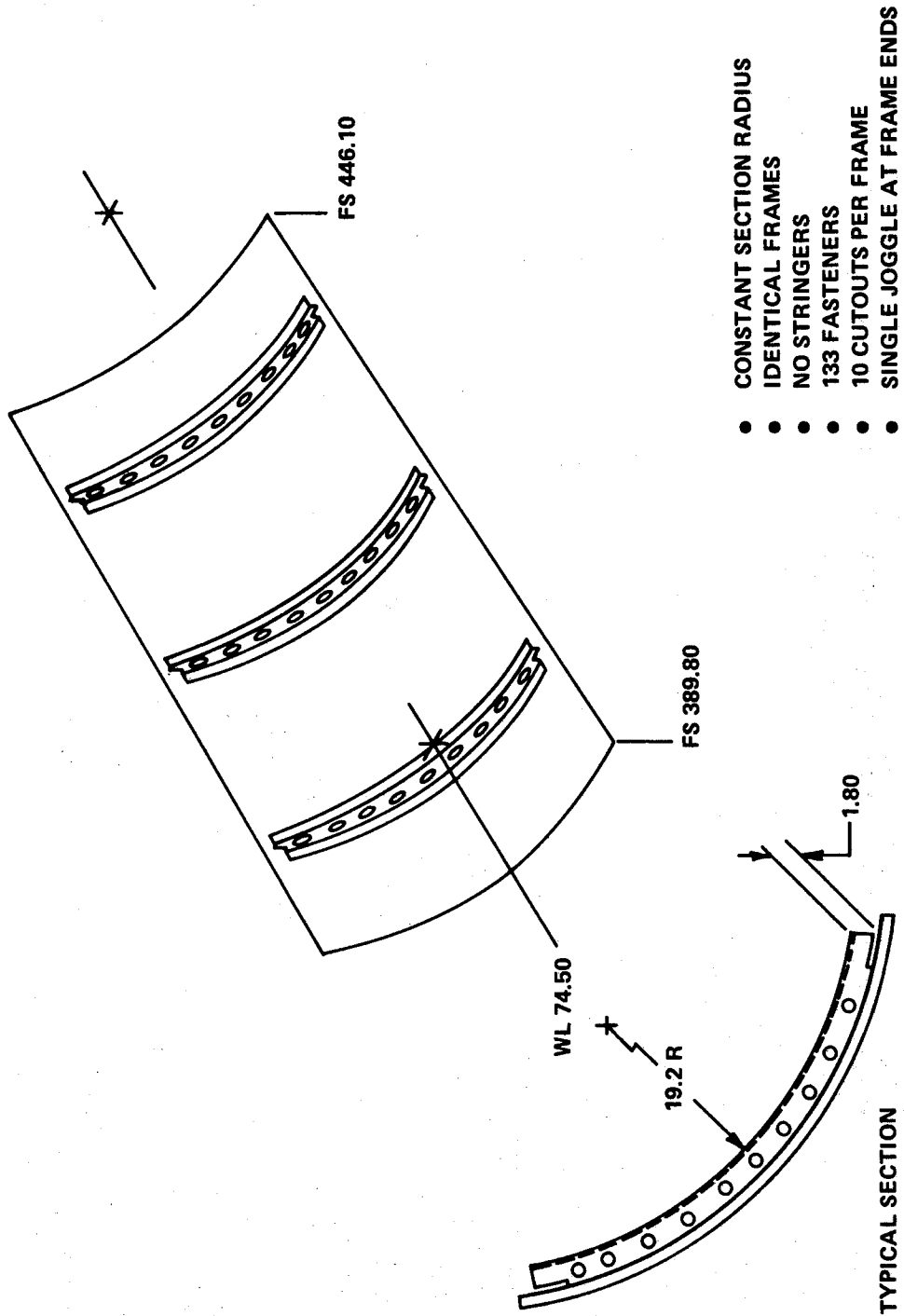


FIGURE G-7. THE F-16 SIMPLIFIED ENGINE ACCESS COVER (16B6530)

CONCEPT IIA

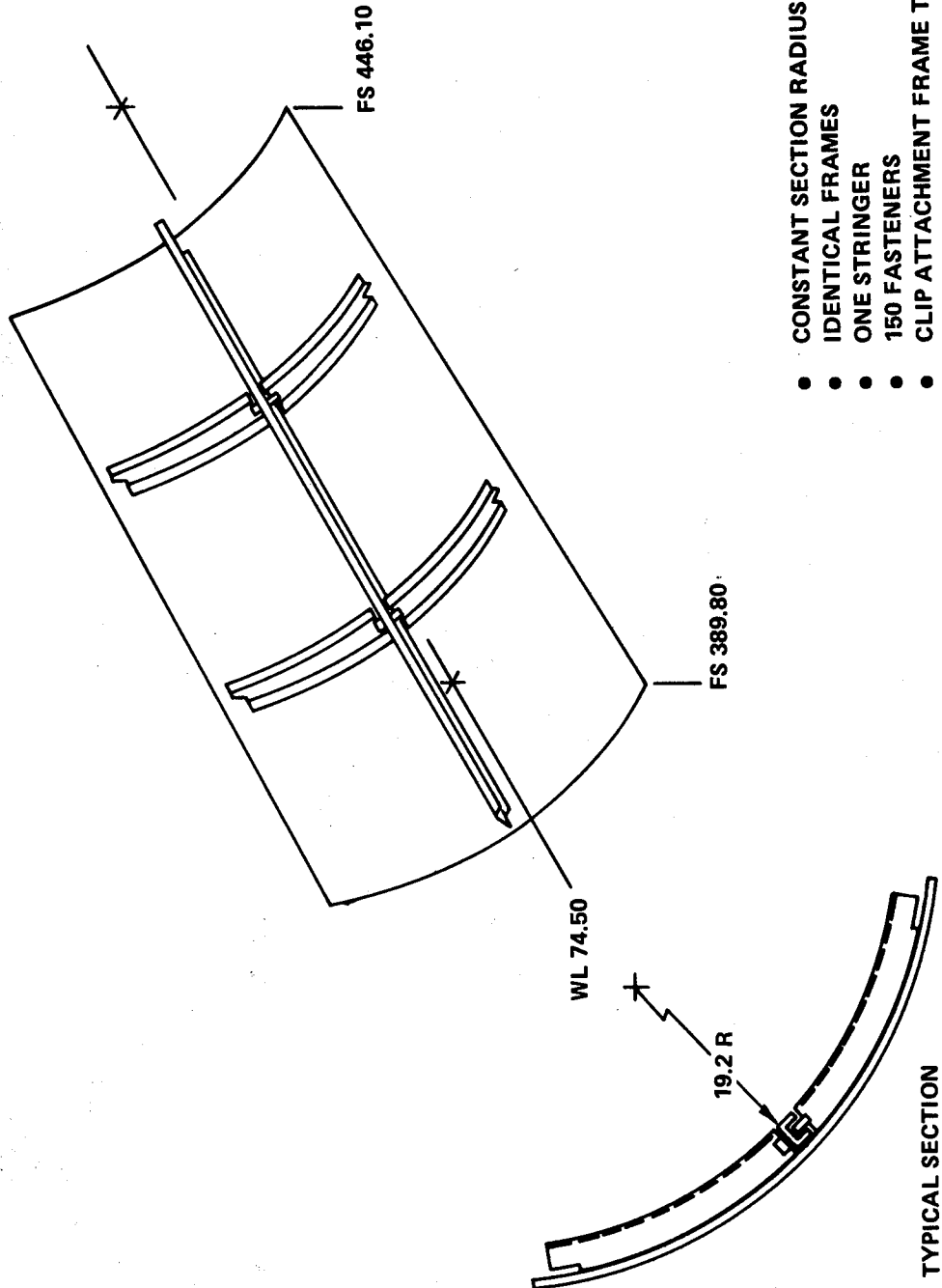


FIGURE G-8. THE F-16 SIMPLIFIED ENGINE ACCESS COVER (16B6530)

CONCEPT IIB

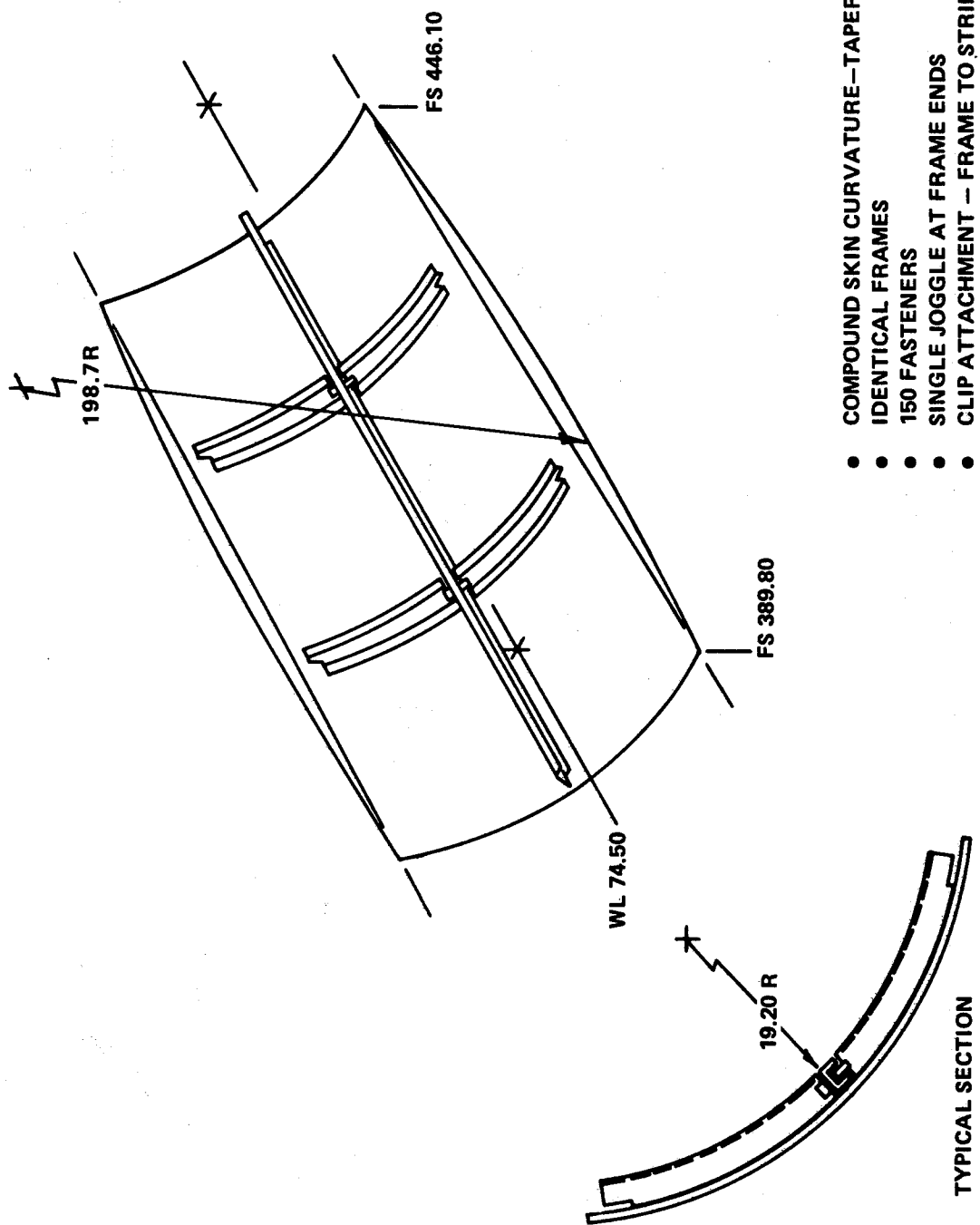
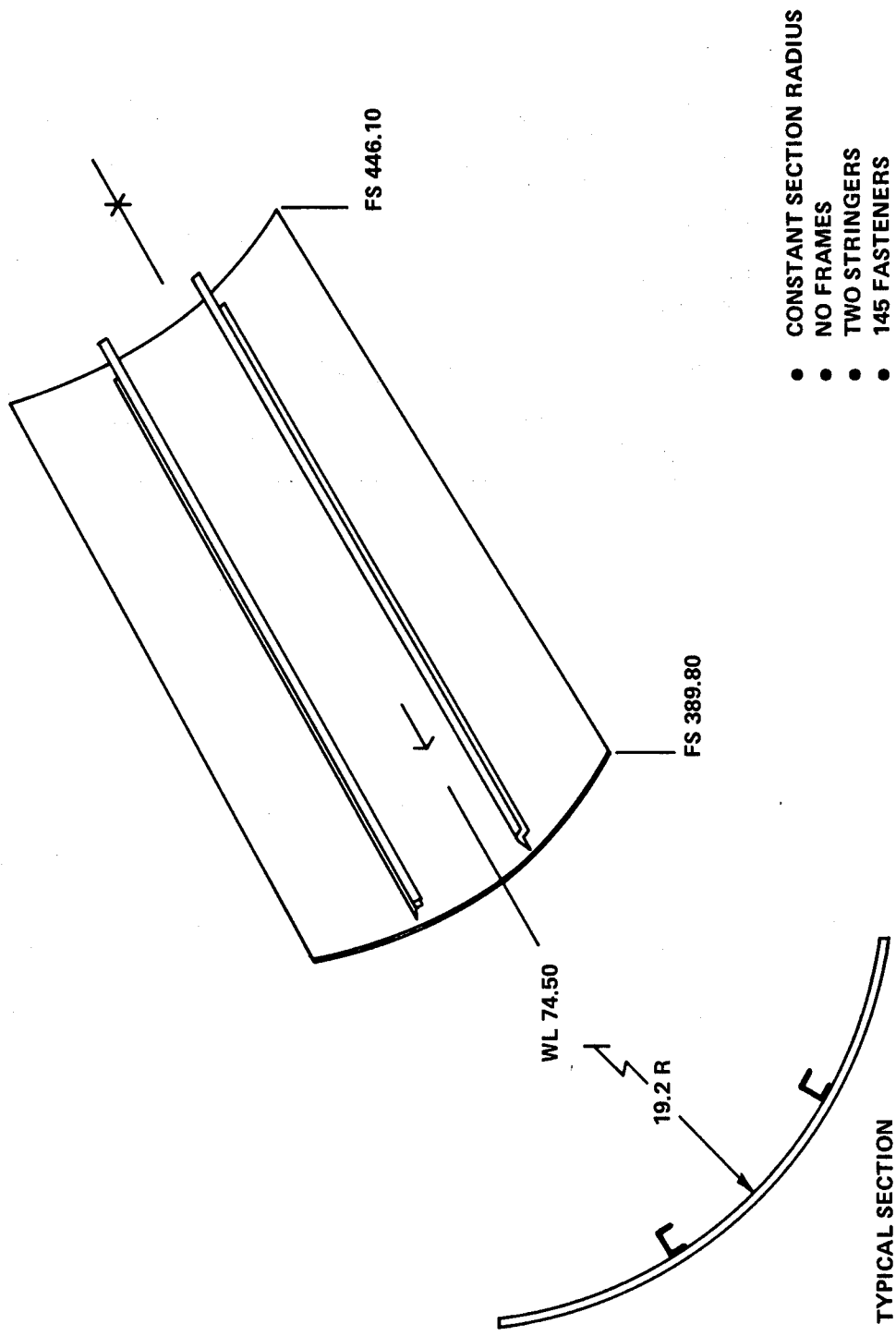


FIGURE G-9. THE F-16 SIMPLIFIED ENGINE ACCESS COVER (16B6530)
CONCEPT IIIA

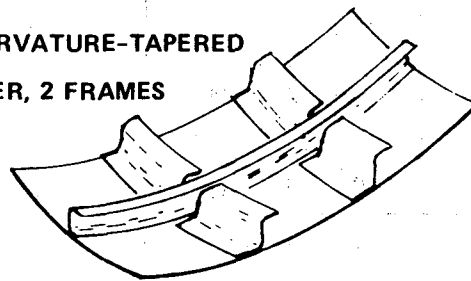


**TABLE G-1. SUMMARY OF COST-WEIGHT RELATIONSHIPS IN
ALUMINUM FUSELAGE SHEAR-PANEL TRADE - STUDY**

| CONCEPT | COST, \$ | WEIGHT, LBS | COST PER LB, \$/LB |
|------------------------------------|---------------------|------------------------|-------------------------------|
| UNSTIFFENED | 62 | 21.22 | 3 |
| 2 STRINGERS | 209 | 19.68 | 11 |
| 2 FRAMES 1 STRINGER | 266 | 19.83 | 13 |
| 3 FRAMES | 213 | 19.06 | 11 |
| 3 FRAMES (WITH CUTOUTS) | 237 | 19.03 | 12 |

TABLE G-2. INFLUENCE OF CURVATURE ON COST AND WEIGHT

**COMPOUND CURVATURE-TAPERED
1 STRINGER, 2 FRAMES**



| CONCEPT | COST, \$ | WEIGHT, LB | COST PER LB WEIGHT, \$/LB |
|--------------------|----------|------------|---------------------------|
| SINGLE CURVATURE | 266 | 19.83 | 13 |
| COMPOUND CURVATURE | 320 | 18.98 | 17 |

**TABLE G-3. SUMMARY OF RESULTS IN ALUMINUM FUSELAGE
SHEAR-PANEL TRADE—STUDY**

| CONCEPT | COST | | WEIGHT | | COST OF WEIGHT SAVED, \$/LB |
|----------------------------|---------|----------|----------|-----------|--------------------------------------|
| | \$/PART | Δ\$/PART | LBS/PART | ΔLBS/PART | |
| UNSTIFFENED | 62 | BASE | 21.22 | BASE | BASE |
| 2 STRINGERS | 209 | 147 | 19.68 | 1.54 | 95 |
| 2 FRAMES 1 STRINGER | 266 | 204 | 19.83 | 1.39 | 147 |
| 3 FRAMES | 213 | 151 | 19.06 | 2.16 | 70 |
| 3 FRAMES (WITH CUTOUTS) | 237 | 175 | 19.03 | 2.19 | 80 |

summarizes the cost-weight trade-offs for the concepts and also shows the cost of weight saved in dollars per pound. These data will allow the design team to select the cost-optimized fuselage shear panel that will satisfy all other program parameters.

The conclusions reached as a result of this study show that the MC/DG is an effective aid to the design engineer. The study showed that the designer can easily and quickly use the qualitative and quantitative manufacturing cost formats provided in the MC/DG. The MC/DG is sensitive to configuration variations. An additional conclusion was that additional CDE/CED formats for other manufacturing processes are required to analyze more complex airframe subassemblies.

APPENDIX H

TITANIUM FUSELAGE PANEL MANUFACTURING COST/DESIGN TRADE STUDY

AIRFRAME TRADE STUDIES

A series of fuselage shear panels were analyzed with regard to weight and manufacturing cost by three airframe industry team members utilizing the manufacturing man-hour data presented on designer-oriented formats in the three demonstration sections described earlier in this report, i.e., "Sheet-Metal Aerospace Discrete Parts", "Mechanically Fastened Assemblies", and "Advanced Composites Fabrication".

The primary objectives of the fuselage shear panel trade studies were to:

- Demonstrate the use of the MC/DG in an industrial environment designing typical airframe structures
- Determine whether the manufacturing cost (man-hour) formats, providing CDE and CED information, meet the format design criteria established for their development
- Determine whether the CDE and CED formats provide the accuracy required by designers in conducting realistic comparisons of airframe configurations utilizing both metallic and composite materials.

Fuselage panel designs were studied in the following structural materials by the design departments in each of the three companies:

- Aluminum alloy - by General Dynamics Corporation, Fort Worth Division
- Titanium alloy - by Lockheed-California Company
- Graphite/epoxy - by Rockwell International, Los Angeles Division.

The fuselage panel trade studies were critically reviewed by:

- Boeing Commercial Airplane Company
- Northrop Corporation, Aircraft Group.

Titanium Fuselage Shear Panel Trade Study

This appendix presents the results obtained by a design team consisting of design, stress, weight, and producibility engineers, for the trade-study of a titanium fuselage shear panel. The approach used for this trade-study is shown in Figure H-1. This commenced with a review of the ground rules and structural sections available. Figure H-2 shows the structural sections selected for this trade study. In the next step the structural design premises and the general characteristics of the panel design were specified. Figure H-3 shows the panel selected of dimensions 36 x 72 inches with a constant 60-inch radius. The design loads, structural design criteria, and analysis methodology are summarized in Figure H-3. These criteria were derived from the first and second generation SST studies; modified to reflect the ground rules set forth by the MC/DG development team.

The third step in the approach to the trade study is to develop candidate design configurations. A generalized drawing of the panel is shown in Figure H-4. Table H-1 is a summary of the seven design concepts considered. The table provides values of A and B, shown in Figure H-4, for each concept. It can be seen from the table that the number of frames, skin thickness, and the number and type of stringers were the variables. Figures H-5 through H-11 show details of each concept, including a parts list. Table H-2 provides a detailed summary of the concepts, including the number, type, and dimensions of each part. Also included on this table are the number of rivets (fastener count) required for assembly of the concept.

The final step, conducted as part of the trade study, is to estimate the cost and weight of each panel concept. The weight was estimated by the weight engineer, using standard weight estimating procedures. To estimate the cost of each concept, the MC/DG Designer Worksheet (shown on page 262 of Volume I) was utilized. Figures H-12 and H-13 provide examples of the utilization of the worksheets with the data inserted for Concept I. Figure H-13 provides the supporting data for the entries on the worksheet. The worksheet is a useful aid to the designer when using the MC/DG, as it provides an orderly outline of what must be accomplished to determine the cost of the panel.

FIGURE H-1. TITANIUM FUSELAGE SHEAR-PANEL TRADE-STUDY PHASES

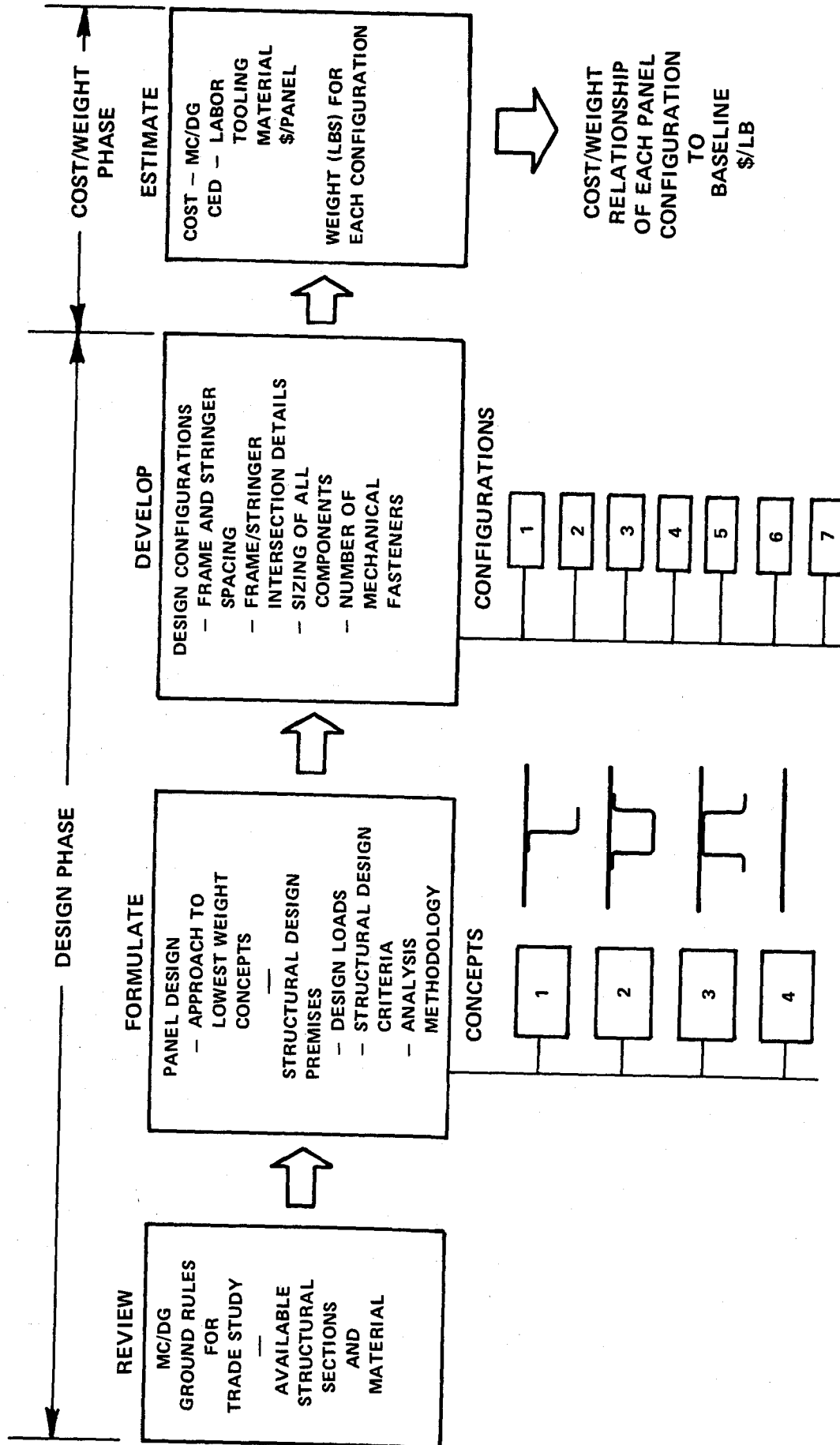
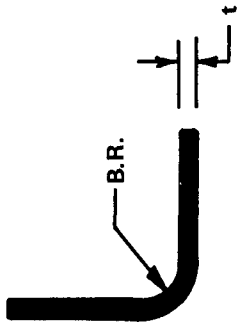
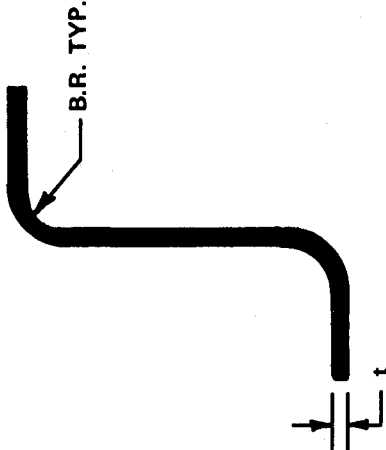


FIGURE H-2. AVAILABLE MC/DG TITANIUM STRUCTURAL SECTIONS

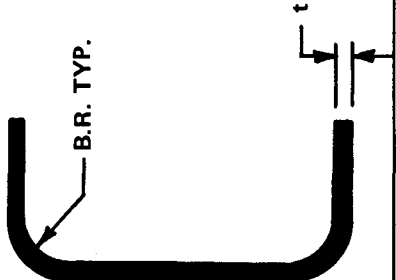
| ITEM | THICKNESS—INCHES | | | | | |
|----------------------|------------------|------|------|------|------|------|
| | .025 | .030 | .040 | .050 | .062 | .080 |
| 5t BEND RADIUS — RT | .12 | .16 | .22 | .25 | .31 | .44 |
| 2t BEND RADIUS — HOT | .06 | .06 | .09 | .12 | .12 | .16 |



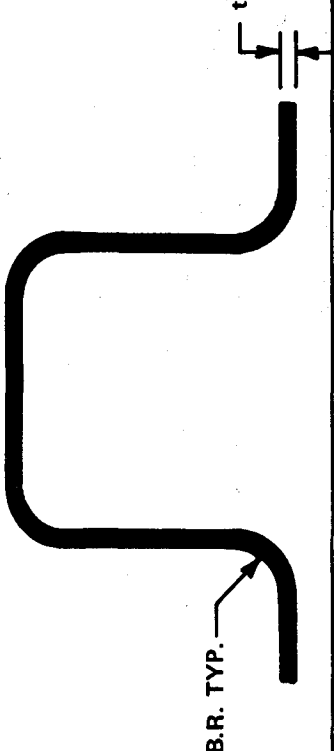
B.R.



B.R. TYP.



B.R. TYP.



B.R. TYP.

FIGURE H-3. TITANIUM FUSELAGE SHEAR-PANEL DIMENSIONS AND DESIGN PREMISES

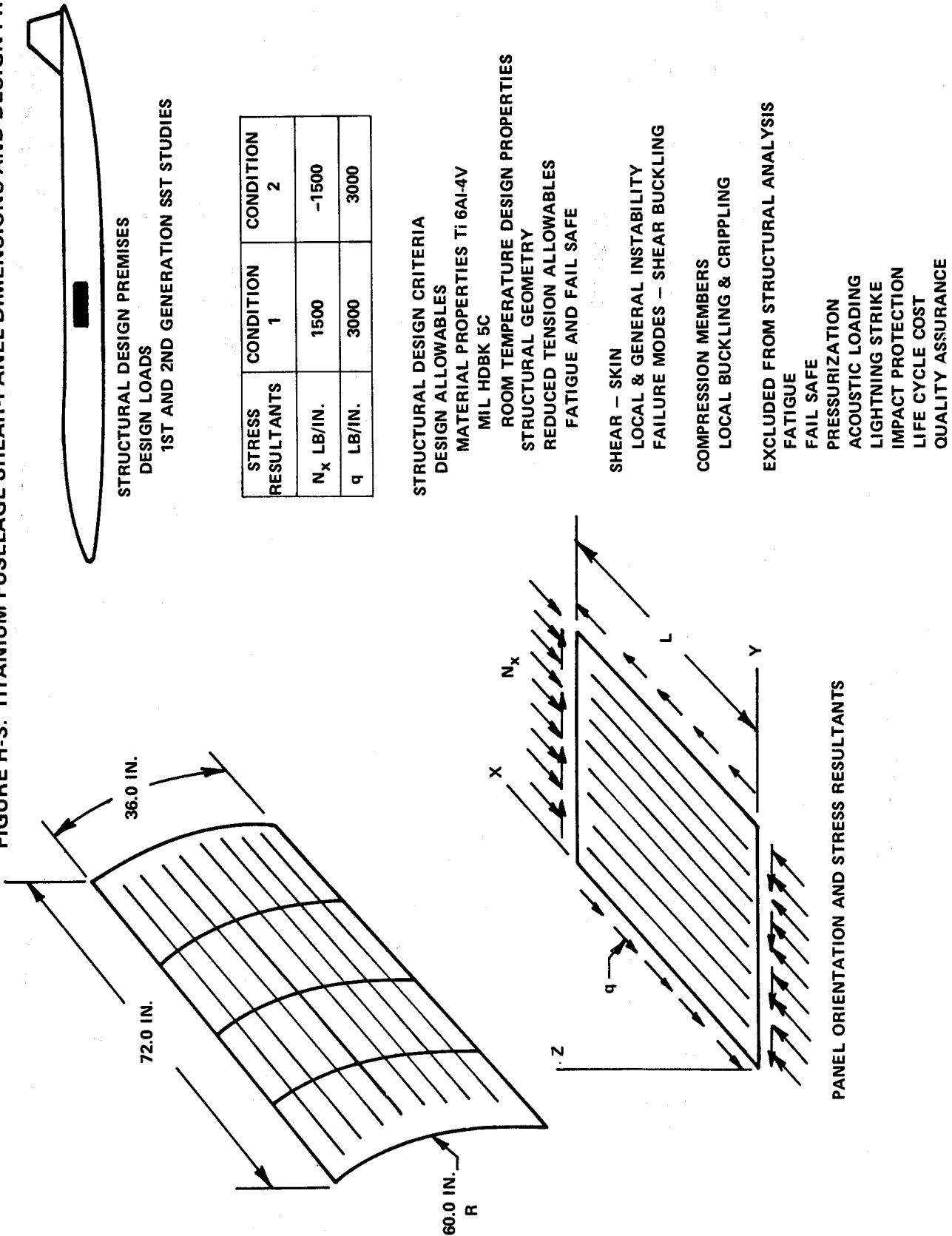


FIGURE H-4. LAYOUT OF TITANIUM FUSELAGE SHEAR-PANEL

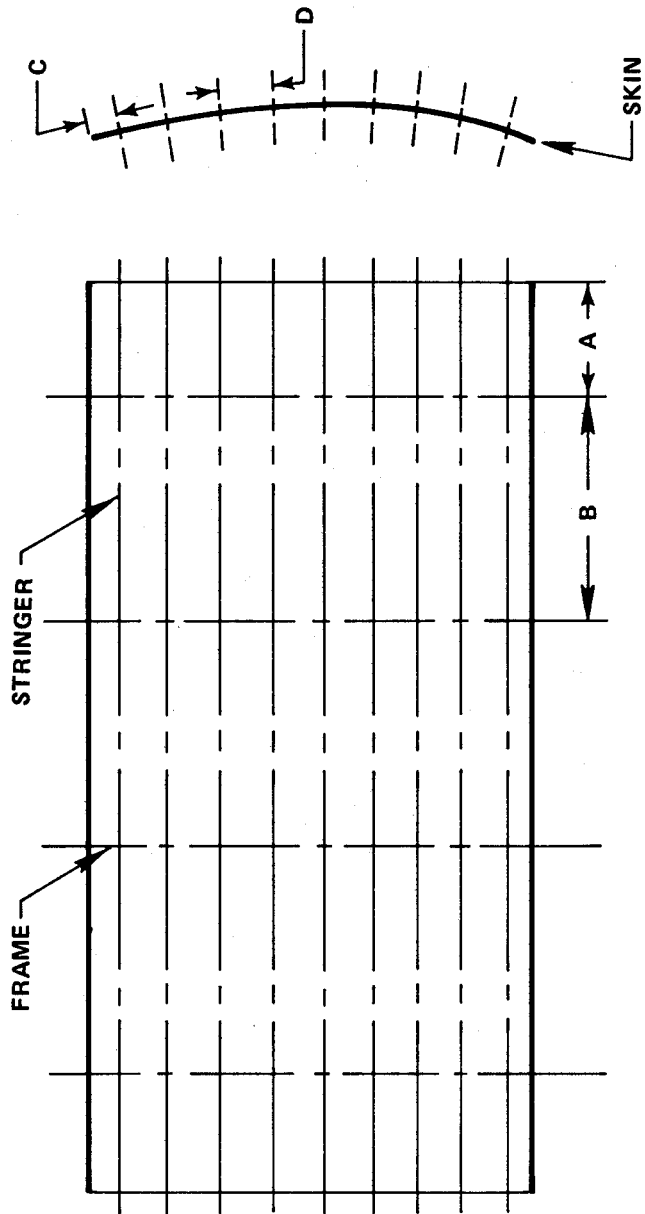
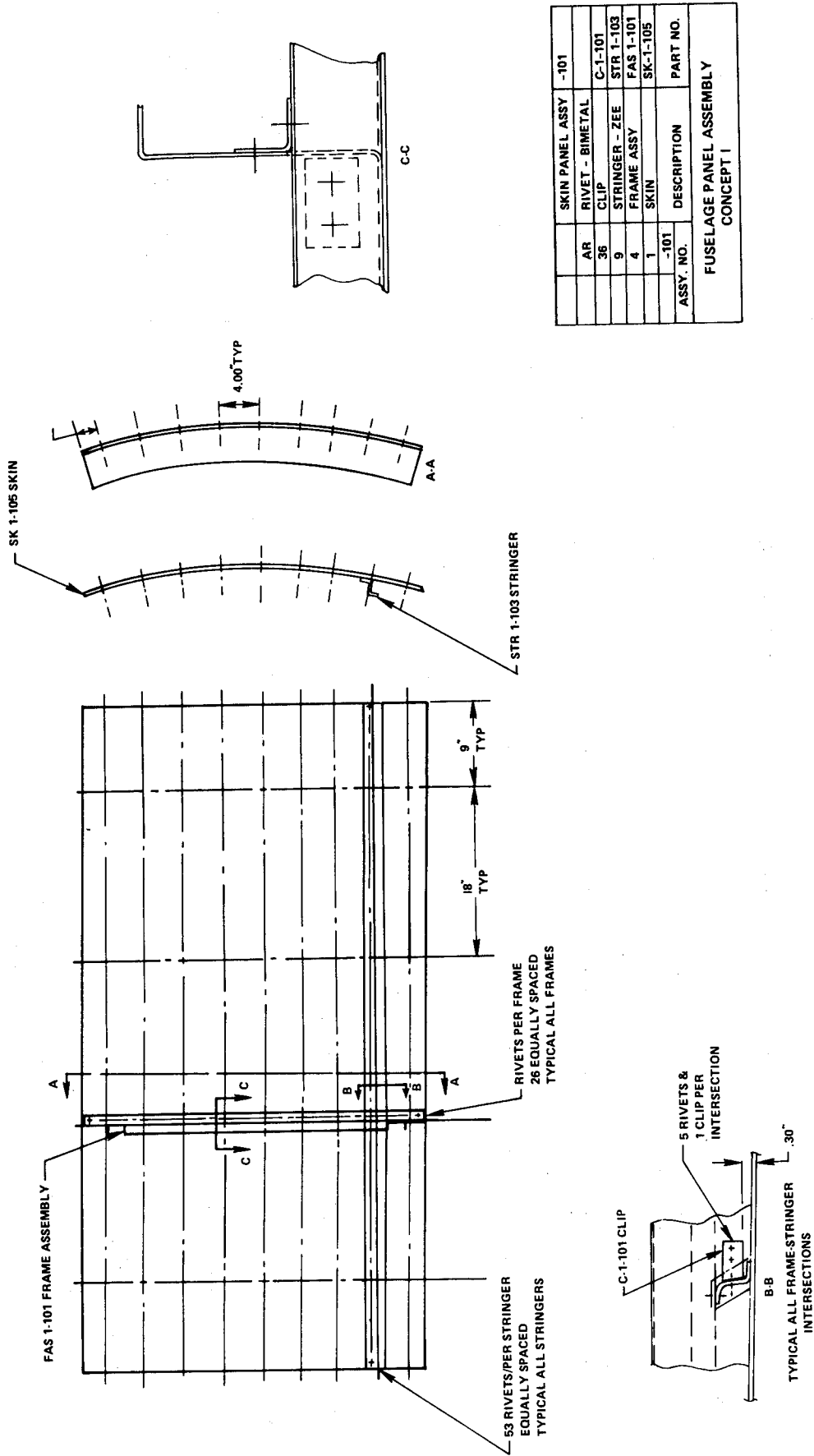


TABLE H-1. SUMMARY OF TITANIUM FUSELAGE SHEAR-PANEL CONCEPTS

| CONCEPT NO. | SKIN THICKNESS, IN. | NO. OF FRAMES | TYPE OF FRAME | NO. OF STRINGERS | TYPE OF STRINGERS | DIMENSIONS IN. | | |
|-------------|---------------------|---------------|---------------|------------------|-------------------|----------------|------|----------|
| | | | | | | A | B | A B |
| 1 | 0.08 | 4 | ZEE | 9 | ZEE | 9.0 | 18.0 | 2.0 4.0 |
| 2 | 0.08 | 3 | ZEE | 9 | ZEE | 12.0 | 24.0 | 2.0 4.0 |
| 3 | 0.06 | 4 | ZEE | 8 | HAT (CLOSED) | 9.0 | 18.0 | 2.25 4.5 |
| 4 | 0.06 | 3 | ZEE | 8 | HAT (CLOSED) | 12.0 | 24.0 | 2.25 4.5 |
| 5 | 0.075 | 4 | ZEE | 8 | HAT (OPEN) | 9.0 | 18.0 | 2.25 4.5 |
| 6 | 0.075 | 3 | ZEE | 8 | HAT (OPEN) | 12.0 | 24.0 | 2.25 4.5 |
| 7 | 0.190 | 9 | ZEE | 0 | - | 4.0 | 8.0 | - - |

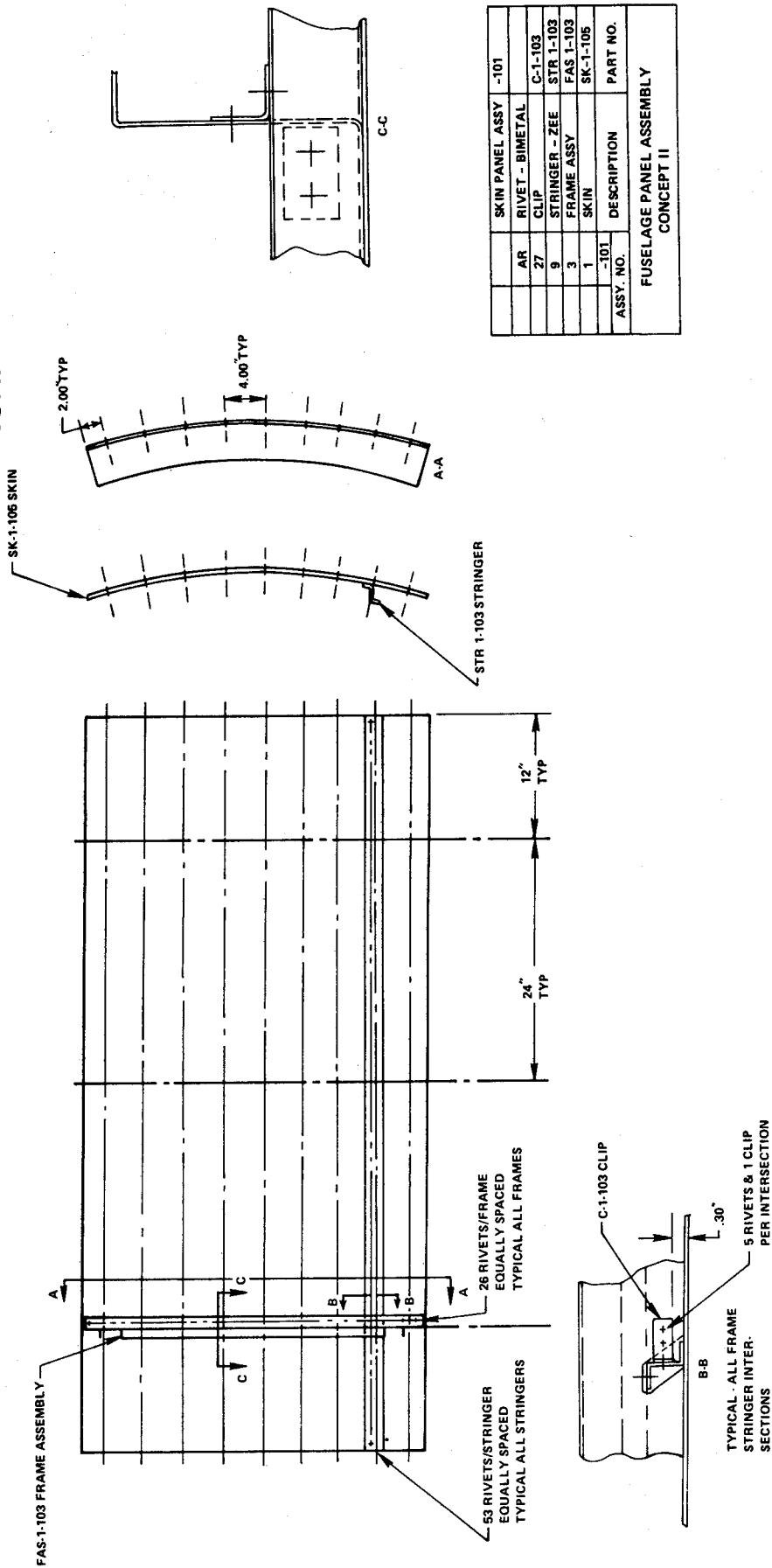
FIGURE H-5. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. 1



| ASSY. NO. | DESCRIPTION | PART NO. |
|----------------------|-----------------|-----------|
| -101 | DESCRIPTION | PART NO. |
| 1 | SKIN | SK-1-105 |
| 4 | FRAME ASSY | FAS 1-101 |
| 9 | STRINGER - ZEE | STR 1-103 |
| 36 | CLIP | C-1-101 |
| AR | RIVET - BIMETAL | |
| SKIN PANEL ASSY -101 | | |

FUSELAGE PANEL ASSEMBLY
CONCEPT I

FIGURE H-6. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. II



| AR | SKIN PANEL ASSY | -101 |
|-----------|-------------------------|-----------|
| 27 | RIVET - BIMETAL CLIP | C-1-103 |
| 9 | STRINGER - ZEE | STR 1-103 |
| 3 | FRAME ASSY | FAS 1-103 |
| 1 | SKIN | SK-1-105 |
| -101 | DESCRIPTION | PART NO. |
| ASSY. NO. | FUSELAGE PANEL ASSEMBLY | |
| | CONCEPT II | |

FIGURE H-7. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. III

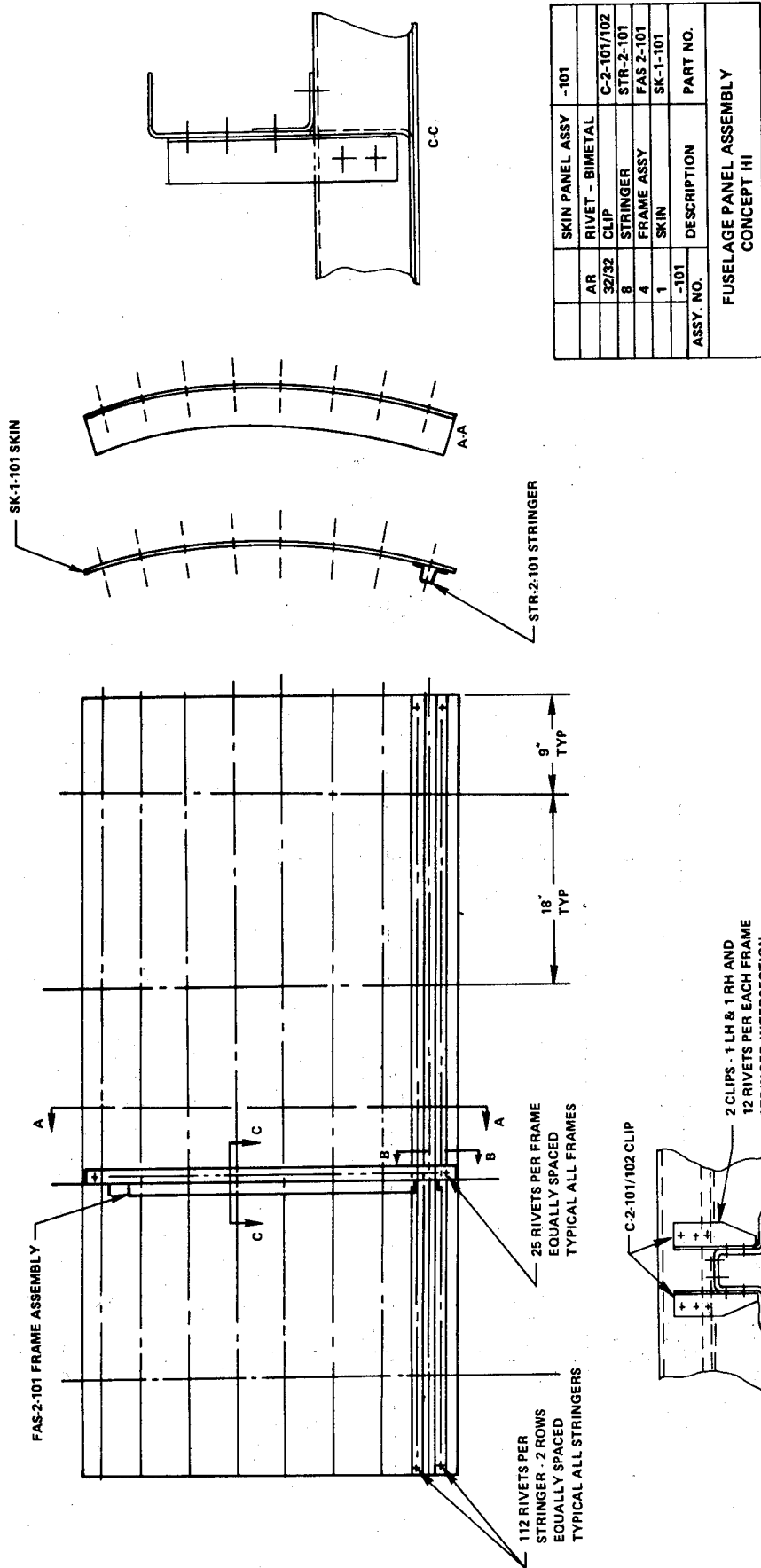
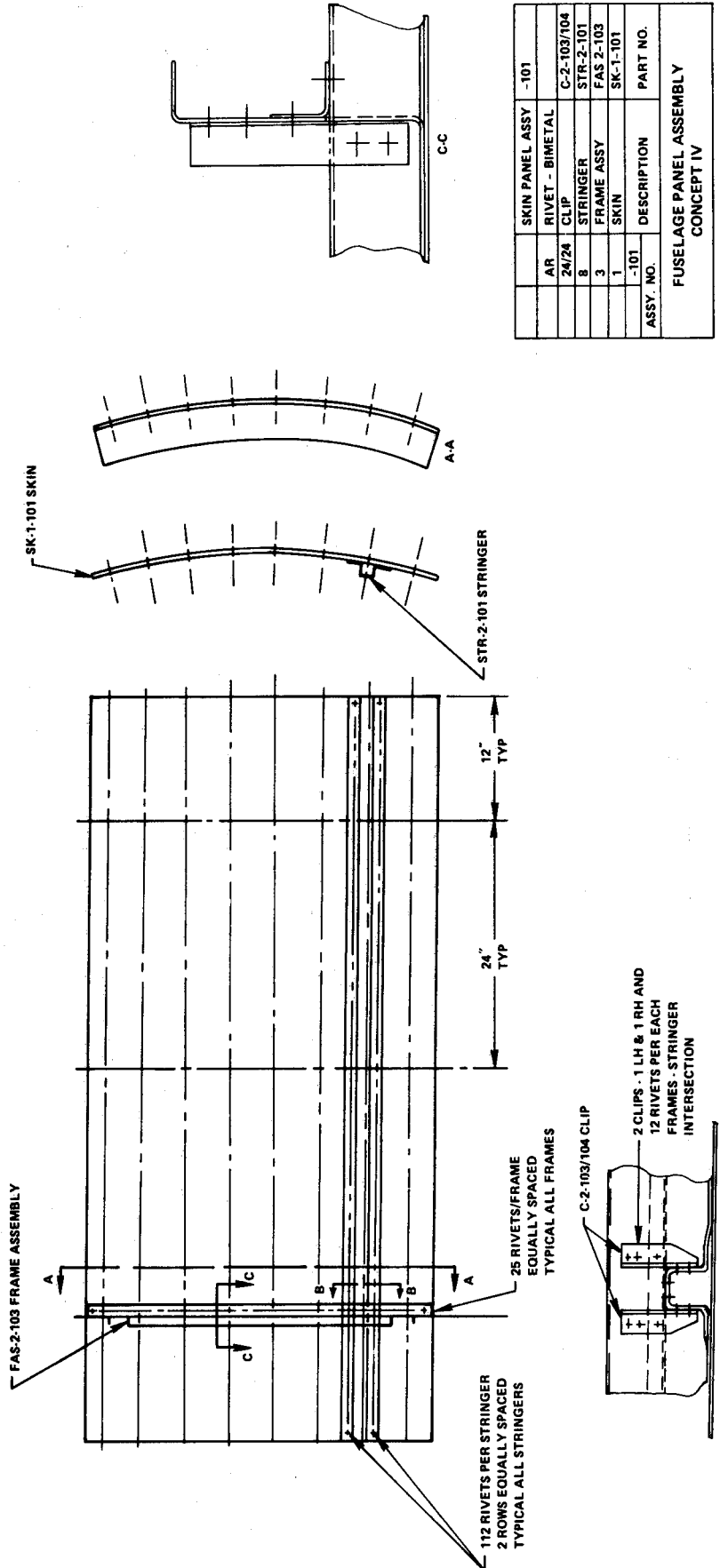


FIGURE H-8. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. IV



| | | |
|---------------------------------------|-----------------|-------------|
| AR | SKIN PANEL ASSY | -101 |
| 24/24 | RIVET - BIMETAL | C-2-103/104 |
| B | CLIP | STR-2-101 |
| 3 | FRAME ASSY | FAS 2-103 |
| 1 | SKIN | SK-1-101 |
| -101 | DESCRIPTION | PART NO. |
| FUSELAGE PANEL ASSEMBLY CONCEPT IV | | |

FIGURE H-9. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. V

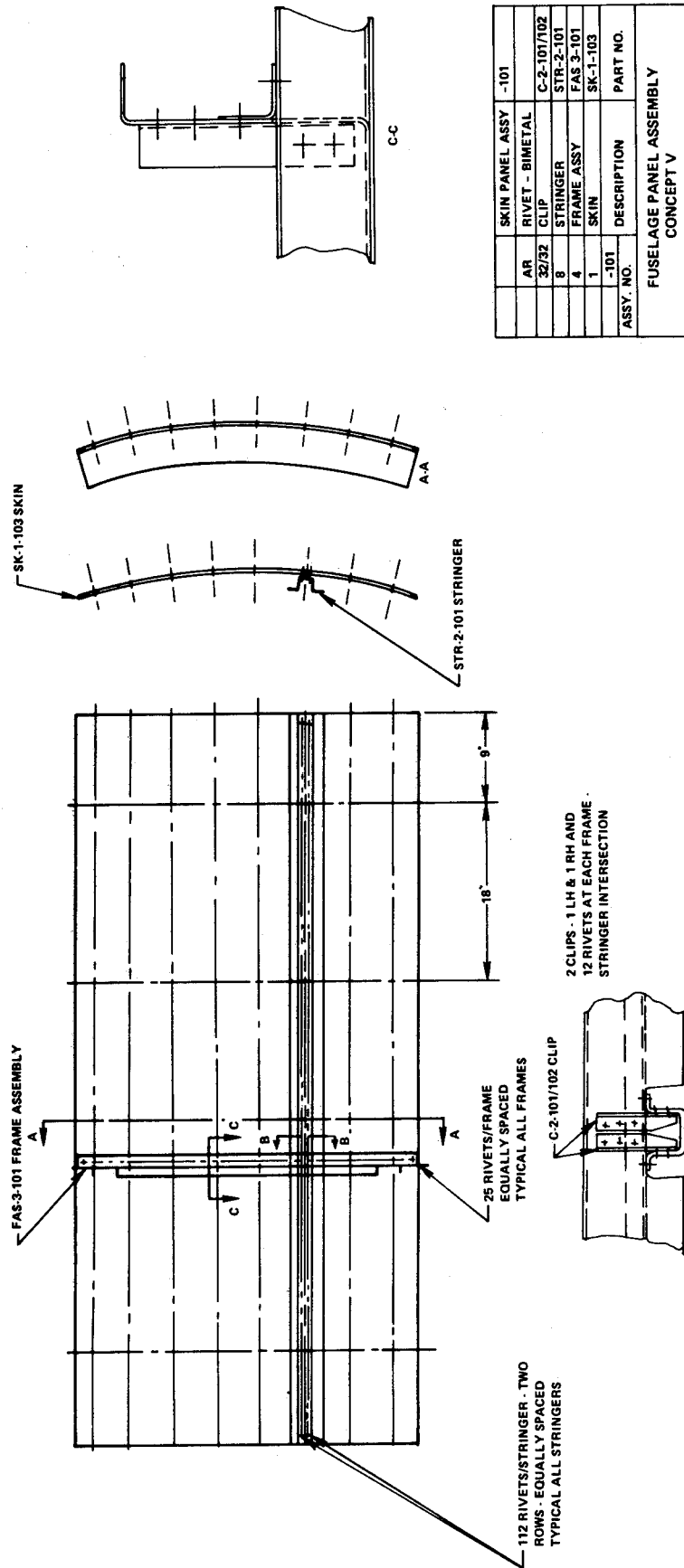


FIGURE H-10. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. VI

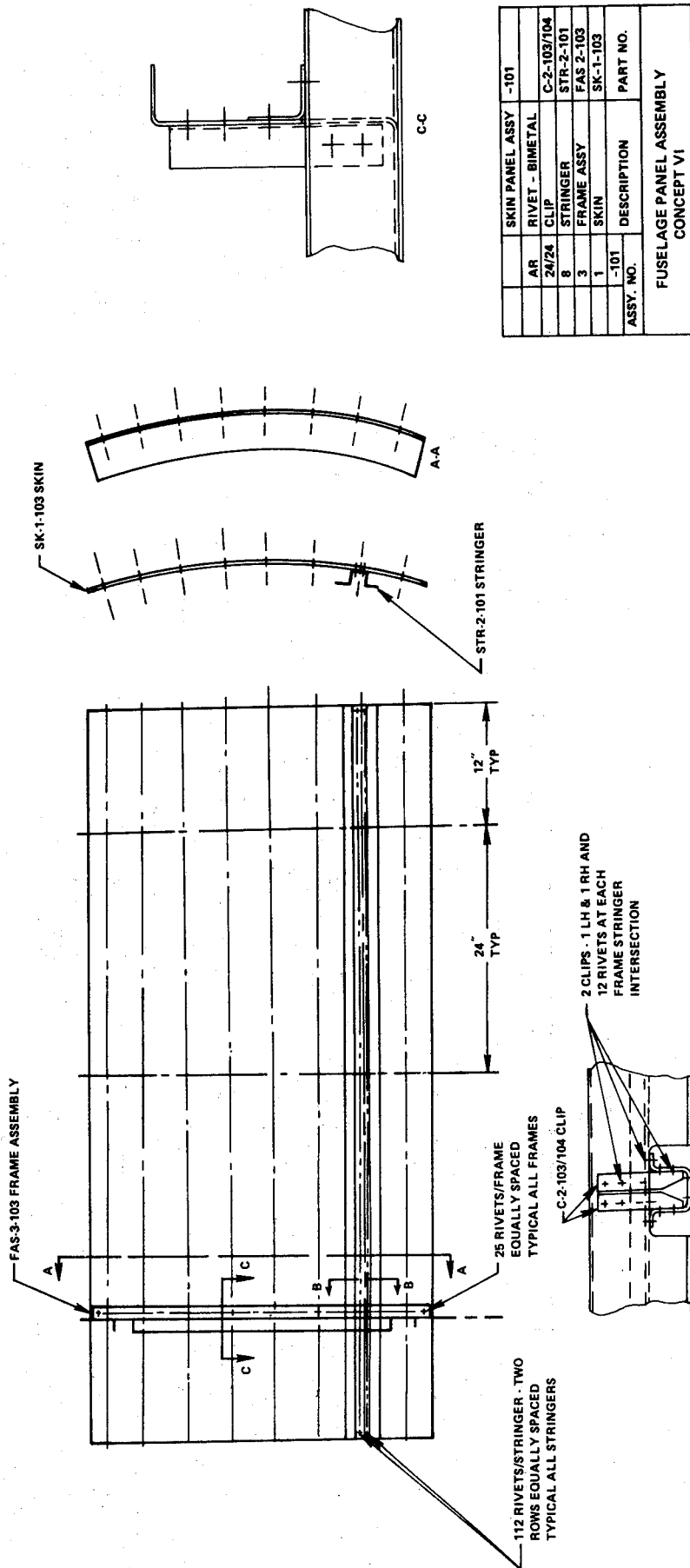
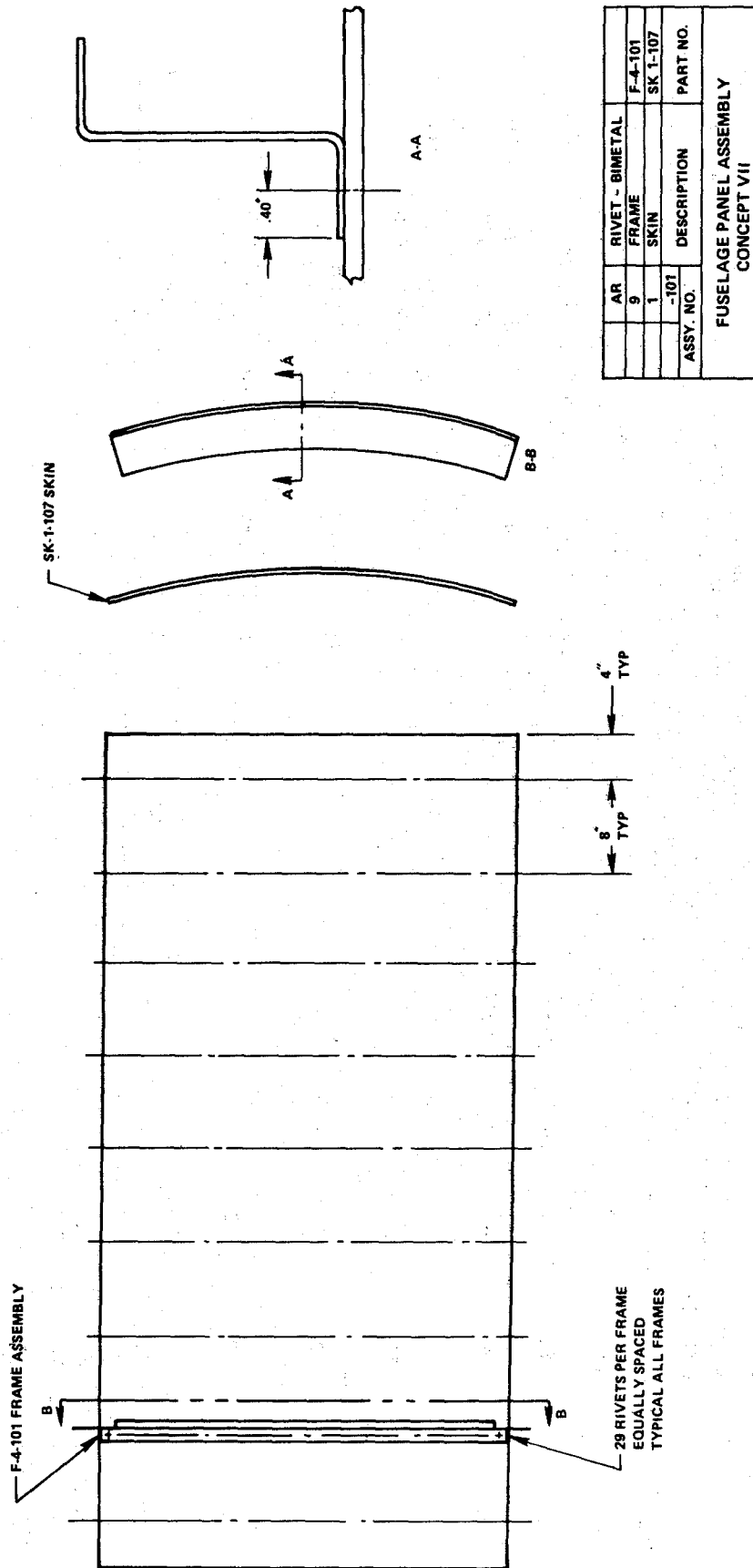


FIGURE H-11. TITANIUM FUSELAGE SHEAR-PANEL CONCEPT NO. VII



| | | |
|--|-----------------|----------|
| AR | RIVET - BIMETAL | F-4-101 |
| 9 | FRAME | SK 1-107 |
| 1 | SKIN | PART NO. |
| -101 | DESCRIPTION | |
| ASSY. NO. | | |
| FUSELAGE PANEL ASSEMBLY CONCEPT VII | | |

TABLE H-2. SUMMARY OF CANDIDATE PANEL CONFIGURATIONS IN TITANIUM FUSELAGE SHEAR-PANEL TRADE-STUDY

| CONCEPT | SKIN THICKNESS* (IN.) | STRINGERS | | FRAME ASSEMBLY | | FRAME (ZEE) | | FRAME ANGLE | CLIP (ANGLE) | NO. OF RIVETS | |
|---------|-----------------------|-----------|-----------------|----------------|---------------|---------------|-----|-------------|--------------|--------------------------|-----------------|
| | | NO. | THICKNESS (IN.) | TYPE | NO. OF FRAMES | NO. OF RIVETS | NO. | | | | THICKNESS (IN.) |
| I | .080 | (9) | .050 | ZEE | 4 | 29 | (4) | .040 | (4) .040 | (36) .040 | 761 |
| II | .080 | (9) | .050 | ZEE | 3 | 29 | (3) | .050 | (3) .050 | (27) .050 | 690 |
| III | .060 | (8) | .040 | HAT** | 4 | 13 | (4) | .040 | (4) .040 | 32 LH .040 32 RH .040 | 1380 |
| IV | .060 | (8) | .040 | HAT** | 3 | 13 | (3) | .050 | (3) .050 | 24 LH .050 24 RH .050 | 1259 |
| V | .075 | (8) | .040 | HAT*** | 4 | 13 | (4) | .040 | (4) .040 | 32 LH .040 32 RH .040 | 1380 |
| VI | .075 | (8) | .040 | HAT*** | 3 | 13 | (3) | .050 | (3) .050 | 24 LH .050 24 RH .050 | 1259 |
| VII | .190 | --- | NONE | --- | --- | NONE | (9) | .040 | NONE | NONE | 261 |

*SKIN SIZE: 36" x 72".

**FLANGES ATTACH TO SKIN.

***FLANGES AWAY FROM SKIN.

FIGURE H-12. MC/DG COST WORKSHEET

CONCEPT I: 9 ZEE STRINGER / 4 FRAME ASSEMBLY

| PART # | DESIGN CONCEPT | RECURRING COST (RC) | | | | | | | | | | NON-RECURRING COST (NRC) | | | | PROGRAM COST | |
|--------|----------------|-----------------------|---------------|----------------------|--------------------|-----------------|----------------------|------------------|---------------|-----------------|-------------------|--------------------------|-------------------|--------------------|----------------|-----------------|--|
| | | Labor MC/DG MH/PT (1) | LC Factor (2) | Labor Rate \$/MH (3) | Labor RC \$/PT (4) | Mat'l \$/PT (5) | Rec. Cost/PT. \$ (6) | Parts Per AC (7) | Des. Qty. (8) | Prog. RC \$ (9) | NRC MC/DG MH (10) | Labor Rate \$/MH (11) | Prog. NRC \$ (12) | Prog. Cost \$ (13) | Des. Qty. (14) | Cost/AC \$ (15) | |
| 1 | SKIN | 1.50 | 1.17 | 25 | 44 | 504 | 548 | 1 | 200 | 109600 | 118 | 25 | | 200 | | | |
| 2 | STRINGER-ZEE | 0.44 | 1.17 | 25 | 13 | 34 | 47 | 9 | 200 | 84600 | 16 | 25 | | 200 | | | |
| 3 | FRAME, ZEE | 1.20 | 1.17 | 25 | 35 | 43 | 78 | 4 | 200 | 62400 | 280 | 25 | | 200 | | | |
| 4 | FRAME, ANGLE | 0.80 | 1.17 | 25 | 23 | 21 | 44 | 4 | 200 | 35200 | 265 | 25 | | 200 | | | |
| 5 | CLIP | 0.18 | 1.17 | 25 | 5.3 | 0.4 | 6 | 36 | 200 | 43200 | 14 | 25 | | 200 | | | |
| | FRAME, ASSY | 1.42 | 1.30 | 25 | 46 | 10 | 56 | 4 | 200 | 44800 | 320 | 25 | | 200 | | | |
| | PANEL ASSY | 15.22 | 1.66 | 25 | 632 | 266 | 898 | 1 | 200 | 179600 | 500 | 25 | | 200 | | | |
| TOTALS | | | | | | | | | | 559400 | 1513 | 25 | 37825 | 597225 | 200 | 2986 | |

REMARKS

BY: _____
DATE: _____

FIGURE H-13. COST WORKSHEET—SUPPORTING DATA

CONCEPT I: 9 ZEE STRINGER / 4 FRAME ASSEMBLY SHEET 2 OF 2

| | |
|---|---|
| <p><u>PART: SKIN</u> BASE PART - CED T5 1.05 MH/PT TOOL 40 MH TRIM - CED T6 0.45 " 78 " TOTAL 1.50 MH/PT 118 MH MAT'L - CED M1 0.080" 3'x6' = 18 SQ.FT. @ \$28/SQ.FT. = \$504 /PART</p> | <p><u>PART: STRINGER-ZEE</u> BASE PART - CED T1 0.44 MH/PT TOOL 16MH R.T. FORM (5T BR) MAT'L - CED M1 0.050" 3.5" /12 x 6' = 1.75 SQ.FT @ \$19.50/SQ.FT. = \$34 /PART</p> |
| <p><u>PART: FRAME, ZEE</u> BASE PART - CED T4 1.2 MH/PT TOOL 280MH HOT SIZE MAT'L - CED M1 0.040" 10'x36' /144 = 2.5 SQFT @ \$17/SQ.FT. = \$42.50 /PART</p> | <p><u>PART: FRAME, ANGLE</u> BASE PART - CED T4 0.80 MH/PT TOOL 265MH HOT SIZE MAT'L - CED M1 0.040" 5" /12 x 3' = 1.25 SQ.FT. @ \$17/SQ.FT. = \$21.25 /PART</p> |
| <p><u>PART: CLIP</u> BASE PART - CED 1 .18 MH/PT TOOL 16 MH R.T. FORM (5T BR) MAT'L - CED M1 0.040" 3.5"x1" /144 = .024 SQ.FT. @ \$17/SQ.FT. = \$0.41 /PART</p> | <p><u>PART:</u></p> |
| <p><u>ASSEMBLY: FRAME</u> CED MFA 1 MANUAL, DRY TOOL 320 MH 29 RIVETS/ASSY @ .049 MH/RIVET = 1.42 MH/ASSY MAT'L - AVE. RIVET COST \$0.35 EACH * 29 RIVETS @ \$0.35 = \$10.15 /ASSY *FROM PROCUREMENT</p> | <p><u>ASSEMBLY: PANEL</u> CED MFA 1 AUTO/MAN, DRY TOOL 500 MH 761 RIVETS @ 0.020 MH/RIVET = 15.22 MH MAT'L - AVE. RIVET COST \$0.35 EACH 761 RIVETS @ \$0.35 = \$266.95</p> |

Having determined both the manufacturing cost and weight of each panel, the designer can now organize the data into a convenient form for selection of the optimum panel design. Table H-3 summarizes the cost and weight of each concept. For this summary, the least costly panel, Concept VII, was chosen as the base design. With a base design selected, a delta for weight and cost of each panel can be calculated relative to the base. These deltas are then combined to give a value for the cost of weight saved, in dollars per pound. These data are also included in Table H-3. The designer concluded from these data that Concept II should be the recommended panel design. In order to confirm this decision, Table H-4 was prepared with Concept II as the base design. The deltas and cost of weight saved were again calculated. The results show that Concept II was the correct choice.

The conclusions, based on a review of the trade study, were that the MC/DG is an effective tool for the design team, and that the methodology followed in this trade study clearly demonstrated the concept of utilizing the MC/DG in the aerospace industry environment. The specific conclusions are listed below.

Program Philosophy and Objective

- Information presented indicative of the ultimate function of the MC/DG
- Use of MC/DG in obtaining manufacturing costs and performing simple cost estimates was well demonstrated
- Demonstrated selection criteria of dollars/pound weight saved
- Fully demonstrated use of the MC/DG in developing cost/weight effective design.

Presentation

- Utilized costing methodology, developed program dollar costs, material, labor, and tooling
- Cost/weight summary chart and recommendations are of particular merit
- Review of each concept given with cost-estimating steps clearly shown.

TABLE H-3. COST-WEIGHT TRADE-OFF SUMMARY FOR TITANIUM FUSELAGE SHEAR-PANEL TRADE—STUDY

| CONCEPT | COST | | WEIGHT | | COST OF WEIGHT SAVED— \$/LB |
|---------|----------|-----------|-----------|---------|--------------------------------|
| | \$/PANEL | Δ\$/PANEL | LBS/PANEL | ΔWT LBS | |
| I | 2986 | 994 | 59.02 | -28.77 | 35 |
| II | 2680 | 688 | 58.46 | -29.33 | 23 |
| III | 4473 | 2481 | 58.26 | -29.53 | 84 |
| IV | 3915 | 1923 | 57.58 | -30.21 | 64 |
| V | 4491 | 2499 | 64.48 | -23.31 | 107 |
| VI | 3933 | 1941 | 63.80 | -23.99 | 81 |
| VII | 1992 | BASE | 87.79 | BASE | BASE |

←
RECOMMENDED
CONCEPT

TABLE H-4. COST-WEIGHT TRADE-OFF SUMMARY FOR TITANIUM FUSELAGE SHEAR-PANEL TRADE-STUDY

| CONCEPT | COST | | WEIGHT | | COST OF WEIGHT SAVED— \$/LB |
|---------|----------|-----------|-----------|---------|--------------------------------|
| | \$/PANEL | Δ\$/PANEL | LBS/PANEL | ΔWT LBS | |
| I | 2986 | 306 | 59.02 | +0.56 | ① |
| II | 2680 | BASE | 58.46 | BASE | BASE |
| III | 4473 | 1793 | 58.26 | -0.20 | 8965 |
| IV | 3915 | 1235 | 57.58 | -0.88 | 1403 |
| V | 4491 | 1811 | 64.48 | +6.02 | ① |
| VI | 3933 | 1253 | 63.80 | +5.34 | ① |
| | | | | | |

←
RECOMMENDED
CONCEPT

① GREATER WEIGHT AND GREATER COST.

APPENDIX I

COMPOSITE FUSELAGE PANEL MANUFACTURING COST/DESIGN TRADE STUDY

OBJECTIVES OF AIRFRAME TRADE STUDIES

A series of fuselage shear panels was analyzed with regard to weight and manufacturing cost by three airframe industry team members, utilizing the manufacturing man-hour data presented on design-oriented formats in the three demonstration sections described earlier in this report, i.e., "Sheet-Metal Aerospace Discrete Parts", "Mechanically Fastened Assemblies", and "Advanced Composites Fabrication".

The primary objectives of the fuselage shear panel trade studies were to:

- Demonstrate the use of the MC/DG in an industrial environment designing typical airframe structures
- Determine whether the manufacturing cost (man-hour) formats, providing CDE and CED information, meet the format design criteria established for their development
- Determine whether the CDE and CED formats provide the accuracy required by designers in conducting comparisons of airframe configurations utilizing both metallic and composite materials.

Fuselage panel designs were studied in the following structural materials by the design departments in each of the three companies:

- Aluminum alloy - by General Dynamics Corporation, Fort Worth Division
- Titanium alloy - by Lockheed-California Company
- Graphite/epoxy - by Rockwell International, Los Angeles Division.

The fuselage panel trade studies were critically reviewed by:

- Boeing Commercial Airplane Company
- Northrop Corporation, Aircraft Group.

Composite Fuselage Shear Panel Trade Study

This appendix presents the details of the trade study conducted on the advanced composite (graphite/epoxy) fuselage panel. This trade study followed the six steps detailed in the main body of the report for cost/weight trades. These six steps are:

- (1) Concept Development
 - Skin panel sizing
 - Frame shape selection
 - Number of frames required
 - Stringer shapes
 - Number of stringers required
 - Candidate manufacturing methods to produce each discrete part
- (2) Determination of manufacturing cost for each panel configuration
- (3) Determination of assembly costs for each configuration
- (4) Determination of weight (lbs) for each panel configuration
- (5) Determination of total manufacturing cost, including materials and tooling
- (6) Presentation of manufacturing man-hours and structural weight on design charts and tables to facilitate selection of the cost-effective designs.

The choice of the fuselage panel for the trade study part is quite appropriate, as this is a promising application for advanced composite materials. The advantages offered by advanced composites for fuselages are briefly as follows. Fabrication of fuselage by conventional methods using metallic materials has resulted in problems in areas of cost (acquisitions and life-cycle), weight, maintenance, crashworthiness, and fatigue resistance. Use of lightweight sandwich panels has increased stiffness, but complicated corrosion and damage control and repair. A large quantity of parts and fasteners typical of metallic assemblies also impacts ownership costs (approximately 75 percent) and life-cycle costs

(approximately 50 percent). Utilization advanced composite materials structures has provided both weight and cost savings in primary structures. New approaches for implementation on advanced tactical aircraft have shown large potential reductions in manufacturing cost with significant impact also on the life-cycle cost of structures such as fuselages.

The material used in this trade study was AS/3501-6, as specified in the ground rules set forth by the BCL/airframe industry team members at the start of the program. The design assumptions for this trade study, specified a panel 36 inches wide by 72 inches long, with single curvature of 60-inch radius. A balanced ply layup with quasi-isotropic skin was selected. The spacing of the structural members was specified as 12 to 24 inches for the frames and 4 inches minimum for the stringers. Assembly was to be performed utilizing titanium Hi-Lock fasteners or by cocuring.

The limit loading conditions were:

- $N_{x(\text{comp})} = 2000 \text{ lb/in}$
- $N_{xy} = 121 \text{ lb/in}$
- Shear buckling was not permitted.

A temperature of 300 F and a dry environment were also specified.

Figure I-1 shows that three basic categories of configurations were considered. These categories are:

- Light weight/high complexity
- Moderate weight/moderate complexity
- High weight/low complexity.

In evaluating the concepts, stringer/frame, stringer/skin, and skin variations were considered. The MC/DG was utilized in analyzing the manufacturing costs of these variations, as indicated by the dashed boxes in Figure I-1. Figures I-2 through I-5 show the baseline fuselage panel and the three configuration categories mentioned above.

Three configurations were analyzed within the category of light weight/high complexity (see Figure I-3). In the concepts the number of stringers and frames were varied to determine the optimum combination. Once it was determined that 4 stringers with 3 frames were the best combination, the type of stringer and the method of assembly were determined. Figure I-6 presents a summary of the stringer shapes and assembly methods considered. Also shown in Figure I-6 is the cost in man-hours for each

FIGURE I-1. DESIGN FUNCTION/MC/DG INTERACTION

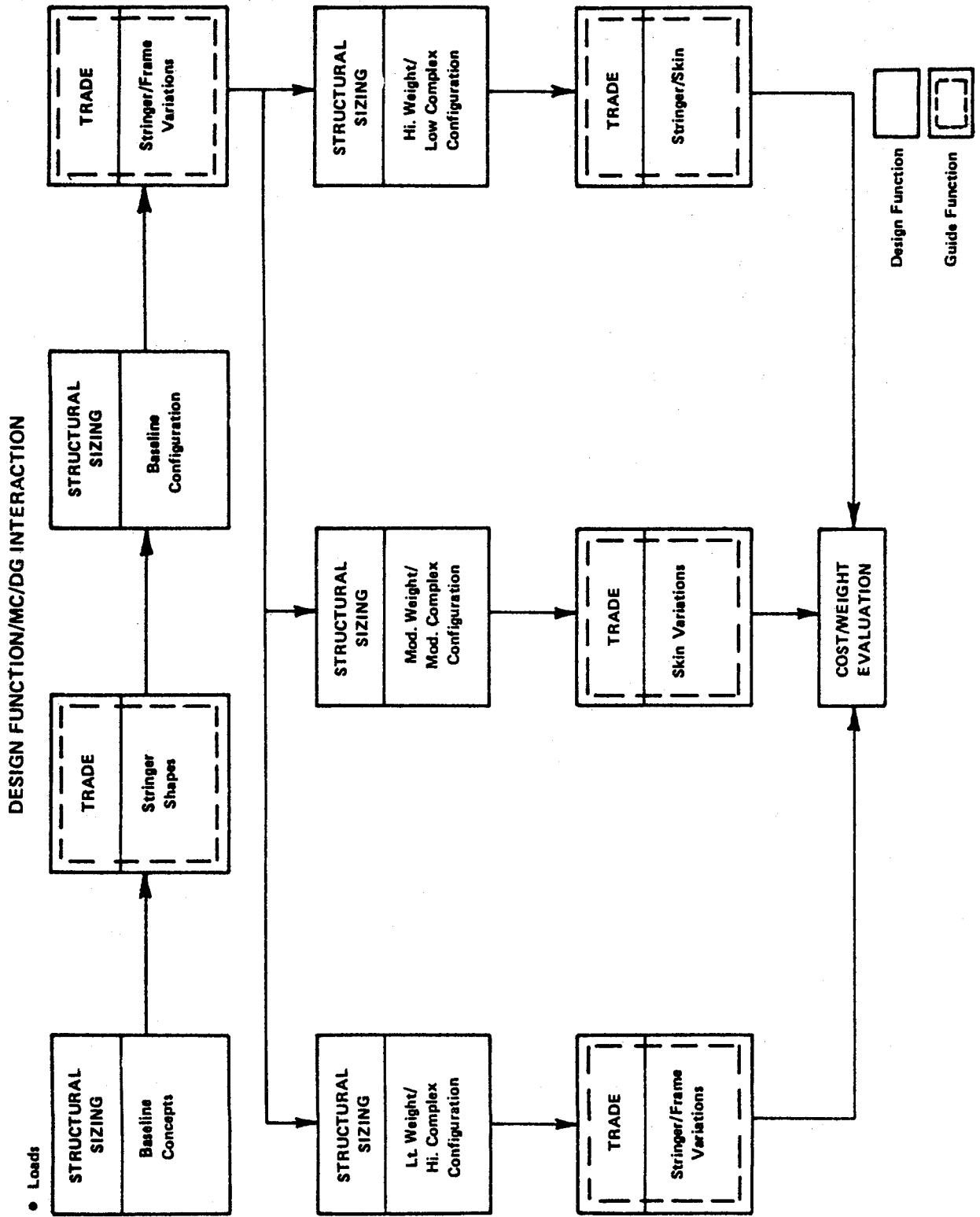


FIGURE I-2. BASELINE FUSELAGE PANEL IN ADVANCED COMPOSITE TRADE-STUDY

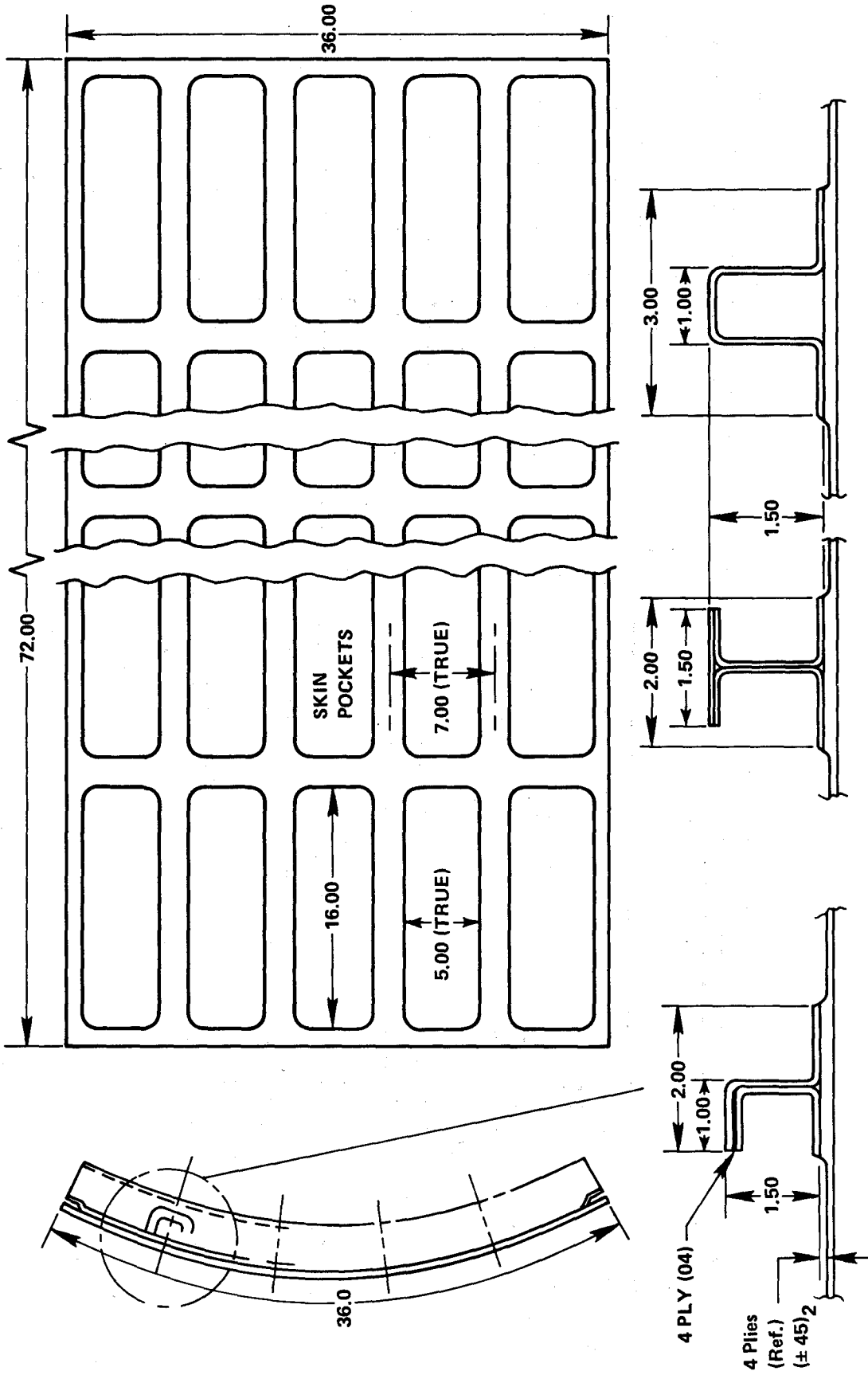
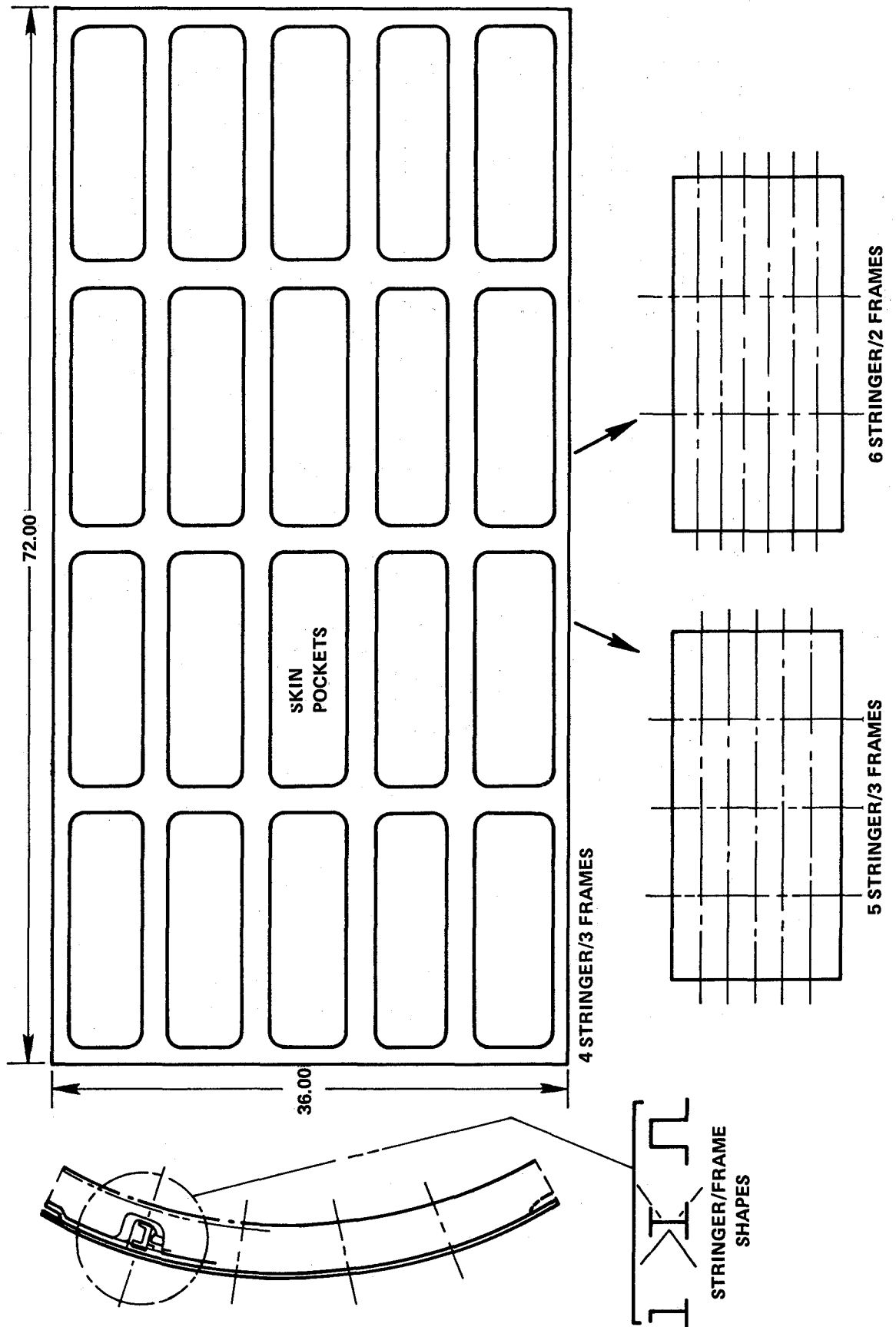
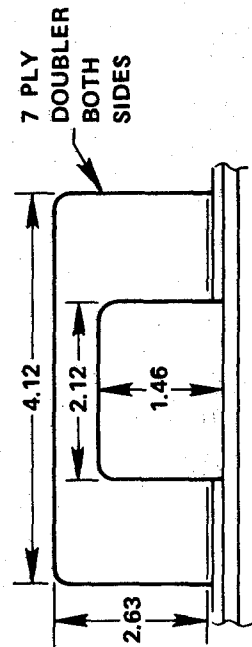
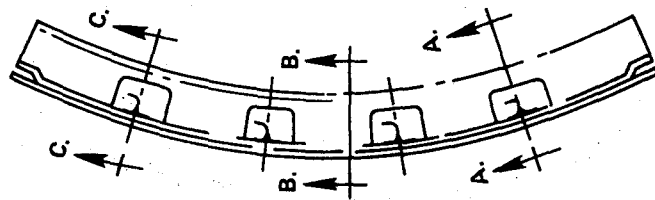
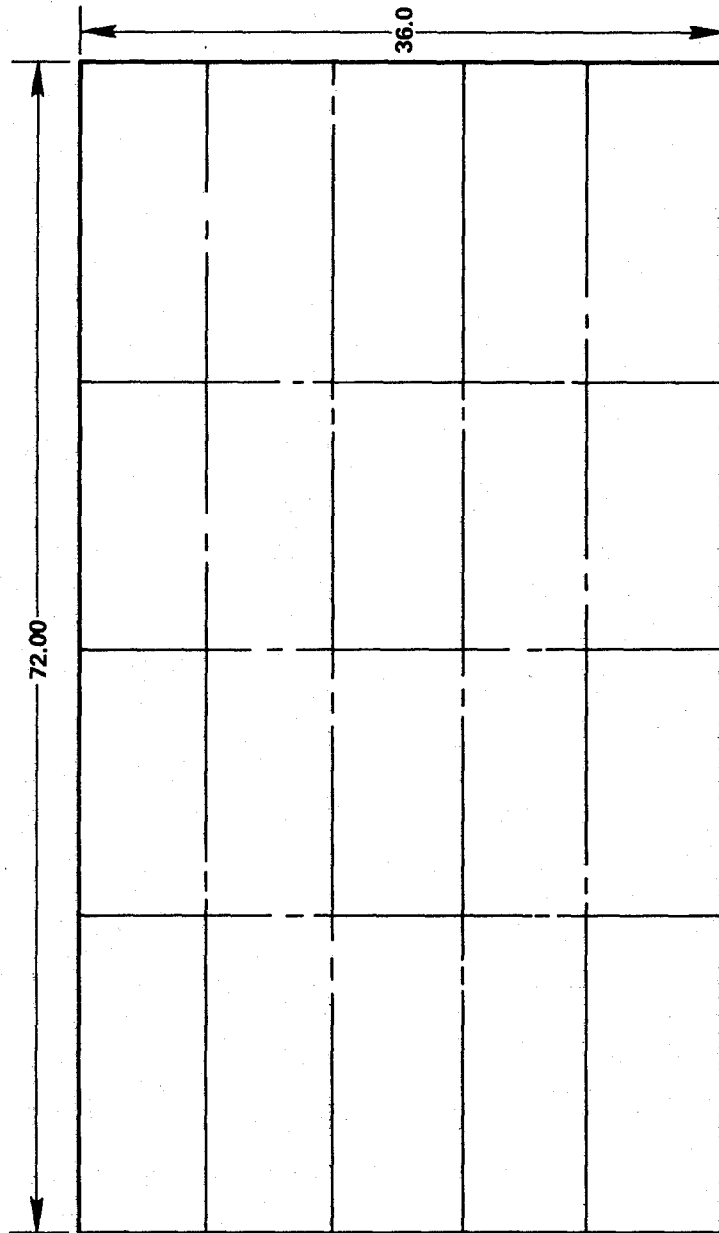


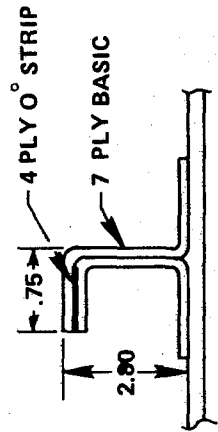
FIGURE I-3. LIGHTWEIGHT/HIGH COMPLEXITY COMPOSITE FUSELAGE PANEL



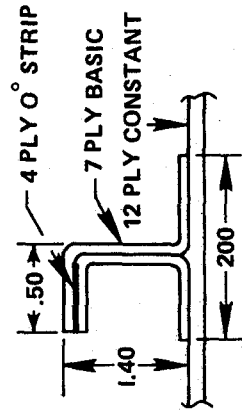
**FIGURE I-4. MODERATE WEIGHT/MODERATE COMPLEXITY COMPOSITE FUSELAGE
PANEL (4 STRINGER/3 FRAME)**



CUT OUT DOUBLER SECTION C-C.



FRAME DETAIL SECTION B-B.



STRINGER DETAIL SECTION A-A.

FIGURE I-5. MINIMUM PART COUNT COMPOSITE FUSELAGE PANEL (PLATE SKIN / 3 FRAMES)

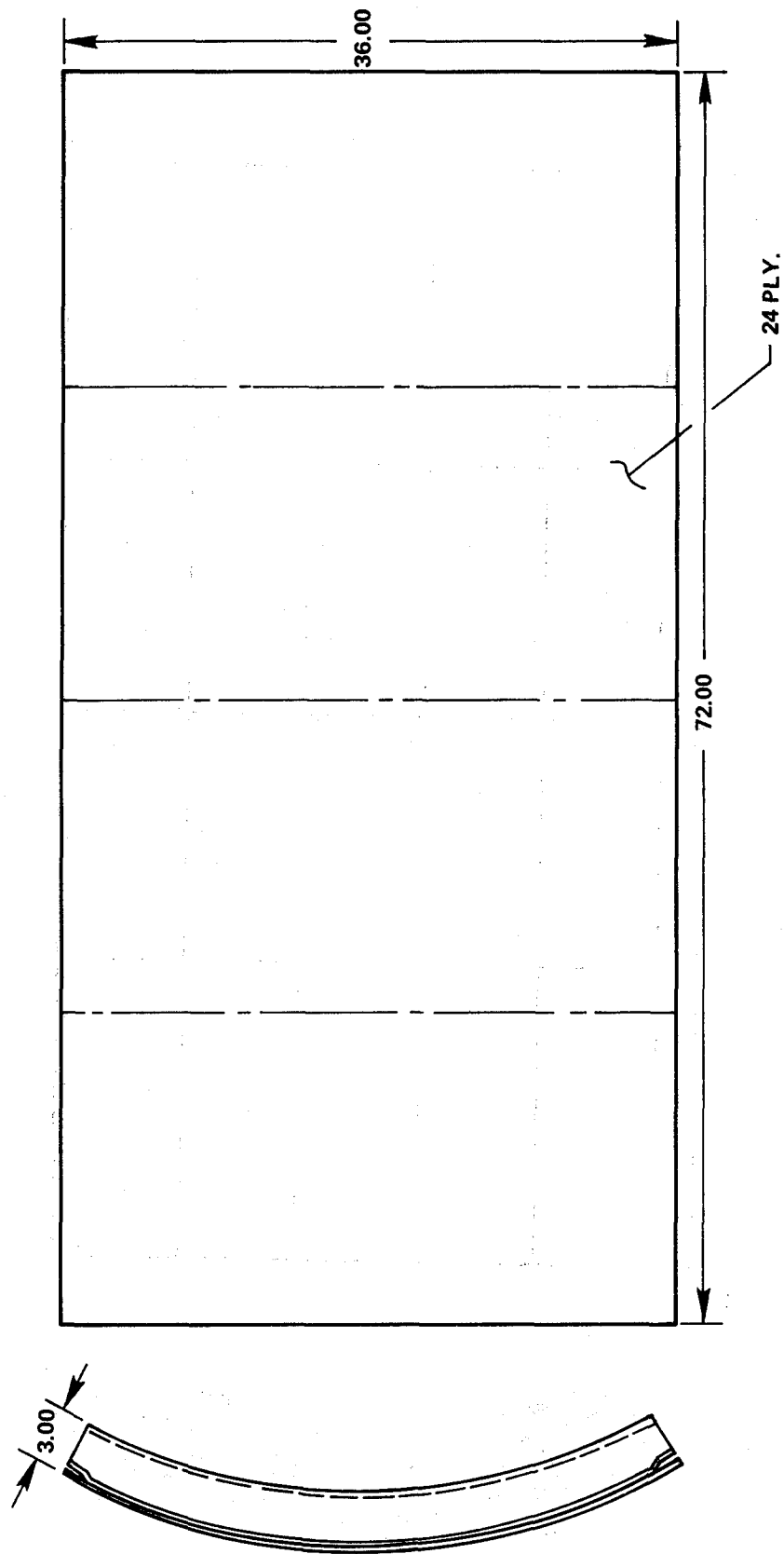
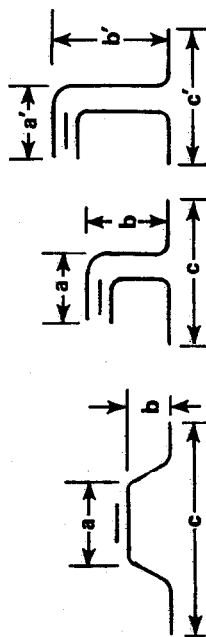


FIGURE I-6. LIGHTWEIGHT/HIGH COMPLEXITY COMPOSITE FUSELAGE CONCEPT
SUMMARY OF DESIGN FEATURES



| CONFIGURATION | STRINGER | | | ATTACHMENT METHOD | FRAME | | | COST, MAN-HOURS | | | | |
|---------------|----------|-----|---------|-------------------|---------|--|------|-----------------|------|----------|----------|----------|
| | TYPE | NO. | a (IN.) | | b (IN.) | c (IN.) | TYPE | | NO. | a' (IN.) | b' (IN.) | c' (IN.) |
| I | HAT | 4 | 1.0 | 1.5 | 3.0 | MECHANICALLY FASTENED (100% MANUAL) | J | 3 | 0.75 | 3.0 | 2.0 | 77.9 |
| II | HAT | 4 | 1.0 | 1.5 | 3.0 | MECHANICALLY FASTENED (80% AUTOMATIC 20% MANUAL) | J | 3 | 0.75 | 3.0 | 2.0 | 61.5 |
| III | J | 4 | 1.0 | 1.5 | 2.0 | COCURED | J | 3 | 0.75 | 3.0 | 2.0 | 51.1 |

concept. Figure I-7 is a plot of these concepts showing weight versus manufacturing man-hours. This figure also shows the relationship of each concept to lines representing specific man-hour per pound values. From these two figures, Configuration III was chosen as most appropriate to represent the light weight/high complexity category in the remainder of the trade study.

A similar methodology was followed to select representative configurations from the other two categories. Figure I-8 provides a summary of the configurations chosen for each category with the cost (in man-hours) and weight of each configuration. Figure I-9 presents this information graphically on a man-hours versus weight scale. Again, lines representing specific man-hour per pound values are shown. Selecting a configuration for production from those summarized could now be accomplished, depending on the relative importance of weight and cost, as well as other design factors for the aircraft under consideration.

In a case where two or more concepts appear to be very close in the cost/weight trade, a detailed cost estimate would need to be performed by cost estimators. This, combined with other factors, would allow the design team to select the most cost competitive design which still meets all other design parameters.

This trade study provided an opportunity to utilize a number of the designer-oriented formats presented in the advanced composites demonstration section of the MC/DG. The formats from the demonstration section used in the conduct of this trade study are listed in Table I-1.

The results of the trade study were independently reviewed by the Boeing Commercial Aircraft Company and by Northrop Corporation's Aircraft Group. These companies studied the results to determine if the accuracy provided by utilizing the MC/DG formats was sufficient to provide a meaningful trade study, and that the trade studies represented the intent of the Air Force for the demonstration of the use of the MC/DG.

FIGURE I-7. RESULTS FOR LIGHTWEIGHT/HIGH COMPLEXITY ADVANCED COMPOSITE CONCEPT

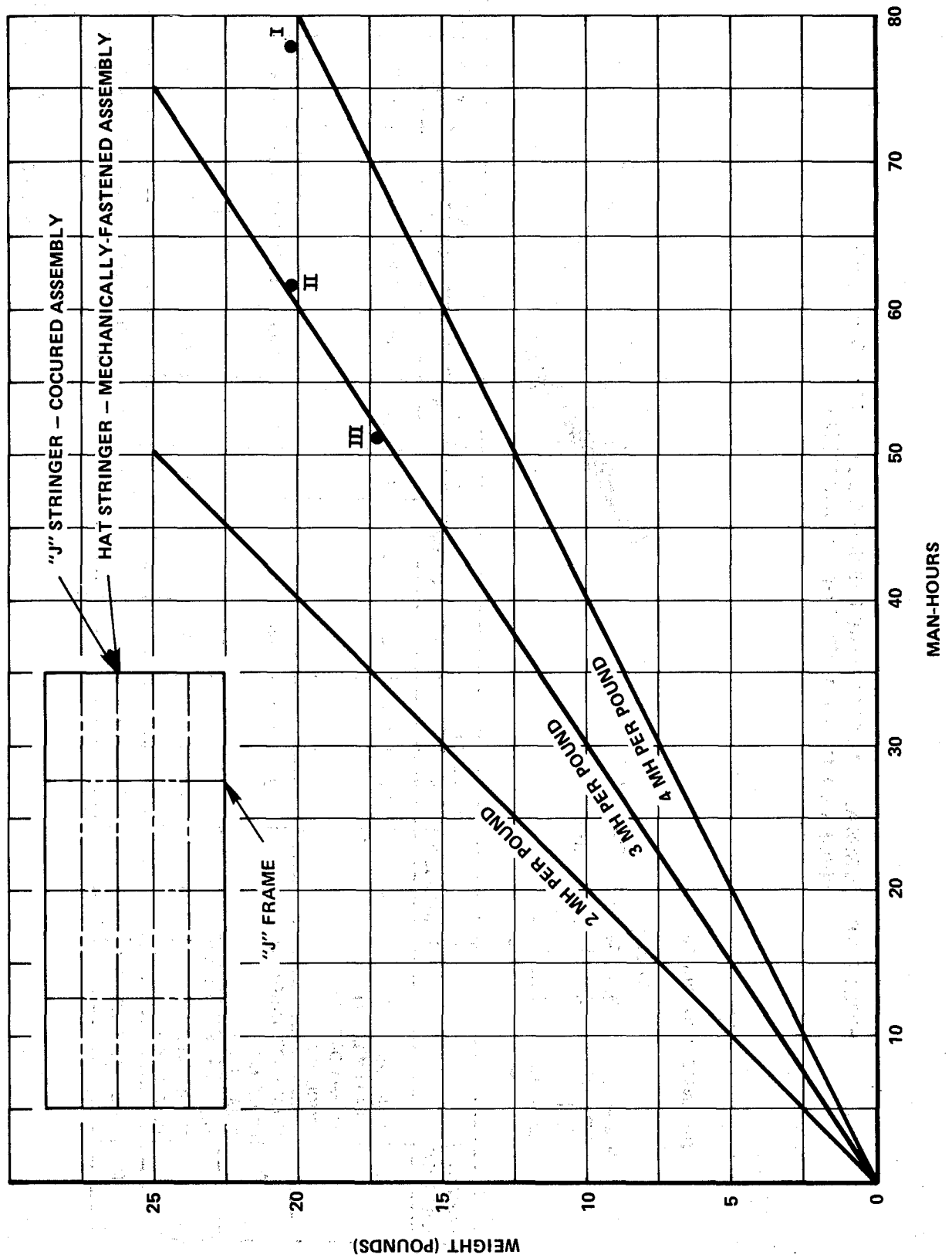
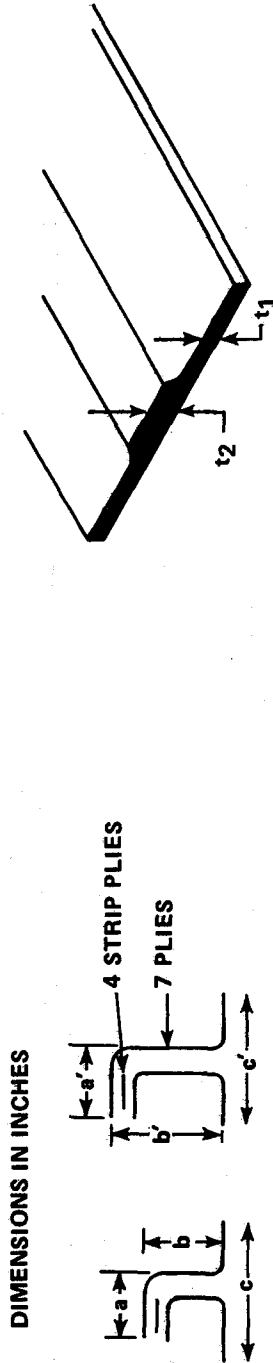


FIGURE I-8. SUMMARY OF MANUFACTURING COST (MAN-HOURS) AND WEIGHT OF COMPOSITE CONFIGURATIONS



| CONFIGURATION | STRINGERS | | | FRAMES | | | | SKIN | | *MAN-HOURS | WEIGHT, LB | |
|---------------|-----------|------|------|--------|--------|-----|------|------|----------------|------------|------------|----------------|
| | NUMBER | a | b | c | NUMBER | a' | b' | c' | t ₁ | | | t ₂ |
| A | 4 | 1.00 | 1.50 | 2.00 | 3 | .75 | 3.00 | 2.00 | 8 PLY | 12 PLY | 51.10 | 17.45 |
| B | 4 | .50 | 1.40 | 2.00 | 3 | .75 | 2.80 | 2.00 | 12 PLY | 12 PLY | 49.20 | 17.65 |
| C | 3 | 1.00 | 1.60 | 2.00 | 3 | .75 | 3.20 | 2.00 | 12 PLY | 12 PLY | 48.04 | 18.80 |
| D | 0 | 0 | 0 | 0 | 3 | .75 | 3.00 | 2.00 | 24 PLY | 24 PLY | 34.79 | 22.50 |

*RECURRING + NON-RECURRING
200

FIGURE I-9. SUMMARY OF RESULTS IN ADVANCED COMPOSITE FUSELAGE SHEAR-PANEL TRADE—STUDY

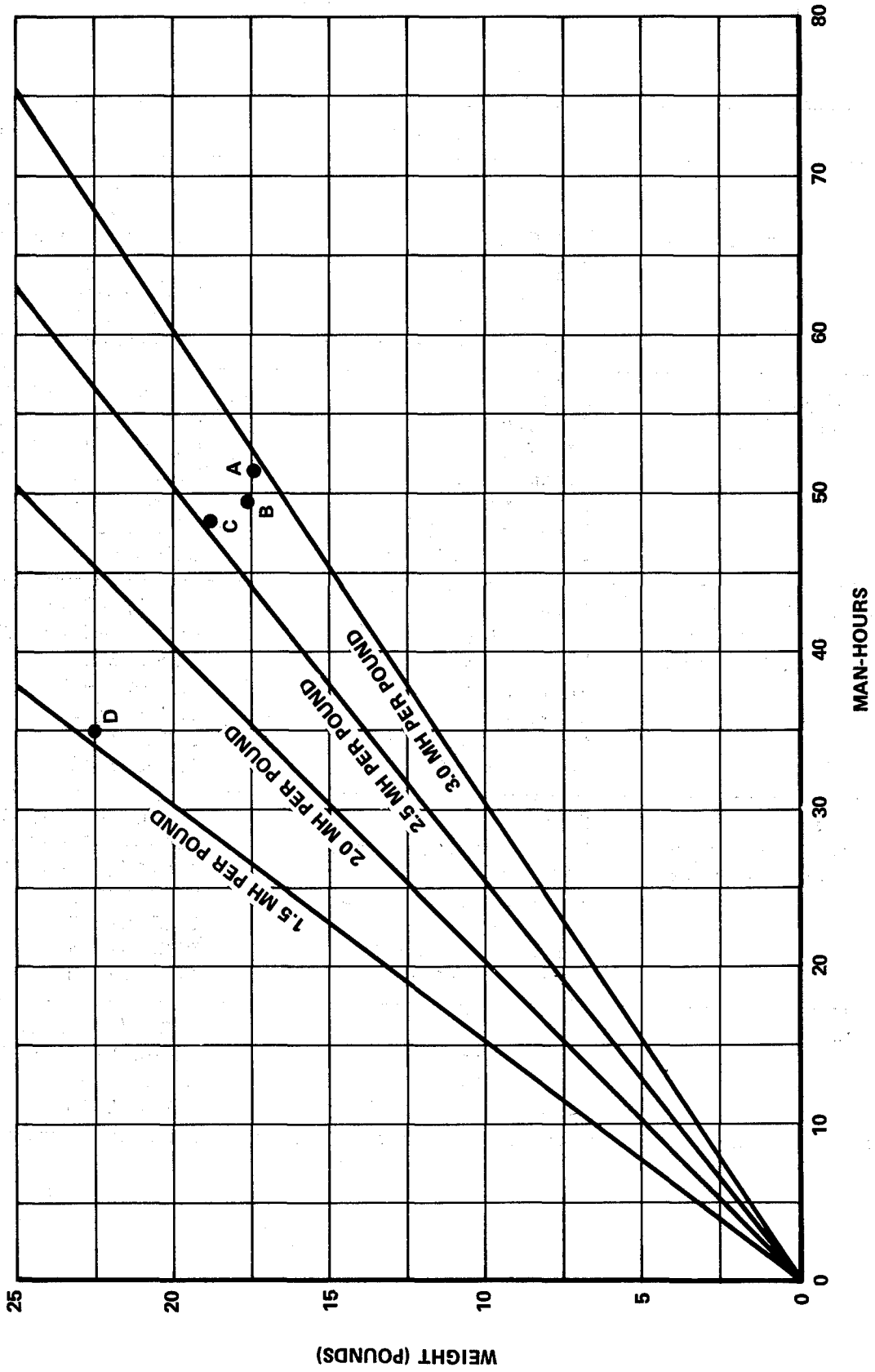


TABLE I-1. ADVANCED COMPOSITES TRADE STUDY

Formats Utilized

| Concept | Cost Item | Format Number |
|---|-----------------------|-------------------------|
| Lightweight/High Complexity Mechanically-Fastened | Skin | CED-G/E-7 and CED-G/E-8 |
| | Hat Stringers | CED-G/E-1 and CED-G/E-2 |
| | "J" Frames | CED-G/E-3 and CED-G/E-4 |
| | Strip Plies | DICE-G/E-1 |
| | Cut-outs | DICE-G/E-2 |
| | Cut-out Doublers | DICE-G/E-4 |
| | Assembly (Mechanical) | CED-MFA-2 and CED-MFA-3 |
| Lightweight/High Complexity Cocured | Skin | CED-G/E-7 and CED-G/E-8 |
| | "J" Stringers | CED-G/E-3 and CED-G/E-4 |
| | "J" Frames | CED-G/E-3 and CED-G/E-4 |
| | Strip Plies | DICE-G/E-1 |
| | Cut-outs | DICE-G/E-2 |
| | Cut-out Doublers | DICE-G/E-4 |
| | Assembly (Cocured) | CED-G/E-10 |
| Moderate Weight/ Moderate Complexity 4 Stringers/3 Frames | Skin | CED-G/E-7 and CED-G/E-8 |
| | "J" Stringers | CED-G/E-3 and CED-G/E-4 |
| | "J" Frames | CED-G/E-3 and CED-G/E-4 |
| | Strip Plies | DICE-G/E-1 |
| | Cut-outs | DICE-G/E-2 |
| | Cut-out Doublers | DICE-G/E-4 |
| | Assembly (Cocured) | CED-G/E-10 |
| Moderate Weight/ Moderate Complexity 3 Stringers/3 Frames | Skin | CED-G/E-7 and CED-G/E-8 |
| | "J" Stringers | CED-G/E-3 and CED-G/E-4 |
| | "J" Frames | CED-G/E-3 and CED-G/E-4 |
| | Strip Plies | DICE-G/E-1 |
| | Cut-outs | DICE-G/E-2 |
| | Cut-out Doublers | DICE-G/E-4 |
| | Assembly (Cocured) | CED-G/E-10 |
| Minimum Part Count | Skin | CED-G/E-7 and CED-G/E-8 |
| | "J" Frames | CED-G/E-3 and CED-G/E-4 |
| | Strip Plies | DICE-G/E-1 |
| | Assembly | CED-G/E-10 |

The following conclusions resulted from the independent review:

- The practicability of the MC/DG was demonstrated
- MC/DG provides a quick, efficient designer's tool which:
 - Develops costs to identify lower-cost designs
 - Reduces design time for screening candidate design
 - Improves schedule compliance
- Use of MC/DG in obtaining manufacturing costs and performing simple cost estimates was well demonstrated
- Demonstrated selection criteria of dollars/pound weight saved
- Fully demonstrated use of MC/DG in developing cost/weight effective designs
- Wider coverage needed to expand data base for manufacturing technologies, structural configurations, and composite material types.

With regard to the presentation of the manufacturing technology man-hour data, the following conclusions were arrived at by the aerospace companies:

- Utilized costing methodology, developed program dollar costs, used material, labor, and tooling costs
- Cost/weight summary chart and recommendations are of particular merit.

APPENDIX J

USERS' NEEDS SURVEY OF AIRCRAFT INDUSTRY DESIGNERS FOR A COMPUTERIZED ICAM MC/DG

ICAM "Manufacturing Cost/Design Guide" (MC/DG) Users' Needs Survey

A survey of aerospace industry designers was conducted as part of the second contract (F33615-77-C-5027) awarded Battelle's Columbus Laboratories (BCL) by the Computer Integrated Manufacturing Branch, Materials Laboratory (AFWAL/MLTC). The objectives of this survey were to determine what should be included in the MC/DG, the form of the information (e.g., x-y graphs, bar charts, text, etc.), and designers' attitudes and needs regarding the provision of the information in an interactive-computerized form, in addition to a hard-copy version. Two preliminary designers and two detail designers from seven major aerospace firms were asked to complete the survey. The companies involved were:

- Boeing Commercial Airplane Company
- General Dynamics Corporation, Fort Worth Division
- Grumman Aerospace Corporation
- Lockheed-California Company
- Northrop Corporation, Aircraft Group
- Rockwell International, North American Aircraft Division
- Vought Corporation

Each designer completing the survey was first given a briefing on the MC/DG covering key items such as: the Objectives of the MC/DG, the Development Criteria, and Definitions and Examples of Cost-Driver Effects (CDE) and Cost-Estimating Data (CED). An example survey form is included in Pages J-12 through J-21.

The final completed surveys were received at Battelle's Columbus Laboratories on July 7, 1978. The completed surveys were analyzed by BCL staff, and the results used to guide the development of the demonstration sections of the MC/DG. The survey was designed such that the majority of the responses could be summarized in a tabular form. The results have been categorized and are displayed as Tables 1 through 3. Several questions were such that the results could not be easily displayed in a tabular form.

The responses to these questions are summarized following Tables 1 through 3.

In addition to responding to the questions on the survey form, the designers were encouraged to comment on their view of what the MC/DG should be and how best to accomplish that goal. A number of these comments are summarized below.

Design Activities

- The MC/DG could be used in all phases of design from conceptual through detail design.
- The most time-consuming functions of the designer are drafting and creative/conceptual activities.
- The most frequently consulted cost data/information sources are graphs of standard parts and materials.
- It would take a directive from either management or the customer to make design-to-cost a major consideration in the design program relative to performance and scheduling requirements.

Format

- The MC/DG should be easy and quick to use.
- Most of those interviewed felt that the MC/DG should be structured so as to guide the designer through the process. This feature would be very beneficial to inexperienced engineers.
- The most preferred presentation modes for MC/DG information are x-y graphs and text.

Computerized MC/DG

- Most designers surveyed have used computerized job aids previously and found them generally helpful, but they do not use them frequently (partially due to management constraints).
- Most designers surveyed felt that a computerized MC/DG would help most in performing trade studies and designing-to-cost in the creative/conceptual design phase.
- The ability to store, in the computer, parts as members of a subassembly and the ability to use design and analysis programs while utilizing the computerized MC/DG were considered valuable.

Hard Copy of MC/DG

- The designers seem to indicate that the MC/DG would be utilized almost equally in the conceptual, preliminary, and detail design phases.
- The hard copy of the MC/DG would be applied in all phases of design as an aid in the selection and evaluation of configurations, for performing trade studies on components, and as a reference manual.
- The support groups for which the MC/DG would be most useful are the following:
 - Structural analysis
 - Manufacturing and producibility
- Designers felt that the hard copy of the MC/DG would be used more than the computerized guide. However, this could be changed by management if they are provided evidence that a computerized guide could speed up the design process. The need is evident to sell computer-aided design to management and convince them to invest in sufficient

computer hardware and software to ensure the availability and usefulness of the computer to the designer.

This survey provided the required guidance to the BCL/airframe industry team developing the Manufacturing Cost/Design Guide so that the MC/DG would be acceptable to the intended users, the aerospace design engineers.

TABLE 1. GENERAL QUESTIONS IN SURVEY ON MC/DG

Number of Responses for Each Question Indicated: (XX)

| Question Number | Question | Response Categories | Total Number of Responses |
|-----------------|---|--|---------------------------|
| 1 | With what aerospace systems are you involved? | Military aircraft (24) Commercial aircraft (12) Spacecraft (2) | 38 |
| | | Large aircraft (15) Medium aircraft (12) Small aircraft (15) | 42 |
| | | Fighter (17) Bomber (6) Attack (12) Cargo (7) Helicopter (1) Missile (4) | 51 |
| | | Other (4) | |
| 2 | At what stage are you in the development cycle? | Research & Development (6) Conceptual Design, Preliminary Design (15) Design Sizing (17) Design Refinement, Design Verification (18) | 84 |
| | | Production Go-Ahead (1) Detail Design (18) Product Manufacture, Product Verification (4) Support (5) | |
| 3 | Primarily a designer of - | Systems (5) Sub-assemblies (14) Parts (15) Other (3) | 82 |
| | | Fuselages (20) Wings (20) Landing Gear (2) Power Plant (0) Other (3) | |
| 4 | Design Experience | 0-5 years (2) 5-10 years (3) 10-20 years (8) Over 20 years (13) | 26 |
| 9 | Would a hard copy of the MC/DG be required for | Personal use (15) Group use (13) Department use (0) | 28 |
| 12 | Should a listing of DICE(1) be included? | Yes (22) No (0) Maybe (4) | 26 |

TABLE 1. GENERAL QUESTIONS IN SURVEY ON MC/DG (Continued)

| Question Number | Question | Response Categories | | | Total Number of Responses | |
|-----------------|---|---------------------|------------|----------------|---------------------------|----|
| 13 | Should CDE(2) and CED(3) be displayed in the MC/DG? | Yes (23) | No (0) | Maybe (3) | 26 | |
| 15 | Should the MC/DG be structured to guide the designer through the process? | Yes (24) | No (0) | Maybe (3) | 27 | |
| 16 | How often would you use the MC/DG if it were available? | Hard Copy: | Often (17) | Sometimes (11) | Never (1) | 29 |
| | | Computerized: | Often (3) | Sometimes (19) | Never (5) | 27 |

(1) DICE refers to designer-influenced cost elements.

(2) CDE refers to cost-driver effects.

(3) CED refers to cost-estimating data.

TABLE 2. DATA SOURCES, RETRIEVAL AND PRESENTATION

Percentage, frequency, or relative values responses or averages indicated: (XX)

| Question Number | Question | Response Categories | Total Number of Responses |
|-----------------|--|--|---------------------------|
| 6 | Which functions are most time consuming? (% of time) | <p>Response Categories</p> <p>Data Gathering (11) Data Browsing (6) Verification of data accuracy, age, and reliability (4) Statistical analysis of data (2)</p> <p>Interpreting retrieved data (4) Drafting (31) Cost analysis/trade-off or design-to-cost (8) Creative/Conceptual (30)</p> <p>Other (7)</p> | 29 |
| 8 | Which cost data/information resources are used and how frequently? Note: Rating indicated - () | <p>Rating system used: 1 - constantly 2 - daily 3 - 2 or 3 times a week 4 - weekly 5 - bi-weekly 6 - monthly 7 - rarely</p> <hr/> <p>Vendor catalogs (6) Handbooks, manuals, guides (3) Tables (4) Reference books (5) Trade Publications (6)</p> <p>Research journals, papers (7) In-house standard parts and shapes lists (3) Cost estimation handbooks (6) Computerized system (6)</p> <p>Other (4)</p> | 26 |
| 10 | Where are most of your sources stored, and in what form? Note: Distance indicated - (yds) | <p>Your office/desk, group, department or area: Average distance (14 yds) Hard copy (25) Microform (9) On-line computer terminal (9)</p> <p>Company Library: Average distance (52 yds) Hard copy (25) Microform (13) On-line computer terminal (1)</p> | 43 |
| | | | 37 |

TABLE 2. DATA SOURCES, RETRIEVAL AND PRESENTATIONS (Continued)

| Question Number | Question | Response Categories | Total Number of Responses |
|-----------------|--|---|---------------------------|
| 10 (Cont'd) | Where are most of your sources stored, and in what form? <u>Note:</u> Distance indicated - (yds) | Other in-house research facility: Average (80 yds) distance Hard (10) copy Microform (8) On-line computer terminal (4) Outside sources: Average (40 yds) distance Hard (2) copy Microform (1) On-line computer terminal (0) | 22 |
| 11 | Prioritize cost data/information in order of frequent usage <u>Note:</u> frequency indicated - () (1 most frequent to 7 least frequent) | <u>Display Mode</u> Statistical (4) Formulas (4) Text (4) Index (5) Charts (3) Graphs (3) Other (6) <u>Topic of Data</u> Standard parts list (2) Standard shapes list (3) Standard materials (2) Formability (4) Tolerance data (4) Surface treatment data (5) Other (7) | 25 |
| 14 | What is your expected presentation mode for the hard copy MC/DG? Rate value of each (1 very valuable to 5 no value) <u>Note:</u> Value indicated - () | Tables (3) x-y graphs (2) Bar charts (3) Pie charts (4) Text (including instructions) (3) Equations (cost tradeoff, etc.) (3) Line drawings (parts illustrations) (3) | 26 |

TABLE 3. EXPERIENCE/ATTITUDES CONCERNING COMPUTERS

Responses or Averages Indicated: (XX)

| Question Number | Question | Response Categories | Total Number of Responses |
|-----------------|---|--|---------------------------|
| 1 | Have you used computerized job aids? | Yes (20) No (6) | 26 |
| | How frequently? | Often (4) Sometimes (13) Rarely (4) | 21 |
| | When did you last use a computerized job aid? | During last week (6) Last month (8) Years ago (7) | 21 |
| 2 | Have the aids been | Very helpful? (14) Somewhat helpful? (5) Of not much use? (2) | 21 |
| | What is your attitude towards using computerized job aids? | Eager (13) Would use (12) Feel uncomfortable using (5) to sometimes Because: Too hard (4) Too much training (3) use Not reliable (0) Other (5) | 30 |
| 3 | How much time could you be authorized to spend learning a new computerized job aid? | Up to 1/2 day (3) 1/2 to 1 day (4) 2 to 7 days (11) More (0) | 18 |
| 4 | What equipment do you have available? | Computers: IBM (19) CDC (9) UNIVAC (0) DEC (3) Other (6) | 37 |
| | | On-line terminals: Teletype (5) Hazeltine (1) Texas Instruments (2) IBM (8) Other (8) | 24 |
| | Graphic display terminals: CRT (Video) (9) Calcomp (5) Tektronix (7) Other (11) | 32 | |

TABLE 3. EXPERIENCE/ATTITUDES CONCERNING COMPUTERS (Continued)

| Question Number | Question | Response Categories | Total Number of Responses |
|-----------------|--|---|---------------------------|
| 5 | What would you accept as an <u>average wait</u> for access to the computer? | (4.0) hours | 18 |
| 6 | Would the ability to store parts as <u>sub-assemblies</u> in a special file be | Very valuable? (6) Valuable? (8) Somewhat valuable? (9) Useless? (1) | 24 |
| 7 | Would the ability to use design and analysis programs with the MC/DG be | Very valuable? (3) Valuable? (14) Somewhat valuable? (6) Useless? (0) | 23 |
| 8 | Are programs maintained by a computer center or by you? | You (2) Computer center (9) Both (8) | 19 |

Summary of Responses to Questions that
Could Not be Presented in a Tabular Form

Question 5. What emphasis do you place on manufacturing cost in contrast to weight, schedule, and performance? What would it take to place it as number one priority?

Answer. Performance appears to be the primary design criteria, with weight and schedule being of about equal importance with cost.

It would take a management directive (possibly forced by the customer) to encourage the designers to consider cost with higher priority.

Question 7. What part of your design work could be helped by utilizing a computerized MC/DG?

Answer. Most designers surveyed felt that a computerized MC/DG would be most helpful in performing trade studies, designing to cost, data gathering, and in the creative/conceptual design phases.

Question 17. How do you feel you would be able to utilize the hard-copy MC/DG in your job?

Answer. The hard-copy MC/DG could be used in all phases of design as an aid in the selection and evaluation of configuration, as well as for performing trade studies and as a reference manual.

Question 18. What support groups do you feel would most benefit by access to the hard-copy MC/DG?

Answer. The support groups mentioned most were:

- stress and structural analysis
- manufacturing and producability
- weight
- value

Question 19. Which part of your design work could be helped by utilizing a hard-copy MC/DG?

Answer. The part of design work that would be aided most by the use of the MC/DG was almost equally spread over conceptual, preliminary, and detail design.

ICAM
 "MANUFACTURING COST/DESIGN GUIDE"
 (MC/DG)
 USERS' NEEDS SURVEY

A "Manufacturing Cost/Design Guide (MC/DG)" is being prepared to aid structural designers in developing lower cost airframes. Since the primary users of the MC/DG will be designers, it is important that the needs of the structural designers are fully considered. Therefore, it would be very helpful if you, the designer and support groups, would assist us in completing this survey. Please make any comments on the MC/DG that you may have.

1. On what type of aircraft do you work? (Please check more than one, if appropriate.)

| | | | |
|-------------------------------------|---------------------------------|----------------------------------|--|
| <input type="checkbox"/> Military | <input type="checkbox"/> Large | <input type="checkbox"/> Fighter | <input type="checkbox"/> Helicopter |
| <input type="checkbox"/> Commercial | <input type="checkbox"/> Medium | <input type="checkbox"/> Bomber | <input type="checkbox"/> Missile |
| | <input type="checkbox"/> Small | <input type="checkbox"/> Attack | <input type="checkbox"/> Other (Specify) |
| | | <input type="checkbox"/> Cargo | _____ |
| | | | _____ |

2. On the following page is a diagram of the development cycle for an aircraft system. Please indicate where your design activities occur in this cycle: _____

3. Do you design primarily:

| | |
|--|--|
| <input type="checkbox"/> Systems | <input type="checkbox"/> Fuselages |
| <input type="checkbox"/> Sub-assemblies | <input type="checkbox"/> Wings |
| <input type="checkbox"/> Parts | <input type="checkbox"/> Landing Gear |
| <input type="checkbox"/> Other (Specify) | <input type="checkbox"/> Power Plant |
| _____ | <input type="checkbox"/> Other (Specify) |
| _____ | _____ |
| _____ | _____ |

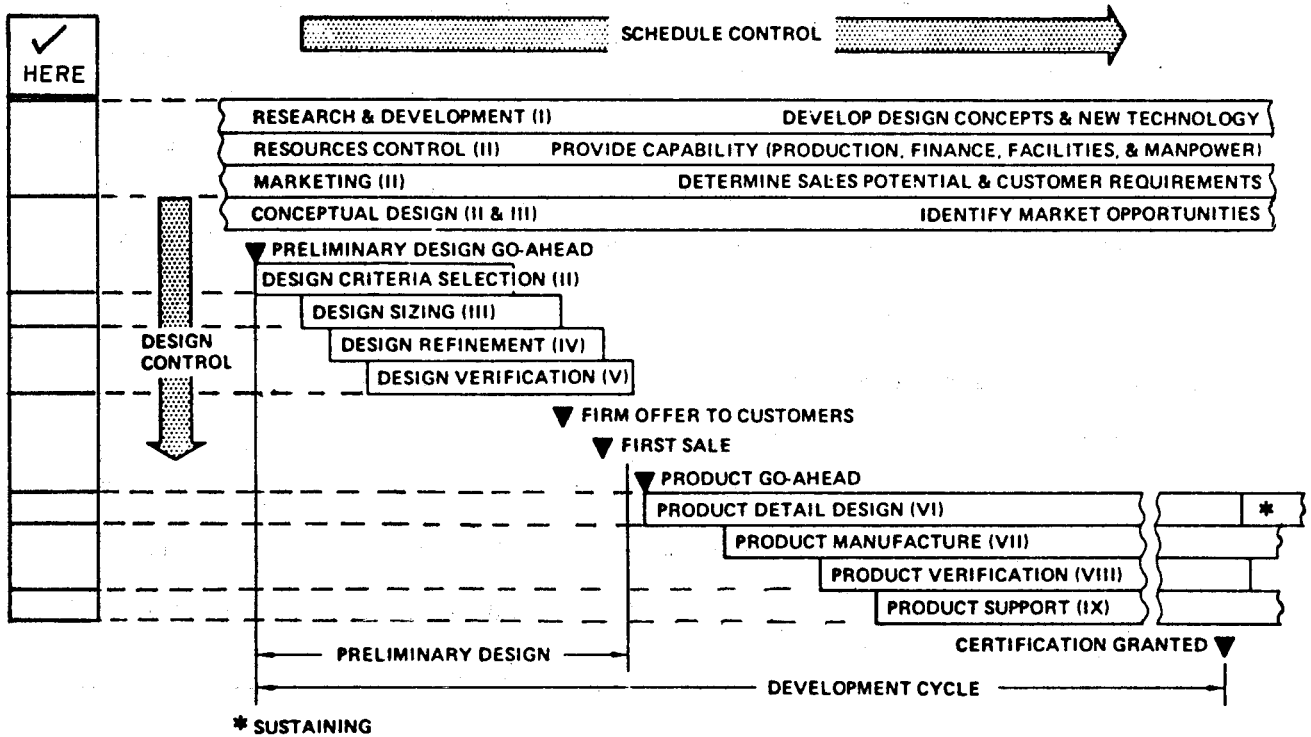


Figure J-1. Development Cycle for an Aircraft System
 ("Reference Design Process", D6-IPAD-70010-D,
 by Donald D. Meyer, Boeing Commercial Airplane
 Company, Contract No. NAS1-14770, March, 1977)

4. How many years' experience do you have as a designer?

_____ Up to 5 _____ 10-20
_____ 5-10 _____ 20+

5. What emphasis do you place on manufacturing cost in contrast to:

_____ Weight
_____ Schedule
_____ Performance

What would it take to place it as No. 1 priority? _____

6. Which function(s) in your design work is (are) the most time-consuming, in your opinion?

(Please fill in the approximate percentage)

| | <u>% of Time</u> |
|---|------------------|
| a. Data gathering | _____ % |
| b. Data browsing | _____ % |
| c. Verification of data accuracy, age, and reliability | _____ % |
| d. Statistical analysis of data | _____ % |
| e. Interpreting retrieved data displayed by means of graphs, charts, etc. | _____ % |
| f. Drafting | _____ % |
| g. Cost analysis/trade-offs or design-to-cost | _____ % |
| h. Creative/conceptual | _____ % |
| i. Other (Specify) _____ | _____ % |

7. Which part of your design work could be helped by utilizing a computerized MC/DG? _____

8. What cost data/information resources do you use to help your design work and to achieve required structural performance, weight, etc.? How often do you use them? E.g., (1) constantly, (2) daily, (3) two or three times a week, (4) weekly, (5) bi-weekly, (6) monthly, or (7) rarely.

| <u>Resources</u> | <u>Frequency</u> |
|---|------------------|
| a. Vendor catalogs | _____ |
| b. Handbooks, manuals, guides | _____ |
| c. Tables | _____ |
| d. Reference books | _____ |
| e. Trade publications | _____ |
| f. Research journals/papers | _____ |
| g. In-house standard parts and shapes lists | _____ |
| h. Cost estimation handbooks | _____ |
| i. Computerized system | _____ |
| (Provide system name _____) | |
| j. Other (Specify) _____ | _____ |

9. Should it be found that the MC/DG is a helpful tool, do you feel that you would want a hard copy for

_____ Your personal use

_____ Group use

_____ Department

10. Where are most of your sources located, and in what form are they stored? (Please indicate distance and description.)

| Location | Distance From Your Location (Yards) | Description | | |
|---|--|-------------|-----------|---------------------------------|
| | | Hard Copy | Microform | On-Line Computer Terminal |
| Your office/desk, group (department), or area | _____ | _____ | _____ | _____ |
| Company library | _____ | _____ | _____ | _____ |
| Other in-house research facility | _____ | _____ | _____ | _____ |
| Outside sources | _____ | _____ | _____ | _____ |

11. Prioritize the type of cost data/information in the order of frequent usage of the following, 1 being the most frequent, 7 being the least frequent:

By Display Mode

| | <u>Frequency</u> |
|--------------------------|------------------|
| a. Statistical Tables | _____ |
| b. Formulas | _____ |
| c. Text | _____ |
| d. Index | _____ |
| e. Charts | _____ |
| f. Graphs | _____ |
| g. Other (Specify) _____ | _____ |

By Topic of Data

| | <u>Frequency</u> |
|--------------------------|------------------|
| a. Standard parts lists | _____ |
| b. Standard shapes lists | _____ |
| c. Standard materials | _____ |
| d. Formability data | _____ |
| e. Tolerance data | _____ |

- f. Surface treatment data _____
- g. Other (Specify) _____

12. After you have chosen a part configuration, would you like to see a listing of design complexities, which would add to the cost? (Examples in Appendix A.)

Yes Comment _____
 No _____
 Maybe _____

13. Would you like to see Cost Driver Effects (CDE) and Cost Estimating Data (CED) displayed in the MC/DG? (Examples for sheet-metal discrete parts appear in the First Interim Report No. IR-701-7(1), February 1978, and explanations of CDE and CED appear in Appendix B.)

Yes No Maybe

Comments _____

14. What type of presentation modes do you expect from the hard-copy MC/DG? Please rate the relative value of each as follows: (1) Very valuable, (2) valuable, (3) useful, (4) limited use, or (5) of no value.

| <u>Relative Value</u> | <u>Mode</u> |
|-----------------------|--|
| _____ | a. Tables |
| _____ | b. X-y graphs |
| _____ | c. Bar charts |
| _____ | d. Pie charts |
| _____ | e. Text (including instructions) |
| _____ | f. Equations (cost tradeoffs, etc.) |
| _____ | g. Line drawings (parts illustrations) |

15. Would you like the MC/DG to be structured to lead the designer through the procedure of the design/cost tradeoff? Will this be helpful to young designers?

| | |
|--------------------------------|----------------|
| <input type="checkbox"/> Yes | Comments _____ |
| <input type="checkbox"/> No | _____ |
| <input type="checkbox"/> Maybe | _____ |

16. How often would you use a MC/DG, if one were available?

| In hard-copy form: | In computerized form: |
|------------------------------------|------------------------------------|
| <input type="checkbox"/> Often | <input type="checkbox"/> Often |
| <input type="checkbox"/> Sometimes | <input type="checkbox"/> Sometimes |
| <input type="checkbox"/> Never | <input type="checkbox"/> Never |

Comments _____

17. How do you feel you would be able to utilize the hard-copy MC/DG in your job? _____

18. What support groups do you feel would benefit by access to the hard-copy MC/DG? _____

19. Which part of your design work could be helped by utilizing a hard-copy MC/DG? _____

Experience/Attitudes Concerning Computers

Consideration is being given to computerizing the MC/DG. Often, when a computerized tool is developed, the users are not consulted, and thus, the program does not meet the needs of the user and subsequently, is not utilized. In order to tailor the computerized MC/DG to the needs of the designer, it is mandatory for us to solicit your ideas and suggestions.

1. Have you used computerized aids in your job? Yes No
If yes, continue answering questions below. If no, state why not:

How frequently did you or do you use these computerized job aids?

Often Sometimes Rarely

Comments

How long ago did you use these computerized job aids?

during last week last month years ago

Have the job aids been:

very helpful sometimes helpful not much use

Please list computerized job aids available for your use and indicate which of those you use most frequently. (Examples are data retrieval, analysis, and drafting.)

If the answer to question 1 is no, please provide comments: _____

2. What is your attitude toward using computerized job aids?

_____ Eager to use them

_____ Would use them sometimes

_____ Feel uncomfortable using because

_____ Too hard to use

_____ Too much training needed

_____ Cannot rely on them

_____ Other (Specify) _____

3. How much time could you be authorized to spend learning to use a new computerized job aid such as the MC/DG?

_____ Up to 1/2 day

_____ 2 to 7 days

_____ 1/2 to 1 day

_____ More (Specify) _____

4. What type(s) of computer system(s)/terminal(s) is(are) available to you at your office or company? _____ Batch _____ Interactive _____ Both
(Indicate more than one choice, if applicable.)

| <u>Computers</u> | <u>On-Line Terminals</u> | <u>Graphic Display Terminals</u> |
|------------------|--------------------------|----------------------------------|
| _____ IBM | _____ Teletype | _____ CRT (Video) |
| _____ CDC | _____ Hazeltine | _____ Calcomp |
| _____ UNIVAC | _____ Texas Inst. | _____ Tektronix |
| _____ DEC | _____ IBM | _____ Other |
| _____ Other | _____ Other | Specify _____ |
| _____ | _____ | _____ |

5. How long do you feel you can wait for access to the computer system?

6. Would you consider the ability to store cost variables of discrete parts as a member of a subassembly, in a special computer file (so that the overall cost of the subassembly could be minimized), to be

- | | |
|--|----------------|
| <input type="checkbox"/> Very valuable | Comments _____ |
| <input type="checkbox"/> Valuable | _____ |
| <input type="checkbox"/> Somewhat valuable | _____ |
| <input type="checkbox"/> Useless | _____ |

7. Would the ability to use your design and analysis computer programs, while operating the computerized MC/DG, be

- | |
|--|
| <input type="checkbox"/> Very valuable |
| <input type="checkbox"/> Valuable |
| <input type="checkbox"/> Somewhat valuable |
| <input type="checkbox"/> Useless |

Comments _____

8. Are your computer programs maintained by a computer center, or do you modify and write your own programs? _____

Comments on information you feel would be needed in the MC/DG, as well as your ideas on how the information in the MC/DG should be presented, would be very helpful (please feel free to add additional sheets, if necessary). Thank you.



DEPARTMENT OF THE AIR FORCE
AIR FORCE RESEARCH LABORATORY
WRIGHT-PATTERSON AIR FORCE BASE OHIO 45433

Rec'd
4/3/2001

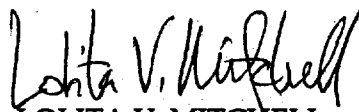
27 March 2001

MEMORANDUM FOR: Defense Technical Information Center/BCS
8725 John J. Kingman Rd, Suite 0944
Ft Belvoir, VA 22060-6218

FROM: Det 1 AFRL/WST (STINFO)
Bldg 640 Rm 60
2331 12th Street
Wright-Patterson AFB OH 45433-7950

SUBJECT: Notice of Change for Technical Reports

1. Reference AFWAL-TR-80-4115, Vol. 3; Title: ICAM Manufacturing Cost/Design Guide, Volume 3: Computerization; AD B206445; and AFWAL-TR-80-4115, Vol. 2, Title: ICAM Manufacturing Cost/Design Guide, Volume 2: Appendices to Demonstration Sections, AD B206444..
2. Please change distribution statement on these reports from Distribution Statement B (US Government agencies only; Test & Evaluation) to Distribution Statement A (Approved for public release, distribution unlimited).
3. Please call me at DSN 785-5197, if more information is needed.


LOLITA V. MITCHELL
STINFO and Tech Editing
Technical Information Branch