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MANUFACTURING COST DATA COLLECTION AND ANALYSIS FOR COMPOSITE PRODUCTION HARDWARE

B.I. Rachowitz
R.J. Coletti
A.J. Tornabe

Grumman Aerospace Corporation
P.O. Box 31
Bethpage, New York 11714

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RICHARD N. MUELLER
Project Engineer

FRANCIS J. JANIK, JR., Chief
Structural Concepts Branch
Structures and Dynamics Division

FOR THE COMMANDER

RALPH L. KUSTER, JR., Colonel, USAF
Chief, Structures & Dynamics Division
Air Force Flight Dynamics Laboratory

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

This technical report documents the procedures used to validate the Advanced Composite Cost Estimating Model, by comparing the model output with actual costs measured during production fabrication. This validation also includes recommendations as to the limitations and improvements that can be made to the model.

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PREFACE

The Grumman Aerospace Corporation, Bethpage, New York, has prepared this report in fulfillment of Contract F33615-77-C-3022 Project Number 1467, for the United States Air Force. The program, titled "Manufacturing Cost Data Collection and Analysis for Composite Production Hardware", was conducted to validate the cost estimates predicted by the model. This was accomplished by comparing model projections to actual costs measured during the fabrication of composite parts produced in a production environment at Grumman. Data recorded during the fabrication of the B-1 Composite Horizontal Stabilizers was used as part of the data base.

The report covers the work accomplished during the period from September 1977 to February 1979 and was submitted by the authors in February 1979.

The work was conducted for the Air Force Flight Dynamics Laboratory, under the direction of Mr. R. Mueller, AFFDL/FBS, whose participation and guidance were instrumental to the success of the program. The Grumman program was conducted by the Grumman Design-To-Cost/Life Cycle Cost team, whose efforts were directed by Mr. B. I. Rachowitz, Manager, Cost Technology Development/Design-To-Cost and Mr. R. Coletti, Program Manager Manufacturing Cost Data Collection and Analysis for Composite Production Hardware Validation Program. Principal contributors to the Grumman activities described in this report and their areas of responsibility are listed below:

Contributors	Responsibility
A. J. Tornabe	Project Engineer
V. Pavlik	Cost Collection and Data Analysis
R. La Manna	Production Supervision, Milledgeville, Ga.
V. Morgan	Cost Estimating
I. Solomon	Project Engineer DTC, R&D Estimating
P. Schwartz	Project Engineer DTC, Cost/Weight Analysis
N. Peckman	Computer Analysis

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SECTION I

INTRODUCTION

Advanced composite materials have been emerging over the last decade showing great advantages for future structural applications. Because of their properties and tailorability, they can be used with advantages in areas that were traditionally all-metal structure. In parallel with this relatively new technology is the emerging cost consciousness within Government and industry. Continuing these two trends, it becomes obvious that an ability to estimate the cost of future aircraft programs means an ability to estimate the effects of using advanced composite structure on aircraft of the future.

Also, the continued application of advanced composites in aircraft structures relies upon its potential for cost and weight savings when compared to conventional materials. However, the lack of reliable cost information has been identified by most sectors of government and industry as a major inhibitor in achieving widespread use of advanced composites. It was for this reason that the Air Force and Navy jointly sponsored the development of the Advanced Composite Cost Estimating Manual (ACCEM - Technical Report AFFDL-TR-76-87 August 1976). The ultimate objective of the ACCEM is to develop an all composite airframe cost model.

The portion of the model which has been completed and documented covers only the manufacturing costs of detail parts. The validity and accuracy of this model must be rigorously tested and it is to this end that this particular effort was directed. The specific program objectives were as follows.

- Incorporate the ACCEM program on the Grumman IBM Computer
- Select a specified number of structural components that represent a wide variation of composite applications
- Collect cost driving data for the above structural components and input into the ACCEM model

- Collect manufacturing operations actual costs for the structural components indicated above
- Make comparison of computer generated outputs with Grumman actuals
- Analyze the overall accuracy and variance of results
- Make recommendations as to the limitations and possible improvements that can be made to the ACCEM model.

This report covers the work accomplished in meeting all program objectives. The overall model provides the framework required for developing component costs of composite structure. There are certain limitations that can be corrected, but of most importance is the need to extend and maintain this necessary tool. This report validates the model as being a good first step in establishing a methodology and technique for costing advanced composite structures.

SECTION II

DATA COLLECTION AND ANALYSIS

At the beginning of the program it was necessary to screen the existing data bank to identify potentially good test parts for the validation process. This inquiry covered the F-14 program, B-1 program, many research and development programs, as well as the E-2 Hawkeye and A-6 Intruder series aircraft that used an extensive amount of fiberglass epoxy structural assemblies.

The F-14 aircraft utilizes boron/epoxy for fabrication of the horizontal stabilizer. At the end of 1978, over 700 stabilizers were manufactured and delivered. To date, this is the largest production run of an advanced composite structure. This available actual cost data base provided a unique ability to verify many of the ACCEM relationships with components that are far down the learning curve. The operations involved in the manufacture of the F-14 fiberglass walkway fairing and missile cover are the same as for graphite/epoxy, and therefore provided a good candidate for validating the ACCEM model.

Aluminum honeycomb structures are used on the F-14 and A-6, thus making verification of the core cutting relationships utilizing cost data from these ongoing production programs possible.

A cost tracking system was initiated at the start of detail part fabrication on the Composite B-1 Horizontal Stabilizer program. Manufacturing process operation sheets were distributed to the shop areas to record the necessary labor hours to complete the designated task. The data gathered represented the total hours expended in the fabrication of approximately 300 graphite/epoxy sine wave web spars, 64 ribs and 16 beams. The parts range in size from 14 to 275 inches long.

The data collected was compared to the ACCEM output for consistency of definition for all cost elements. For example, it was necessary to adjust (normalize) the collected raw data because the definition of Grumman lay-up did not conform to the ACCEM format. In some instances, generation of cost data was necessary by experienced manufacturing estimators to fill the gaps that existed when adjustments were made. Obvious anomalies were eliminated from the data. These adjustments and estimates will be discussed in the following sections where the changes are made.

A technical description of the sequence of operations used in Grumman's production shops to manufacture both graphite/epoxy and fiberglass parts is outlined below:

2.1 GRAPHITE/EPOXY FABRICATION

2.1.1 Lay-Up Elements

2.1.1.1 Preparation (Setup)

- Obtaining material from freezer storage area
- Normalizing material to room temperature
- Recording Lot, Batch & Roll No. in log book
- Installing roll in dispenser at work station.

2.1.1.2 Mylar Preparation

- Obtaining the designated mylar templates
- Positioning mylar template on light table
- Taping outer template perimeter to light table
- Cleaning template surfaces
- Applying release agent to template surfaces.

2.1.1.3 Ply Lay-Up (Manual)

- Deposition of composite material onto mylar template(s) to template layout lines
- Simultaneous removal of backing tape, butting edges to previous strip and manually dewrinkling
- Trimming both ends of layout line on template.

2.1.1.4 Application of Temporary Film Covers

- Cutting off and application of protective polyethylene sheet over each layup
- Sequentially stacking of mylar/plies.

2.1.1.5 Ply Transfer to Master Stacking Template

- Preparing master stacking template by cleaning and applying release agent
- Sequentially inverting each laid-up mylar, transferring to master tool and aligning to previously stacked lay-up
- This sequence is repeated until the maximum quantity of lay-ups for compacting is stacked (dependent on part configuration).

2.1.1.6 Compacting In Flat State

- Preparing compacting tool by cleaning and application of release agent to cavity area of tool
- Fabricating two pieces of separator cloth for top and bottom of ply stack (Teflon impregnated cloth)
- Fabricating one piece of 116/120 fiberglass bleeder for top of ply stack
- Application of one separator cloth into tool cavity and trimming to size
- Transfer of laid-up plies from master tool into vacuum table
- Application of one separator cloth and one fiberglass bleeder over lay-up
- Trimming material to size
- Cutting of plastic (disposable) vacuum bag material
- Application of sealing tape to fixture flanges
- Application of vacuum bag over lay-up onto sealing tape
- Applying vacuum
- Compressing vacuum bag edges to sealing tape to maintain vacuum

- Utilizing a heat source, ironing stacked plies to dewrinkle
- Allowing stack to cool
- Removing vacuum bag, fiberglass sheet and separator cloth
- Adding of additional stacks atop and repeating process.

2.1.2 Forming Composites for Sine Wave Plain Web Channels

- Preheating, cleaning of tool and application of release agent
- Application of fiberglass and peel ply up to tool flange on fixture
- Apply separator film to tool
- Apply bleeder system onto tool (plain web)
- Apply lay-up onto tool (plain web)
- Corrugate bleeder system onto tool (sine wave)
- Rough forming of lay-up into sine wave configuration on corrugating fixture, simultaneously removing separator film during cycle
- Application of steel rollers to sine wave web areas (sine wave)
- Transferring tool lay-up to vacuum assist table
- Silicone rubber bagging of assembly, and clamping of strips atop bag edges to seal
- Vacuum application and forming of flanges and corrugations
- Vacuum release, debagging and lay-up checking
- Repeating procedures for mating half of channel
- Assembly of channel halves, checking fit and clamping of halves together as mates
- Application of rope adhesive to fill gaps.

2.1.3 Pre-Cured Trimming

- Setting and locating of trimming template atop stack/tool
- Manual trimming of plies to template outline
- Trimmed stack removal.

2.1.4 Fabrication and Application of Bleeder System

2.1.4.1 Material Cutting

- Cut peel ply
- Cut teflon impregnated separator cloth
- Cut fiberglass bleeder cloth - quantity of plies utilized dependent upon number of plies in lay-up for purposes of maintaining bleeder cloth to laid-up plies ratio
- Cut 0.015 thick silicone rubber sheet (sine wave spars only)
- Cut scrim cloth (sine wave spars only)
- Cut nylon disposable vacuum bag.

2.1.4.2 Lay-Up Tool Preparation

- Heating and cleaning of lay-up tool to remove residue from previous curing operation
- Release agent application.

2.1.4.3 System Preparation

- Stacking and collating into sets of pre-cut bleeder system material in correct sequence of functional usage, and application to top and bottom of laid-up ply stack
- Recutting of stacked/collated bleeder plies to finished part configuration using template or layout lines/straight edge method.

2.1.4.4 System Application

- Setting in of either flat or roll corrugating in one collated set of bleeders into tool cavity
- Setting of laid-up stacked plies atop bleeders
- Setting atop stacked plies of second set of bleeder plies (step is applicable only to web regions of parts shown in Table 1).

2.1.4.5 Vacuum Bag Application

- Application of sealing tape to tool flanges
- Draping of nylon vacuum bag over tool/lay-up onto sealing tape
- Vacuum application

- Compressing of vacuum bag edges to sealing tape to seal, using heat gun and roller.

2.1.5 Autoclave Curing Operation

- Checking of autoclave interior
- Placing vacuum bagged detail/lay-up tool onto transfer car
- Connecting thermocouple leads
- Connecting vacuum lines and applying vacuum pressure
- Rechecking vacuum bag sealing and fittings
- Moving of transfer car with detail part(s) into autoclave
- Closing autoclave door
- Setting of curing cycle recorders
- Starting of curing cycle
- Part(s) curing per cycled procedures
- Monitoring of curing cycle to assure adherence to procedures
- Upon completion of cycle, system shut down
- Removal of completed curing cycle charts
- Opening of autoclave door
- Disconnecting thermocouple leads
- Disconnecting vacuum lines
- Rolling transfer car/vacuum bagged parts to debagging area
- Removing fixture(s)/bagged lay-up(s) from transfer car table
- Removing vacuum bag, sealing tape, bleeder system from atop detail part
- Removing part from tool
- Removing bleeder system from tool cavity
- Discarding vacuum bag, bleeder system plies
- Returning lay-up tool(s) and completed part(s) to designated areas.

2.1.6 Autoclave Post-Curing Operation

- Checking of autoclave interior
- Placing detail part onto transfer car table
- Moving of transfer car with detail part(s) into autoclave
- Closing autoclave door
- Setting of post-curing cycle recorders
- Starting of post-curing cycle
- Part(s) post-cured per cycled procedures
- Monitoring of post-curing cycle to assure adherence to procedures
- Upon completion of cycle, system shutdown
- Removal of completed post-curing cycle charts
- Opening of autoclave door
- Rolling transfer car with work piece(s) out of oven
- Removing work piece(s) from transfer car
- Returning post-cured part(s) to designated areas.

2.2 FIBERGLASS REINFORCED PLASTIC

2.2.1 Material Cutting (Initial Cut)

Walk to and from material dispensing/cutting area

- Unroll material onto table from dispenser
- Flatten material on table for cutting
- Measure to specified length
- Mark two places for cutting
- Using straight edge, align to marks
- Cut prepreg fiberglass material to length
- Put aside cut piece for stacking.

2.2.2 Material Cutting (Secondary Cut)

- Pick up pre-cut piece(s) from stack

- Set piece(s) on cutting table
- Measure and mark for specified width or length
- Locate template atop piece(s)
- Cut material to specified width or configuration
- Put aside cut piece(s) for stacking
- Move cut/stacked pieces to lay-up area.

2.2.3 Lay-Up of Prepreg Plies

Heating and cleaning of lay-up tool - application of release agent to tool surfaces

- Removal of one pre-cut prepreg piece of ply from stack
- Removal of backing paper from ply
- Aligning edge or centralizing ply on lay-up tool
- Draping of ply material over tool, manually compressing edges or surfaces to adhere to tool surfaces
- Molding of material onto tool surfaces including:
  - Using teflon wiper and roller to dewrinkle surfaces
  - Using utility knife during molding for trimming and removing overlap excess and arrowheads in corners
  - Trimming of excess material from tool edge periphery
- Repeating previous procedures until specified layers of plies are laid-up.

2.2.4 Compacting of Plies

Walking to and from material dispenser area

- Cutting off sufficient material to fabricate vacuum bag
- Application of sealing tape to tool flanges
- Draping vacuum bag material over lay-up, manually compressing material to sealing tape
- Hooking up vacuum line to fixture fitting

- Applying vacuum
- Using heat gun and roller, heating outer areas of vacuum bag atop sealing tape and compressing areas to seal in vacuum
- Using teflon wiper and roller, compacting seam areas and corner radii to blend
- Vacuum bag removal
- Removing of excess material in areas of lapped edges and corners utilizing utility knife
- Repeating previous procedures after each four ply lay-up (variable - dependent on tool/part complexity).

2.2.5 Bleeder System Material Cutting (Initial Cut)

Walking to and from material dispenser area

- Unrolling of bleeder material from dispenser onto table
- Measuring material to specified length
- Marking two places for cutting
- Using straight edge, aligning to marks
- Cutting of bleeder cloth and peel ply material
- Placing aside or stacking of cut piece.

2.2.6 Bleeder System Material Cutting (Secondary Cut)

- Picking up of pre-cut piece(s) of bleeder cloth or peel ply material from stack
- Setting of piece(s) on cutting table
- Measuring, marking for specified width
- Locating template atop piece(s)
- Cutting material to specified width or configuration
- Placing aside or stacking of cut piece(s)
- Moving cut/stacked pieces to vacuum bagging area.

2.2.7 Bleeder System Application and Vacuum Bagging

- Cutting of sufficient length and width of vacuum bag material to cover lay-up
- Setting in of peel/bleeder plies atop laid-up part
- Trimming of excess bleeder cloth material
- Applying of sealing tape to flange edges
- Draping vacuum bag over lay-up, compressing edges to sealing tape
- Cutting and application of sealing tape to vacuum bag edges when necessary to splice
- Hooking up of vacuum line to work table, vacuum application
- Compression of vacuum bag edges to sealing tape, using heat gun, roll to seal
- Disconnecting vacuum line
- Moving of work table, tool and bagged lay-up to autoclave area.

2.2.8 Autoclave Curing Operation

- Checking of autoclave interior
- Placing vacuum bagged detail/lay-up tool onto transfer car
- Connecting thermocouple leads
- Connecting vacuum lines and applying vacuum pressure
- Rechecking vacuum bag sealing and fittings
- Moving of transfer car with detail part(s) into autoclave
- Closing autoclave door
- Setting of curing cycle recorders
- Starting of curing cycle
- Part(s) curing per cycle procedures
- Monitoring of curing cycle to assure adherence to procedures
- Upon completion of cycle, system shut down

- Removal of completed curing cycle charts
- Opening of autoclave door
- Disconnecting thermocouple leads
- Disconnecting vacuum lines
- Rolling transfer car/vacuum bagged parts to debagging area
- Removing fixtures/bagged lay-ups from transfer car table and setting on work table
- Removing vacuum bag, sealing tape, bleeder system from atop detail part and discarding
- Setting tool part on roll cart and moving to lay-up area
- Removing part from tool
- Returning lay-up/curing tool and completed part to designated areas.

2.3 CORE DATA (ALUMINUM/NOMEX)

2.3.1 Bandsawing

Walking to and from storage area to obtain core panel or section(s)

- Identifying and tagging core sections
- Heating in oven for core stabilization
- Application of masking tape to core for layout lines
- Clamping of template atop core section
- Marking core outline on masking tape using template
- Template removal after layout of outline
- Off-setting of bandsaw table to obtain correct face angle
- Bandsawing of edge(s) to layout line/template outline
- Repositioning of clamps for bandsawing remaining face(s)
- Vacuum cleaning and repackaging of core sections.

2.3.2 Core Machining

- Table routing undercuts or steps in core

- Table routing chamfers on step edges
- Table routing using indexing fixture, valve stem cutter and machining outer surfaces to shape (scarf)
- Sanding chamfers
- Manual routing using guide bar/locating pins on fixture for machining undercuts
- Bandsawing of cutouts outlined on masking tape
- Numerically controlled contour machining of assembled core sections
- Guide roller/template automatic indexing contour machining
- Multiple part machining, by means of hydraulically assisted multi-spindle equipment, template/light beam path control.

2.3.3 Additional Core Operations

- Potting (powder form)
- Adhesive tape application
- Hand/power brake forming
- Core section assembly into fixture/skin.

SECTION III

TECHNICAL DESCRIPTION AND APPROACH

After a consistent set of operational elements within a manufacturing operation was determined, the task of selecting an adequate cross section of parts was initiated. The structural arrangements of the B-1 Horizontal Stabilizer and the F-14 were reviewed for representative candidates (See Figures 1, 2 and 3 for location of parts contained in Table 1).

3.1 PARTS SELECTION

The list of parts shown in Table 1 will be used for the validation of the model. Although this list is significantly larger than that originally conceived, Grumman considers this larger sample necessary to adequately cover all important aspects of the ACCEM.

TABLE 1 PARTS SELECTION

Part No.	Unit No.	Nomenclature	Construction
A44B2032 B-1	6	Spar Assembly	Graphite Epoxy Sine Wave
A44B2056 B-1	6	Spar Assembly	Graphite Epoxy Sine Wave
A44B2063 B-1	6	Spar Assembly	Graphite Epoxy Sine Wave
A44B2030 B-1	4	Beam Assembly	Graphite Epoxy Plain Web
A44B2024 B-1	6	Rib Assembly	Graphite Epoxy Plain Web
A44B2027 B-1	4	Rib	Graphite Epoxy Plain Web
A51B21003 F-14	564	Walkway Fairing Assembly	Fiberglass Epoxy/Honeycomb Sandwich
A51B23108 F-14	282	Stores Closure Skin Fairing	Fiberglass Epoxy Plain Panel

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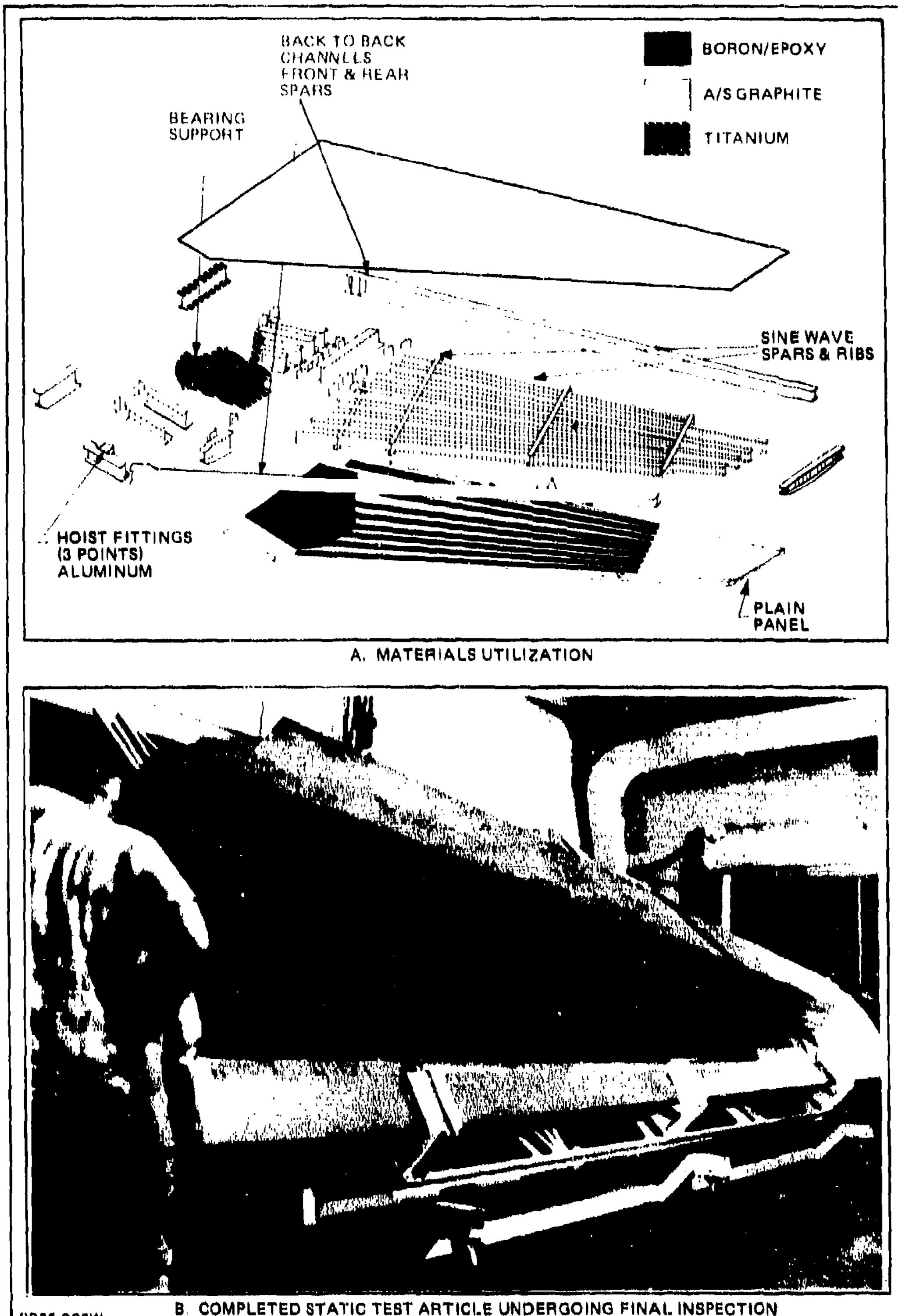
3.1.1 Parts of the Model Exercised

Grumman and the Air Force decided to select a grouping of parts that would exercise the model in its most significant areas, utilizing a maximum of the models' cost estimating relationships. Using this premise as a ground rule, the parts list was generated. The final results are shown in Table 2.



A. MATERIALS UTILIZATION

B. COMPLETED STATIC TEST ARTICLE UNDERGOING FINAL INSPECTION

Figure 1 Materials Utilization/Completed Static Test Article Undergoing Final Inspection

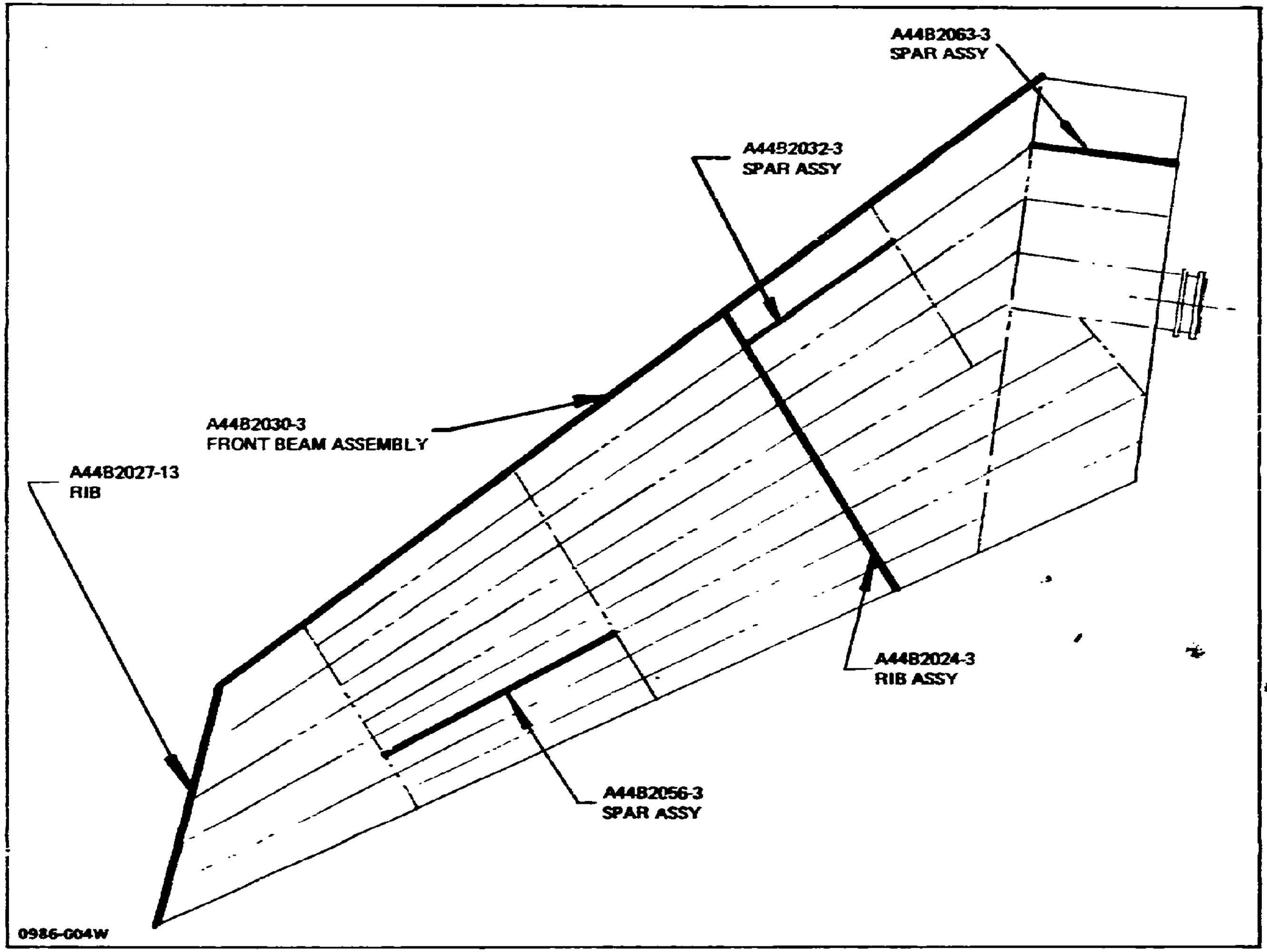


Figure 2 B-1 Horizontal Stabilizer Structural Arrangement

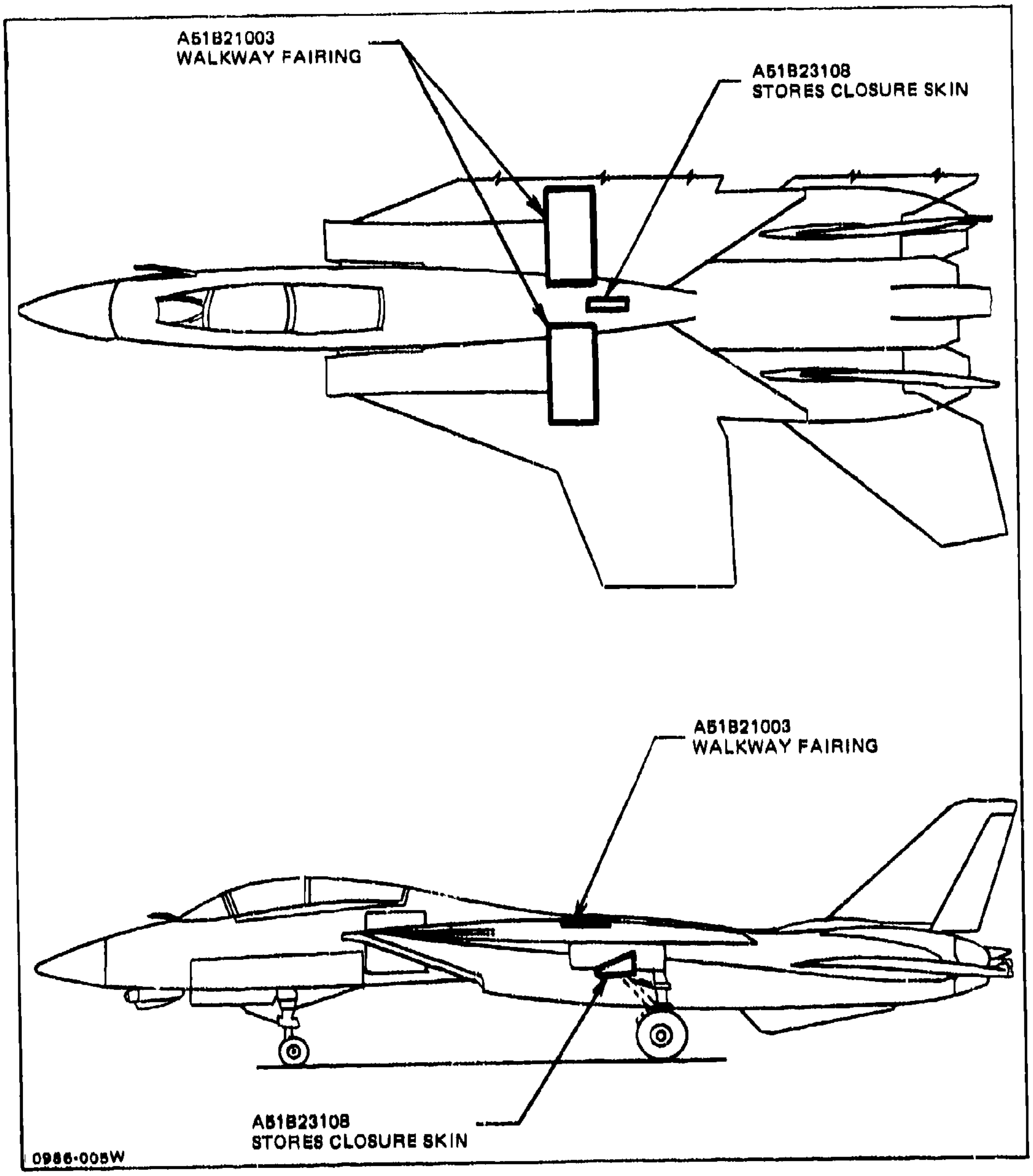

A51B21003
WALKWAY FAIRING
A51B23108
STORES CLOSURE SKIN
A51B21003
WALKWAY FAIRING
A51B23108
STORES CLOSURE SKIN
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Figure 3 F-14

TABLE 2 PARTS OF THE MODEL EXERCISED

Manufacturing Operation	Number of Equations	Average Percentage of Total Cost of Parts
Lay-Up	56%	72 – 93%
Core Preparation	59%	30 – 34%
Vacuum Bag/Autoclave Cure	100%	7 – 28%
Finishing	16%	1 – 4%

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3.1.2 Cost Drivers

It can be seen that better than 50% of the model's equations were utilized in the most significant areas; that is, in the areas of the highest cost drivers: lay-up, core preparation, vacuum bag/autoclave cure. Areas of the model, such as automated equipment for lay-up operation, power brake forming for core preparation, vacuum bag/oven cure and thermal expansion molding were not exercised, as these operations were not used in the fabrication of the parts selected.

3.1.3 Final Cost Comparisons

The cost data was collected for the parts previously indicated. The description of the parts was then inputted into the ACCEM program. Figure 4 provides both pictorial and dimensional views of sample parts. Grumman's actual fabrication hours are shown in Table 3. It was obvious during the programming input that some of the parts selected were more complex than the program could handle. In addition, some operations necessary to make the part could not be identified in the program. It was no surprise, therefore, that the variations in the results were sometimes significant.

The existing data was collected on a work center basis (i.e., lay-up, stacking, bleeder system, autoclave, etc.) and was not sufficient to identify and explain these discrepancies. In order to explain the differences in the fabrication times, it became evident that the data had to be reduced to a manufacturing operation level. (A technical description of the sequence of operations used in the Grumman shop to create the composite parts is given in Section II). A further investigation was made into the bookkeeping records to find these functional values. In some cases, the raw data was supplemented by actual work measurement techniques, and in a few cases, by manufacturing cost estimating data.

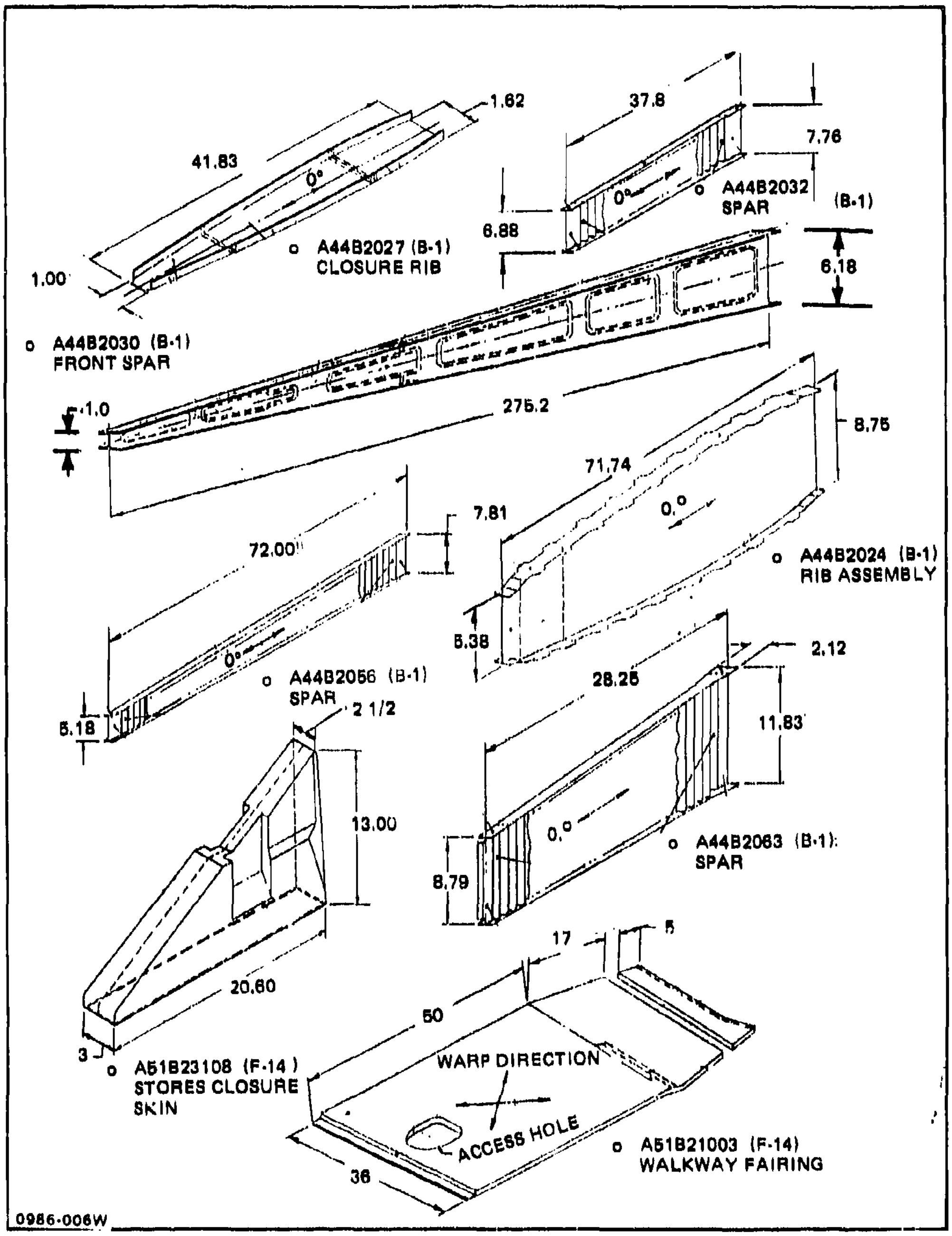

Figure 4 B-1 Horizontal Stabilizer Graphite Epoxy and F-14 Fiberglass Epoxy Parts

TABLE 3 GAC ACTUAL VERSUS ACCEM PREDICTED HOURS

Manuf. Operation	GAC Actual (Person/Hours)	GAC Normalized (Person/Hours)	ACCEM (Person/Hrs)	Part Type/Number
Lay-Up	36.81	32.28	27.25	Sine Wave Spar A44B2032
Part Consolidation	8.95	7.12	5.37	
Total	45.76	39.40	32.62	
Lay-Up	61.47	51.81	41.47	Sine Wave Spar A44B2056
Part Consolidation	10.57	7.99	5.77	
Total	72.04	59.80	47.24	
Lay-Up	53.32	43.41	39.62	Sine Wave Spar A44B2063
Part Consolidation	8.55	6.62	5.04	
Total	61.87	50.03	44.66	
Lay-Up	168.09	168.09	158.16	Plain Web Channels A44B2030
Part Consolidation	35.14	21.71	11.82	
Total	203.23	189.80	169.98	
Lay-Up	105.70	105.70	96.90	Straps A44B2030
Part Consolidation	27.26	16.82	9.33	
Total	132.96	122.52	106.23	
Pre-Bonding	48.12	38.90	16.23	Long Front Beam Assy A44B2030
Bonding Cycle	5.46	5.46	4.45	
Finishing	13.75	13.75	15.72	
Total	67.33	58.11	36.40	
Lay-Up	101.82	92.88	89.00	Plain Web Rib A44B2024
Part Consolidation	9.54	7.23	9.33	
Total	111.36	100.11	98.33	
Lay-Up	16.41	16.41	13.99	Plain Web Rib A44B2027
Part Consolidation	5.67	4.88	2.92	
Total	22.08	21.29	16.53	
Lay-Up	8.19	8.19	5.42	Walkway Skin A51B21003
Part Consolidation	7.18	6.23	2.31	
Total	15.37	14.42	7.73	
Core Preparation	11.29	11.29	4.44	Walkway Fairing Core & Assy A51B21003
Pre-Bonding	4.55	3.27	5.09	
Bonding Cycle	3.50	3.50	1.11	
Finishing	0.25	0.25	0.64	
Total	19.59	18.31	11.30	
Lay-Up	7.27	7.27	4.16	Stores Closure Skin A5123108
Part Consolidation	1.54	1.39	0.95	
Total	8.81	8.66	5.11	

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After the parts were compared on an operation by operation basis, it was apparent that some operations included in the Grumman sequence must be factored to permit a comparison with the ACCEM model. The report will refer to this procedure of factoring as "normalizing" of data. It was these normalizations that were applied to the example problems that enabled the validation to proceed. These normalizations are shown in the sample problem summary sheets included in the comparison study and are shown as GAC normalized values in Table 3. Even with these applied normalizations, differences in cost exist. As a result, an in-depth look at the differences in person hours for the manufacturing operations involved, on a part by part basis, was accomplished.

A general description of the parts with the fabrication techniques will be given in Section 3.2. In addition, the tooling required to fabricate the parts will be addressed and analyzed.

3.2 OVERVIEW OF SELECTED PARTS

3.2.1 General Description

- Sine Wave Spar (A44B2032-3)

  The sine wave spar member is 38 inches long and an average depth of 7.32 inches. The detail elements are composed of two 6 ply thick channels, capped by two 8 ply thick straps, one each top and bottom. Reinforcing 2 ply thick doublers are added to the web at each end and a 6 ply thick doubler is added to one end of each strap. The sine wave spar is located directly aft of the main front beam and adjacent to the bearing support fitting. This structure was designed to carry shear and compression loads inboard to the bearing support fitting (see Figures 2 and 4).

- Sine Wave Spar (A44B2056-3)

  The basic spar laminate consists of a 12 ply thick web and a 14 ply thick cap. Additional reinforcement doublers are added on each side of the web and to the cap. The beam is 6 feet long and an average depth of 9 inches. This represents a typical minimum gage sine wave spar located in the outboard region of the stabilizer. The spar design provides the required foundation modules for the cover in addition to carrying shear loads inboard (see Figures 2 and 4).

- <u>Sine Wave Spar (A44B2063-3)</u>

  The four part sine wave spar assembly consists of two channels, 10 plies each, and two straps, 12 plies each. In addition, localized doublers are added on each end of the spar, eight on the outboard end and two on the inboard end. The spar is 28 inches long and an average depth of 10.3 inches. The sine wave spar is located at the root of the stabilizer, directly forward of the bearing support fitting. This thick gage spar represents one of the more heavily loaded structural members in the stabilizer (see Figures 2 and 4).

- <u>Plain Web Rib (A44B2024-3)</u>

  The rib member is composed of two basic 11 ply thick channels and two basic 11 ply thick straps. An additional 18 plies are inserted in web at the rib's narrow end. The rib assembly is nearly 6 feet long and 10.5 inches deep. This represents the longest and most heavily plied outboard rib. The structure was designed to control the aerodynamic shape of the stabilizer under load, in addition to limiting the length of sine wave spars to an efficient column compressive length (see Figures 2 and 4).

- <u>Plain Web Closure Rib (A44B2027-13)</u>

  This rib represents the simplest load carrying component of the stabilizer torque box. The single channel elements consist of a basic 12 ply thick laminate, with six additional reinforcement plies covering 75% of the rib. The rib was designed to interact with the stabilizer torque box, thus enhancing its torsional rigidity. The rib is nearly 42 inches long and 2.5 inches deep at its widest point. This rib is the most outboard member of the torque box, located about 300 inches from the root rib (see Figures 2 and 4).

- <u>Plain Web Long Front Spar (A44B2030-3)</u>

  The front spar accommodates the fiberglass epoxy leading edge installation and additionally provides torsional rigidity to the stabilizer torque box. The spar is nearly 23 feet long and an average depth of 3.6 inches. A four piece secondary bonded assembly system methodology was used as a least risk manufacturing approach for the early articles. The assembly consists of a two channel 12 ply basic laminate with four additional intermediate plies, and a two strap 14 ply basic laminate with two additional semi-span plies (see Figures 2 and 4).

- <u>Stores Closure Skin Fairing (A51B23108)</u>

  The triangular shaped fairing provides an internal compartment for a missile fin, enabling flush mounting of weapon to the fuselage. The fairing is approximately 21 inches long and 13 inches deep. The skin is a constant 16 ply thickness, except in the pocketed area, where it reduces to 4 plies. Fiberglass epoxy material was chosen because of its high impact resistance to ground handling damage during weapon insertion (see Figures 3 and 4).

- <u>Walkway Fairing Assembly (A51B21003)</u>

  The assembly is a fiberglass epoxy skin bonded to a reinforced phenolic core structure. The fairing, located atop the wing center section was designed specifically to provide aerodynamic smoothness to the gull wing torque box. The selection of fiberglass epoxy material provided the impact toughness required for a walkway area. The relatively flat fairing is approximately 6 feet long and 3 feet wide, with a 10 degree break in the surface (gull wing effect) at one end (see Figures 3 and 4).

3.2.2 <u>Fabrication Technique</u>

- <u>B-1 Sine Wave Spars (A44B2032, A44B2056 and A44B2063)</u>

  The fabrication technique employed for these sine wave spars was cocuring an integrated assembly of prelayed-up details (channels, straps, rope fillers) utilizing matched metal mold forms. The mated assemblies were vacuum bagged and autoclave pressure cured.

  The following manufacturing plan is representative of all the sine wave spars fabricated: The sine wave channel halves were laid up on flat mylar drawings, one drawing (LT) for each ply, utilizing 3 inch wide graphite epoxy unidirectional tape. The individual plies were stacked onto one master mylar and inspected.

The stacked plies or channel assembly was transferred to a mold form tool prior to corrugating. Before corrugation took place, the mold form was treated with a release agent and covered with a bleeder system. The channel assembly was then processed through an automatic corrugating machine, thus creating the sine wave effect in the channel web. The channel assembly on the mold form was transferred to a vacuum table for forming flanges and compacting the sine wave web once again. A twin channel assembly was fabricated identically to the aforementioned process. After lay-up/forming, these channel assemblies were joined together and gap checked.

A structural rope adhesive was required to fill the void at the corner between the two channel assemblies. The upper and lower caps were laid-up, per the above sequence, and installed on the mold form. Caul plates installed on the top and bottom of the mold form completed the assembly procedure. Lastly, the sine wave spar assembly was placed in an autoclave and covered with a nylon film bag, where the bleeding, heat and pressure cycle is accomplished. The following cycle was used:

- full vacuum plus 85 psi autoclave pressure
- 350°F for 7 hours
- post-cure 350°F for 8½ hours.

- <u>B-1 Plain Web Ribs (A44B2024 and A44B2027)</u>

The manufacturing plan for these ribs is similar to the sine wave spars. These ribs were constructed from 3 inch wide unidirectional tape into a multipart (channels, straps, rope fillers) integrated assembly. Matched metal mold forms served as a forming, assembly and curing tool, as well as providing an excellent means of controlling cordal height. Cocuring fabrication techniques (bleeder and vacuum bag fabrication and application) used for these ribs followed the same guidelines as the sine wave spars. However, there is one distinct difference between plain ribs and sine wave spars; that is, the design omission of corrugations in the webs. The non-existence of this operation greatly simplifies other associated manufacturing costs, such as flange forming, bleeder application and compacting.

- <u>Plain Web Long Beam Details (Channels and Straps) (A44B2030)</u>

  Mylar templates were used to lay up the two channels and two straps comprising the beam assembly. The basic plies for the channels and the straps represented standard lay-up techniques. The six windowed areas in the channel web sections were generated by laying up tape to cutout lines on the templates. Laid-up plies were sequentially transferred onto master templates. Stacked plies were set into compacting tool atop previously fabricated bleeders, and compacted. A final bleeder system and vacuum bag were fabricated. Then the plies were transferred into mold forms; followed by the application of bleeders and a vacuum bag. The assembly was then autoclave cured under full vacuum and autoclave pressure.

  Upon completion of curing and post-curing, parts were inspected and set aside, awaiting assembly and secondary bonding.

- <u>F-14 Walkway Fairing (A51B21003-11 Skin)</u>

  The manufacturing plan consisted of laying up fiberglass prepreg epoxy material directly in a female mold form, bleeder vacuum bag, cutting and application, and autoclave pressure curing.

  Two men were utilized to facilitate the lay-up operation. During the initial stage of the first ply lay-up, a previously scribed 45° angular indicator was utilized to orient the first corner piece. Next, a second piece was layed into the mold form, aligned to the previous corner piece and overlapped at the seam. A third piece was laid into the mold form in a similar fashion, thus completing the lay-up of the first ply. Some dewrinkling and trimming was needed to complete this operation. In addition, skin flanges were formed by laying in strips around the outer perimeter and access hole portion of the mold form. Lastly, the entire first ply was dewrinkled, utilizing vacuum bag pressure and manual rolling. The remaining three plies were laid up in a like manner. Finally, pre-cut bleeders were added to the assembly which was vacuum bagged and autoclave cured.

The following cycle was used:

- full vacuum plus 40-60 psi autoclave pressure

- 350°F for 4 hours

- post-cure 300° - 400° for 2 - 2½ hours.

- Stores Closure Skin (A51B23108)

  The manufacturing plan used for this fiberglass epoxy skin member was the single curing of four sets of separately laid-up skin details, over a metal mold form. The assembly was vacuum bagged and autoclave pressure cured.

  Initially, four plies were laid up from both sides of the tool centralized on tool face, and slit for flange folding. Flanges were formed and excess material was trimmed. Compaction was performed to dewrinkle faces and bend flange areas. This procedure was repeated until a total of sixteen plies per side were laid up. Intermittently, four pieces were set into the pocket area, wrapped across the top, slit, compacted and trimmed to contour. Next, three slacks of lay-up material were cut to shape, intermittently set atop the lay-up to form a 12 ply splice plate. A bleeder system was fabricated and tool/lay-up was final vacuum bagged for autoclave curing. The vacuum bagged tool/work piece was placed on a roll cart and transported to the autoclave area.

  The following cure cycle was used:

  - full vacuum plus 40 - 60 psi autoclave pressure

  - 350°F for 4 hours

  - post-cure 300° - 400° for 2 - 2½ hours.

3.2.3 Core Fabrication

Nomex core sections (2) used to fabricate the walkway fairing were band sawed to finished outer dimensions. Additionally, a 1 inch x 31 inch spacer was also cut as a wedge between two core sections and cut undersized to minimize prefitting time. These three sections were taped together and stored as a set.

All undercuts on core/skin face were routed on a vertical table router to specified widths and depths. Relief slots were routed using a guide bar and hand router. The access hole cutout was generated with a reciprocating saw.

3.2.4 Assembly Fabrication

3.2.4.1. F-14 Walkway Fairing (A51B21003) - Installing of the core sections to the cured skin consisted of setting the skin into a holding fixture, cutting and setting expandable f am strips into the inner wall perimeter areas and around the access hole area. Additional strips were fabricated for application to core splice surfaces. An adhesive cloth was cut and applied to the base cavity portion and a peel ply set atop the cloth. The three piece core section with the 1 inch wide wedge was prefitted prior to installation. Foam strips were applied to the splice area, the two outer sections were set into the skin and the one inch wide wedge was inserted between two core sections.

Bleeders were fabricated and applied before sending the part to the autoclave for bonding the core to the skin.

The final contour configuration was machined and automatically indexed on a vertical gantry type core cutting machine. The core/skin assembly was set into a holding fixture with size blocks of predetermined heights. Lastly, the core surfaces were contour cut to the predetermined core heights.

3.2.4.2 B-1 Plain Web Front Spar (A44B2030) - The front spar assembly was fabricated by bonding together previously cured channels and straps, utilizing a film adhesive-vacuum bag curing system. The component parts of the assembly were laid up and cured individually, utilizing similar manufacturing techniques developed for the plain web structure. However, the residual manufacturing operations that followed were unique to this structure.

The precured channels and straps were dimensionally inspected for chordal height and per ply thickness, in addition to ultrasonic/X-ray inspection. Next, the component parts were assembled in a bonding tool, with aluminum alloy sheet material and mylars sandwiched between the parts to facilitate the gap check and shimming operations that followed.

This pre-fit assembly was vacuum bagged and inserted into an autoclave. Resulting high spots were uncovered as a result of this procedure. All peel plies were removed from bonding surfaces of the channels and straps. Finally, the component parts were again assembled together using film adhesive at the interface surface of the aforementioned parts. A vacuum bag system was then installed over the uncured assembly and autoclave cured to complete the cycle. The assembly, once removed from the autoclave, was dimensionally checked, trimmed, deburred and ultrasonically inspected.

3.2.5 Tooling

- B-1 Graphite Epoxy Parts

  The following tooling description summarizes all the basic tools applied to the manufacture of the sine wave spars, plain-web ribs and the long front spar used in the torque box sub-structure (see Table 4).

  The tooling family and the manufacturing approach for each of these items were basically alike. The laminate details were all laid up using mylar templates and vacuum bagged formed over mold form blocks.

TABLE 4 TOOLING B-1 GRAPHITE EPOXY PARTS

	Spars				Ribs		
Tool Description	A44B2030	A44B2032	A44B2056	A44B2063	A44B2024	A44B2027	Tool Function
Mylar Templates	X	X	X	X	X	X	Lay-Up Operations
Master Stacking Template	X	X	X	X	X	X	
Auto-Corrugation Machine	X	X	X	X			
Vacuum Forming Table	X	X	X	X	X	X	
Matched Metal Mold Forms		X	X	X	X		
Single Mold Forms	X						
Net Trim Templates		X	X	X	X	X	Part Consolidation Operations
Caul Plates		X	X	X	X		
Assembly Bonding Tool	X						
Routing Fixture	X						Finishing Operation
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Numerous secondary tools provided the backup required for various operations resulting from part complexities; i.e., auto-corrugating machines, machine routing templates, etc. In addition, some hand tools required to fabricate these detail parts were as follows:

- Heat Gun
- Roller
- Teflon Wiper
- Utility Knife.

- F-14 Fiberglass Epoxy Parts

The tooling concept, employed in fabricating both the missile closure skin and the walkway fairing, is a result of Grumman's vast experience in fiberglass epoxy fabrication (see Table 5). Mold forms, both male and female, served as primary tooling for Missile Closure Skin and Walkway Fairing, respectively. Skin assemblies were compacted, utilizing a vacuum table and/or assortment of hand tools such as rollers, heat guns, wipers and utility knives. Basically, this was the only similarity in tooling methodology employed by these two components. However, additional tooling was utilized to fabricate the honeycomb core, and to assemble and bond the Walkway Fairing. First, the precured skin was inserted into a bonding fixture, followed by pre-cut core sections and film adhesive. An autoclave cure process completed the bonding operation. Next, a holding fixture and a series of core templates provided the required tooling to facilitate the machining of the assembly to its predetermined dimensions.

SECTION IV

DETAIL COST COMPARISONS

The ACCEM model, which was constructed in the 1975-1976 time frame, deals with a relatively new and rapidly changing technology. In this atmosphere, it is difficult to keep a model current, accurate and generic.

The ACCEM model's current limitations include such operations in composite manufacture as windowing, lay-up of small ply doublers, and web corrugating. These basic treatments are mandatory in many currently used shear web designs.

4.1 DETAIL MANUFACTURING OPERATIONS COST COMPARISONS

Only one conclusion can be made after considering the final total assembly cost comparisons (see Table 6). The Grumman actuals for graphite epoxy parts are an average of 18% higher than the ACCEM model predictions and the fiberglass epoxy parts are an average of 40% higher.

The following sections will analyze each manufacturing operation used in the fabrication of graphite epoxy and fiberglass epoxy parts, and compare the costs for these operations. The analysis will include rationale and explanations as to the differences of actuals versus model estimates.

Due to the fact that complete normalization within each operation is not attainable (see Section 3.1.3), as outlined in each operation category to follow, we will display the actual and model values by operation and indicate present differences on the total part.

4.1.1 Tool Preparation and Ply Deposition

Table 7 summarizes the results of both graphite epoxy and fiberglass epoxy material deposition and tool preparation. Manufacturing cost estimates for parts a. through f. were made utilizing the ACCEM standard equation for manual lay-up of 3 inch unidirectional tape. Cost estimates for items g. and h. were based on manual lay-up of woven material.

TABLE 5 TOOLING F-14 FIBERGLASS EPOXY PARTS

Tool Description	Stores Closure Skin A51B23108	Walkway Fairing A51B21003	Tool Function
Male Mold	X		Lay-Up Operation
Female Mold		X	Lay-Up Operation
Vacuum Table	X	X	Lay-Up Operation
Skin Trim Template		X	Finishing Operation
Honeycomb Core Outline and Hole Templates		X	Core Fabrication
Honeycomb Core Machining Fixture		X	Core Fabrication
Assembly Bonding Fixture		X	Part Consolidation Operation

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TABLE 6 TOTAL COST COMPARISONS

Part Description and Number	GAC Actual (Person Hours)	ACCEM Using GAC Experience Learning Curves (Person Hours)	Percent Difference Relative to GAC Hours
Sine Wave Spar (1) A44B2032	39.4	32.62	17%
Sine Wave Spar (1) A44B2056	59.80	47.24	21%
Sine Wave Spar (1) A44B2063	50.03	44.36	11%
Plain Web Long Beam A44B2030			
Assembly	58.11	36.40	37%
Channels (1)	189.80	169.98	10%
Straps (1)	122.52	106.23	13%
Plain Web Rib (1) A44B2024	100.11	98.33	2%
Plain Web Rib (1) A44B2027	21.29	16.63	22%
Walkway Core & Assembly A51B21003 (2)	18.31 14.42	11.30 7.73	38% 46%
Stores Closure Skin (2) A51B23108	8.66	5.11	41%

(1) Indicates Graphite Epoxy prepreg material
(2) Indicates Fiberglass Epoxy prepreg material

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TABLE 7 TOOL PREPARATION AND PLY DEPOSITION

	Part Description and Number	GAC Actual (Person Hours)	ACCEM Using GAC Experience Learning Curves (Person Hours)
a.	Sine Wave Spar A44B2032	22.03	22.45
b.	Sine Wave Spar A44B2056	31.40	33.29
c.	Sine Wave Spar A44B2063	28.63	33.89
d.	Plain Web Long Beam A44B2030		
	Channels	126.20	139.0
	Straps	89.15	88.79
e.	Plain Web Rib A44B2024	58.6	68.73
f.	Plain Web Rib A44B2027	9.80	9.98
g.	Walkway Skin A51B21003	3.71	3.11
h.	Stores Closure Skin A51B23108	4.03	3.02

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The Grumman required manhour values for ply deposition of graphite epoxy components are slightly lower than the ACCEM estimates, whereas the values for fiberglass epoxy components are higher than the model predicts. However, of the six graphite epoxy parts studied, items c., d. and e. show differences of 10% or greater.

Assessment of these three components indicate that heavier plied component members experience a greater learning, which results in a decrease in ply deposition time. The ACCEM is insensitive to this operation in that it calculates the time to lay up one ply and then multiplies that time by the number of plies, thereby not taking advantage of learning between plies for this operation within the fabrication of one part.

At first observation, the documented values for items g. and h. do appear as large percent differences. However, considering the relatively few total hours for fabrication, any misplacement of hours, for any reasons, such as model simplification for computerizing, or entry and retrieval of actual hours logged, can easily result in small deviations from actual values.

4.1.2 Transfer to Lay-Up Tool (Stacking)

Table 8 summarizes the results for stacking graphite epoxy plies, items a. through f. The ACCEM model generated estimate for ply transfer is automatically computed when the user selects deposition technique of "ply-on-mylar".

TABLE 8 TRANSFER TO LAY-UP TOOL (STACKING)

	Part Description and Number	GAC Actual (Person Hours)	ACCEM Using GAC Experience Learning Curves (Person Hours)
a.	Sine Wave Spar A44B2032	1.63	1.19
b.	Sine Wave Spar A44B2056	6.53	2.54
c.	Sine Wave Spar A44B2063	5.40	1.73
d.	Plain Web Long Beam A44B2030		
	Channels	10.18	4.16
	Straps	7.93	2.96
e.	Plain Web Rib A44B2024	14.43	3.26
f.	Plain Web Rib A44B2027	1.60	0.47
g.	Walkway Skin A51B21003	–	–
h.	Stores Closure Skin A51B23108	–	–

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In general, the required time generated by the model is not sufficient to complete the aforementioned task. In addition, the model's insensitivity to recognize the requirement of more than one person needed for handling oversize ply boundaries can be attributed to the larger differences shown in items b. through e. Stacking time for the fiberglass epoxy parts, items g. and h., was not required because the technique utilized in the fabrication of fiberglass epoxy parts precludes the intermediate step of stacking plies onto a mold form.

4.1.3 Debulking

The actual and estimated manufacturing costs for debulking are summarized in Table 9. These estimates were based on the standard equation for debulking, in conjunction with a disposable bag. These parts can be grouped into categories by the number of debulking cycles. Items a. through c. required only one debulking cycle, while items d. through g. required two debulking cycles and item h. required four debulking cycles.

TABLE 9 DEBULKING

	Part Description and Number	GAC Actual (Person Hours)	ACCEM Using GAC Experience Learning Curves (Person Hours)
a.	Sine Wave Spar A44B2032	4.05	1.86
b.	Sine Wave Spar A44B2056	6.29	2.44
c.	Sine Wave Spar A44B2063	5.02	1.68
d.	Plain Web Long Beam A44B2030		
	Channels	10.65	8.56
	Straps	8.62	5.16
e.	Plain Web Rib A44B2024	7.07	6.03
f.	Plain Web Rib A44B2027	1.75	0.75
g.	Walkway Skin A51B21003	3.30	2.00
h.	Stores Closure Skin A51B23108	1.80	0.88

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Within the debulking sequence, ACCEM addresses itself solely to vacuum bag pressure to complete this operation. However, the Grumman debulking procedure requires additional manual rolling, as well as vacuum pressure. The relatively small cutting requirements for fabricating vacuum bags and vent cloths is also associated with the total Grumman values shown in Table 9.

These additional operations can be attributed as the cause of the aforementioned differences. Lastly, it would have been desirable to have conducted a study into the relatively small differences in costs for items d. and e., but funds and time did not permit it. However, part of the cost decrease can be attributed to the following: 1) a drop in the GAC per square inch rate cost for larger size parts (item d.) and 2) item e. required a separate local area debulk cycle, in addition to a full area cycle, considering that a buildup of 40 plies existed at the rib's end.

4.1.4 Bend Factors (Flange Forming)

The required person hour values for flange forming graphite epoxy and fiberglass epoxy members are summarized in Table 10. Several lay-up complexity equations were utlized for estimating the various bend types. These bend types are as follows:

	Items
• Straight Sharp Male	a. through d., h.
• Straight Sharp Female	g.
• Curves Bends, Shrink Flange.	e., f.

TABLE 10 BEND FACTORS (FLANGE FORMING)

	Part Description and Number	GAC Actual (Person Hours)	ACCEM Using GAC Experience Learning Curves (Person Hours)
a.	Sine Wave Spar A44B2032	2.53	0.31
b.	Sine Wave Spar A44B2056	4.18	0.59
c.	Sine Wave Spar A44B2063	1.22	0.38
d.	Plain Web Long Beam A44B2030		
	Channels	21.06	6.44
	Straps	–	–
e.	Plain Web Rib A44B2024	6.71	6.68
f.	Plain Web Rib A44B2027	2.26	2.08
g.	Walkway Skin A51B21003	1.18	0.31
h.	Stores Closure Skin A51B23108	1.43	0.27

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Comparison of Grumman actuals and ACCEM estimating hours for bend factors (flange forming) demonstrates that the ACCEM values for forming straight sharp male and female bend flanges are low. An apparent oversimplification of criteria that generated this CER has created this situation. The criteria at Grumman is the application of vigorous amounts of rolling and wiping motions, supplemented by vacuum pressure applications which are required to form, smooth down and remove irregularities along a flange bend line. However, the ACCEM statement of "a straight bend simply involves the application of pressure along the exposed bendline" (Volume 1 of Advanced Composite Cost Estimating Manual), has led Grumman to believe that this CER has been oversimplified. Furthermore, the inability of the model to estimate the time required for vacuum pressure for initial forming of the flange, as well as providing backup pressure for rolling and wiping, can also be attributed to part of the differences shown in Table 10.

In contrast, the comparison of shrink flange actuals and ACCEM generated hours, as shown in items e. and f., reveal something different. An in-depth investigation showed that distinct differences existed in manufacturing methodologies between Grumman and ACCEM shrink flange procedures. The Grumman technique is to physically fold over the flange using vacuum pressure and work out any irregularities by vigorously rolling the material until a smooth surface is attained. The ACCEM technique is to individually dart and fold each ply until all the plies in the book are completed.

An interesting note resulting from this study is that although the forming techniques differ between Grumman and ACCEM, the associated costs for each were approximately the same.

4.1.5 Net Trim (Pre-Cured Trimming)

Table 11 summarizes the manufacturing cost comparison for the net trimming of five graphite epoxy pre-cured assemblies. The person hour costs shown represent the level of effort required to remove an excess of material required for the flat pattern lay-up and forming of the detail parts. A user's selection that best represents material types and shapes to be trimmed is limited to but one equation in ACCEM. The manufacturing plan, for items d. and g. (secondary bonded assemblies) and item h. (a subassembly component) did not require pre-cure trimming. Post-cured machining provided the necessary means for removal of all oversize edges.

TABLE 11 NET TRIM (PRE-CURED TRIMMING)

	Part Description and Number	GAC Actual (Person Hours)	ACCEM Using GAC Experience Learning Curves (Person Hours)
a.	Sine Wave Spar A44B2032	2.04	1.44
b.	Sine Wave Spar A44B2056	3.41	2.61
c.	Sine Wave Spar A44B2063	3.14	1.94
d.	Plain Web Long Beam A44B2030		
	Channels	–	–
	Straps	–	–
e.	Plain Web Rib A44B2024	6.07	4.29
f.	Plain Web Rib A44B2027	1.0	0.71
g.	Walkway Skin A51B21003	–	–
h.	Stores Closure Skin A51B23108	–	–

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Grumman's experience in net trimming is that close tolerance precision cutting is necessary to shape parts to their final form. It is this technique that is represented in the Grumman hours shown. However, after careful research of the "Advanced Composite Cost Estimating Manual" Volume III backup data, it was learned that the ACCEM net trimming operation H = 0.00011P, was based on cutting broadgoods length and cross widths, a rather elementary procedure, which does not model the Grumman close tolerance precision cutting procedure described above.

4.1.6 Assembly of Details

Table 12 summarizes the manufacturing costs for assembling composite pre-cured details prior to final cure.

In general, the computer generated estimates for this manufacturing operation are fairly representative of the actual hours experienced at Grumman. However, as parts become very long, the need for more than one person and special handling equipment becomes apparent.

The model is size limited and can only treat parts to a maximum length of 6 to 9 feet. Item d. is such a part, with a length of approximately 23 feet. This is the cause of the large difference in person hours shown.

TABLE 12 ASSEMBLY OF DETAILS

	Part Description and Number	GAC Actual (Person Hours)	ACCEM Using GAC Experience Learning Curves (Person Hours)
a.	Sine Wave Spar A44B2032	1.08	1.06
b.	Sine Wave Spar A44B2056	1.19	1.31
c.	Sine Wave Spar A44B2063	1.18	1.06
d.	Plain Web Long Beam A44B2030		
	Assembly	20.85	2.68
	Channels	–	–
	Straps	–	–
e.	Plain Web Rib A44B2024	1.51	1.57
f.	Plain Web Rib A44B2027	–	–
g.	Walkway Assembly A51B21003	0.76	0.69
h.	Stores Closure Skin A51B23108	–	–

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4.1.7 Bleeder System (Application)

Table 13 summarizes the results of actual and estimated manufacturing hours for bleeder system application.

The comparison shown in Table 13 will be analyzed by category of bleeder applications shown below.

	Item
1. Applications for flat surfaces	d., e., f.
2. Applications for sine wave spars	a., b., c.
3. Application for oversize parts	g.
4. Application for unusual part shapes	h.

The items in category 1 represent the only type of application that is addressed by the ACCEM model. The predicted values, however, are higher than Grumman actual experience. Categories 2, 3 and 4 have unique complexities that ACCEM does not address, which contribute to the differences shown in Table 13. These complexities are:

	Items
• Corrugating bleeders into place	a., b., c.
• Oversize widths requiring walking and reaching over tool	g.
• Unusual part shape, requiring additional smoothing and dewrinkling.	h.

It is these complexities that produced higher hours than accounted for by the ACCEM model, except for item c. In this case, the model CER is functionally dependent on area of resin bleeder plies. Since item c. is a heavy plied part (20 plies), the model is predicting a much higher value than Grumman's experience indicates. The curve below illustrates the difference in Grumman experience to the ACCEM estimated values. The curve for the ACCEM model clearly indicates a lack of sensitivity to complexities, as explained above.

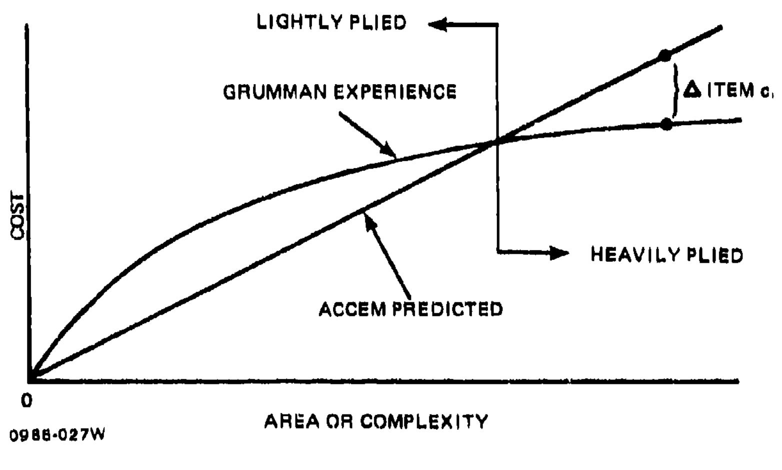


TABLE 13 BLEEDER SYSTEM (APPLICATION)

	Part Description and Number	GAC Actual (Person Hours)	ACCEM Using GAC Experience Learning Curves (Person Hours)
a.	Sine Wave Spar A44B2032	0.88	0.81
b.	Sine Wave Spar A44B2056	1.61	0.95
c.	Sine Wave Spar A44B2063	0.59	0.97
d.	Plain Web Long Beam A44B2030		
	Channels	1.22	4.38
	Straps	0.65	2.39
e.	Plain Web Rib A44B2024	0.15	2.88
f.	Plain Web Rib A44B2027	0.04	0.21
g.	Walkway Skin A51B21003	0.87	0.53
h.	Stores Closure Skin A51B23108	0.13	0.07

0986-017W

4.1.8 Vacuum Bagging (Application)

The comparison of composite vacuum bagging actual costs compared to preducted values are summarized in Table 14.

The relatively small differences between the Grumman actuals and the ACCEM estimates is indicative of the model's accuracy to predict required hours for vacuum bagging. However, it is evident in items d. and g. that the complexity of oversize vacuum bags influences costs significantly. That is, it becomes necessary now for two persons to handle one bag. This reflects the model's insensitivity to bag sizes requiring more than one person for handling.

4.1.9 Autoclave (Monitoring and Part Removal)

Table 15 summarizes the comparison of Grumman actual hours to the ACCEM predicted values for the monitoring and removal of composite parts during and after the autoclave process.

TABLE 14 VACUUM BAGGING (APPLICATION)

	Part Description and Number	GAC Actual (Person Hours)	ACCEM Using GAC Experience Learning Curves (Person Hours)
a.	Sine Wave Spar A44B2032	1.00	0.92
b.	Sine Wave Spar A44B2056	1.03	1.09
c.	Sine Wave Spar A44B2063	0.69	0.76
d.	Plain Web Long Beam A44B2030		
	Assembly	5.18	4.52
	Channels	11.65	3.42
	Straps	7.33	3.31
e.	Plain Web Rib A44B2024	1.41	1.39
f.	Plain Web Rib A44B2027	0.68	0.65
g.	Walkway Assembly	1.26	0.77
	A51B21003 Skin	1.26	0.56
h.	Stores Closure Skin A51B23108	0.19	0.21

0986-018W

TABLE 15 AUTOCLAVE (MONITORING AND PART REMOVAL)

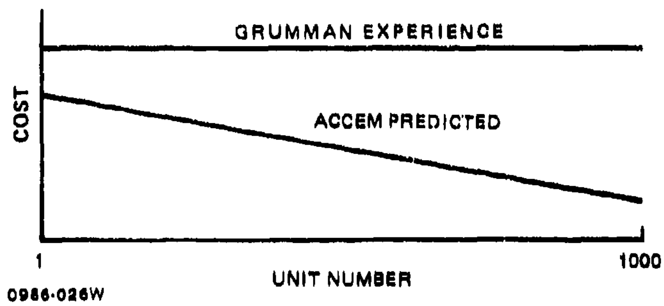
	Part Description and Number	GAC Actual (Person Hours)	ACCEM Using GAC Experience Learning Curves (Person Hours)
a.	Sine Wave Spar A44B2032	4.16	2.58
b.	Sine Wave Spar A44B2056	4.16	2.42
c.	Sine Wave Spar A44B2063	4.16	2.25
d.	Plain Web Long Beam Assembly A44B2030	5.46	4.45
	Channels	8.84	4.02
	Straps	8.84	3.63
e.	Plain Web Rib A44B2024	4.16	3.49
f.	Plain Web Rib A44B2027	4.16	1.68
g.	Walkway Assembly	3.50	1.12
	A51B21003 Skin	4.10	1.22
h.	Stores Closure Skin A51B23108	1.08	0.57

0986-019W

In general, the ACCEM model values for this composite manufacturing operation is unreasonably low. Assessments of the accuracy of the ACCEM model for autoclave monitoring and part removal are discussed below and the results shown in Table 15.

- The ACCEM values were probably generated using a larger number of parts per cure cycle than Grumman experience indicates, thus resulting in smaller costs per unit value.
- ACCEM applies learning curves to its Monitoring Operation, thus resulting in lower values for higher unit parts as in item g., which depicts the cost for the 564th unit and item h. for the 282nd unit. This is illustrated in the curve below.

Grumman's experience shows no learning for this operation.



- Grumman's historical data and specific experience for the sample parts surveyed indicate that the model does not estimate sufficient time for removal of cured parts from the bonding tools.

4.1.10 Secondary Bonding and Finishing

Table 16 summarizes the Grumman actual hours compared to the ACCEM generated values for secondary bonding and finishing.

Pre-Bonding

Tool Preparation

The ACCEM model makes no provision for tool preparation prior to prefit and assembly of details for bonding. This would be considered a model limitation.

TABLE 16 SECONDARY BONDING AND FINISHING

Part Description and Number	GAC Actual (Person Hours)	ACCEM Using GAC Experience Learning Curves
Plain Web Long Beam A44B2030		
Operational Description		
Pre-Bonding		
a. Tool Prep.	1.41	–
b. Prefit and Assembly of Details	20.85	2.68
c. Adhesive Application	12.87	9.03
d. Vacuum Bagging	7.99	4.52
	43.12	16.23
Finishing		
e. Machine Routing	11.00	12.35
f. Hand Sanding	2.75	3.37
	13.75	15.72
Walkway Fairing A51B21003		
Operational Description		
Pre-Bonding		
g. Tool Prep.	1.14	–
h. Prefit and Assembly of Details	0.76	0.70
i. Adhesive Application	1.25	3.63
j. Vacuum Bagging	1.40	0.77
	4.55	5.10
Finishing		
k. Machine Sawing	0.12	0.38
l. Hand Sanding	0.13	0.26
	0.25	0.64

0955-020W

Prefit and Assembly of Details

While the model's accuracy for estimating exists for dimensionally short parts (Walkway Fairing), it underestimates manufacturing costs for longer parts (B-1 Plain Web Long Beam) requiring the use of more than one person with special handling equipment.

Adhesive Application

In item c., the person hours for adhesive application also includes two secondary bonding procedures.

- Checking for excessive voids at faying surfaces
- Filling voids with adhesive material.

Removing the times alloted to do these additional operations accounts for approximately one half of the 12.87 person hours. Comparing the remaining hours to the ACCEM estimates for both items c. and i. shows that the ACCEM model overestimates the run time for applying film adhesive.

Vacuum Bagging

(See explanation in Section 4.1.8.)

Finishing

Machine Routing

Machine routing, machine sawing, and hand sanding differences shown between ACCEM and Grumman are insignificant for both the Walkway Fairing (A51B21003) and the Plain Web Long Beam Assembly (A44B2030).

4.1.11 Core Machining

Table 17 summarizes the work accomplished for validating the ACCEM Aluminum Honeycomb Core sub-routine.

TABLE 17 CORE MACHINING

Operational Description	GAC Actual (Person Hours)	ACCEM Est GAC Experience Learning Curves (Person Hours)
Honeycomb Core Preparation		
Sawing	2.43	0.74
Polyglycol	–	0.88
Flat Machining	7.28	1.06
Step Cut Machining	0.62	0.61
Scarf Cut Machining	0.56	0.54
Cutout Machining	0.11	0.15
Hand Forming	0.17	0.19
Set-up	0.11	0.27

0986-021W

The data shown in Table 17 represents the actual time required to basically saw and machine Nomex reinforced phenolic honeycomb core for the Walkway Fairing (A51B21003). The very close similarities between sawing and machining of Nomex core, compared to aluminum honeycomb core at Grumman led to this selection of the Walkway Fairing for validating the ACCEM Aluminum Honeycomb Core subroutine.

Polyglycol

The ACCEM model always includes in the estimate hours for polyglycol application. The polyglycol operation is not a part of the core assembly fabrication for this part at Grumman. Bonding the core to the pre-cured skin automatically provides the necessary core stabilization required for machining. The ACCEM model needs a convenient means for deleting these hours on parts which do not require polyglycol.

Sawing

The manufacturing operation of sawing at Grumman consists of the following steps.

1. Masking tape is applied to the flat surface of the core sections.
2. An outline template is placed over the masking tape and secured to the core detail.
3. The outline of the template is transferred to the core.
4. The outline template is removed and core section transferred to the bandsaw table.
5. The bandsaw table is offset to the correct face angle.
6. The core section is then sawed to the proper shape.

These operations are accomplished on all five Walkway Fairing core details. The ACCEM model estimates the sawing operation only and does not account for steps 1 through 5 presawing operations.

Flat Machining

The ACCEM model only accounts for one machining pass to completely machine off approximately two inches of the 2.25 inch starting thickness. However, to completely machine the core at Grumman a total of seven passes are required over the entire surface. Since the cutter diameter and feed rates are comparable, this can be the only reason for the difference in manhours.

4.2 COST PROJECTION SUB-ROUTINE

The cost projection sub-routine enables the user to conduct detail cost/weight trade studies. Several costing elements have been developed, providing the user with enough comprehensive data for these trade studies. Such elements are:

- Factory Labor
- Support Labor
- Labor Overhead
- Material Cost
- Administrative Overhead.

Apart from factory labor, the ACCEM program provides the user with default Support Function CER's for each of the cost functions. However, the user has the option to override these CER's and input his own factors and equations. Grumman elected to address these default Support Function CER's, developed under the ACCEM program, as part of this validation program. Early B-1 production units (A44B2027 and A41B2032) were chosen for the validating of these CER's. Several assumptions used in this trade are:

- A cumulative total of 200 units
- A delivery schedule of approximately 8 units/month
- Single tool concept.

Results of these studies are shown in Tables 18 and 19. Several of ACCEM CER's were not included in this study, as they are generally associated with Grumman overhead costs. The following is a list of these CER's.

- Graphic Services
- Administrative Overhead
- Support Material
- Material Overhead.

Overhead rates are directly related to a particular company's way of doing business. To compare Grumman overhead rates with ACCEM default overhead factors would be meaningless. The different methods companies use to account for different labor and material overhead would affect the magnitude of such rates.

TABLE 18 B-1 CLOSURE RIB SUSTAINING
MANHOUR COST COMPARISON

CER	A44B2027 GAC	A44B2027 ACCEM
Quality Control	337.00	204.06
Tooling	215.00	191.39
Mfg Engineering		299.37
Engineering	318.00	124.66
Support Total	870.00 Hrs	819.48 Hrs
Total Factory Labor Hours	1,786.13 Hrs.	1,362.36 Hrs

Note: ACCEM model values are based on fiberglass data. The above GAC values are for graphite/epoxy.

0986-022W

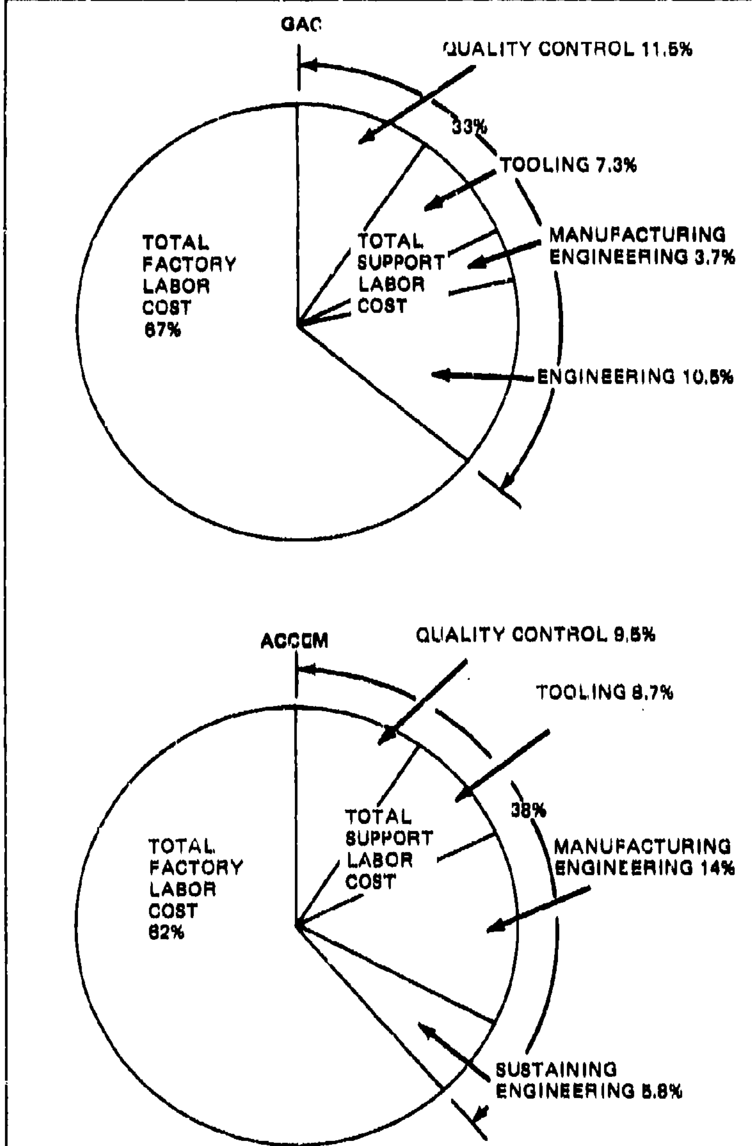
TABLE 19 B-1 SINE WAVE SPAR SUSTAINING
MANHOUR COST COMPARISON

CER	A44B2032-3 GAC	A44B2032-3 ACCEM
Quality Control	456.15	423.83
Tooling	377.00	399.63
Mfg Engineering		625.23
Engineering	655.80	259.93
Support Total	1,488.95 Hrs	1,708.52 Hrs
Total Factory Labor Hours	3,142.51 Hrs	2,810.77 Hrs

Note: ACCEM model values are based on fiberglass data. The above GAC values are for graphite/epoxy.

0986-024W

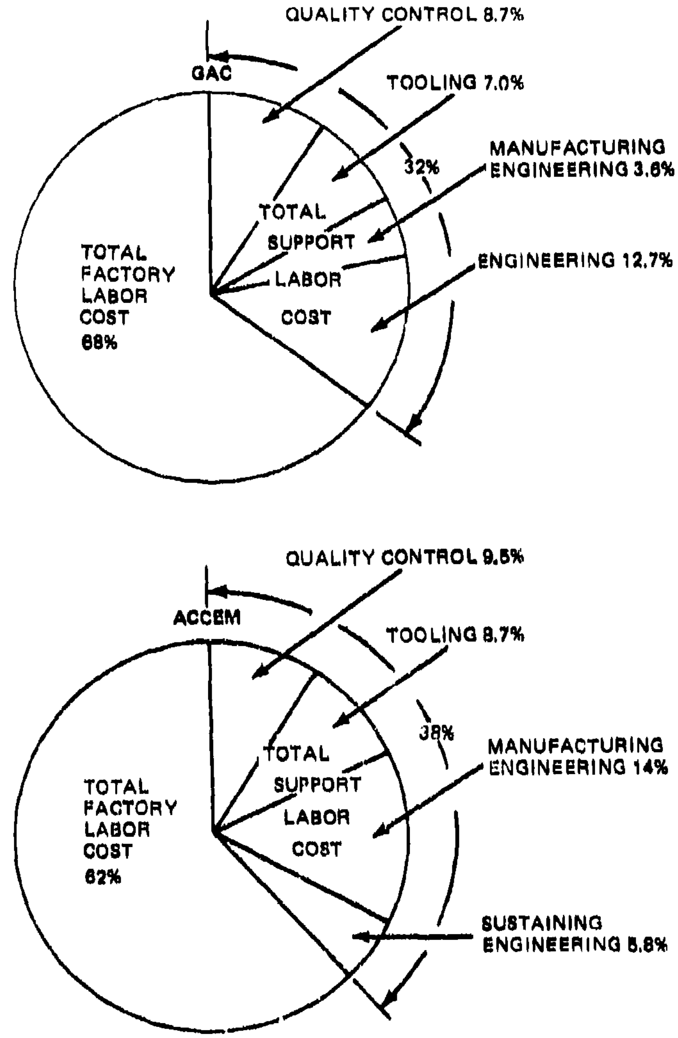
The Support Function CER's developed under the ACCEM program were based on fiberglass experience. The data that Grumman has evaluated represents graphite, material and manufacturing processes. The large variances shown in Figures 5 and 6 are probably caused by these data base differences. The ACCEM CER support functions are all based on a fixed percentage of the factor labor hours. In the case of Quality Control and certain specific supporting manufacturing functions, Grumman agrees to this approach, with the exception that our composite material and manufacturing processes reflect a higher percentage for graphite than fiberglass. It is our opinion that the CER'S for these two disciplines reflect fiberglass only and is the reason that the Grumman numbers are significantly higher.



- USING CUMULATIVE TOTAL OF 200 UNITS
- A DELIVERY SCHEDULE OF APPROXIMATELY 8 UNITS PER MONTH
- USING ALL SUPPORT FUNCTION COST (LESS GRAPHIC SERVICES)

0986-023W

Figure 5 A44B2027, B-1 Horizontal Stabilizer Rib Total Factory and Support Labor Cost Comparison



- USING CUMULATIVE TOTAL OF 200 UNITS
- A DELIVERY SCHEDULE OF APPROXIMATELY 8 UNITS PER MONTH
- USING ALL SUPPORT FUNCTION COST (LESS GRAPHIC SERVICES)

0986-025W

Figure 6 A44B2032, B-1 Horizontal Stabilizer Spar Total Factory and Support Labor Cost Comparison

In the case of manufacturing engineering and tooling, Grumman's experience is that not only are these functions dependent on the factory labor hours, but are also sensitive to rate tooling and the number of tools to be maintained. In addition, our experience in rate tooling and tool maintenance reflects a significantly lower level of effort than that generated by ACCEM CER's. This difference is probably due to the variations in approach between the two companies.

In conclusion, while Grumman's actual values presented graphite epoxy data, the ACCEM values, as stated in the ACCEM final report (see Ref. 2) were generated from fiberglass experience. In order to correct for the above, default support function modifications to the CER sub-routine should be made as follows:

- Add a material dependent variable to the CER's
- Modify the CER's to become sensitive to length of schedule
- Modifying the tooling CER to become sensitive to number of tools to maintain would improve the versatility of the model in addressing material and manufacturing processes for other than fiberglass epoxy.

SECTION V

RECOMMENDATIONS AND CONCLUSIONS

5.1 CHANGES TO IMPROVE ACCURACY

- Change autoclave monitoring time to include post-cure time.
- The finishing operations (sawing, drilling., etc.) for kevlar, boron epoxy, and graphite epoxy differ substantially, but the model does not distinguish the material change.
- Expand ACCEM program to include provisions for more than one pass for machining of core.
- Change ACCEM program to eliminate the application of learning curve to autoclave cure monitoring time. This is a constant and should not decrease with quantity of parts fabricated.
- ACCEM program cannot eliminate applications of polyglycol to stabilize core prior to machining. In some assemblies, the core is bonded in place prior to machining, therefore requiring no additional stabilization feature.

5.2 ADDITIONS TO IMPROVE VERSATILITY

- Expand program to include windowing, lay-up of small doublers and corrugating of webs.
- Expand program to treat parts greater than 9 feet in length.
- Expand program to input different resin systems, especially the polyimides.
- Much more effort should be spent in the area of automatic lay-up devices. The model uses the performance of the CONRAC System, a mechanical device that lays up tape at a rate of 6:1 compared to the manual process. Grumman's laminating center not only lays up, but trims, transfers, and stacks automatically. Any new innovations should be explored and included in the model. The

impact of automatic devices, such as robotics, will have a distinct effect on the future costs of composite structure.

- Include a provision for using pre-plied graphite tape and woven graphite epoxy.
- Add on complexities such as forming of flanges from corrugated webs.
- Add fabrication time for bleeder and vacuum bags in debulking bleeder systems and vacuum bagging operations.
- Small plies encompassed by larger plies must be reoriented in ACCEM orientation. The model recognizes the longest side of a ply boundary as the edge parallel to the 0° direction. However, this would not necessarily be the case relative to the part's ply orientation. The orientation of the small ply's longest edge could be a 90° direction, thus the user must change it to a 0° direction to insure proper ply deposition values. This is confusing and could result in computation errors. Perhaps a sub-routine could be developed to solve this problem.
- In the Support Function Sub-Routine add the following:
  - Add a material dependent variable to the CER's.
  - Modify the CER to become sensitive to production rate.
  - Modify the tooling CER to become sensitive to maintenance of rate tooling to improve the versatility of the model in addressing material and manufacturing processes for other than fiber-glass epoxy.

5.3 ENHANCEMENTS

- Include provisions for a stitching process that replaces mechanical attachments for fastening.
- ACCEM cannot address the operation of tape wrapping non-constant section mandrel type tools. Grumman is presently under contract with the Air Force to produce a trailing edge section of the F-111 Horizontal Stabilizer, utilizing trapezodial shape corrugations sandwiched between two skins in a single cured panel.

Also, a hat shaped stiffener is typically used to support many monocoque designs.

- The ACCEM program in its present configuration is too laborious to use in detail design, and not suited at all for preliminary design. Use in detail design with some program restructuring could eliminate a great deal of part modeling and keypunch/remote terminal entry time.

APPENDIX A

DETAIL COST COMPARISON FOR THE EIGHT SELECTED STRUCTURAL COMPONENTS

ADVANCE COMPOSITE COST ESTIMATE

"ACCEM"

DATE 6-28-78

PART NAME: SPAR ASSY. HORIZ. STAB.

PART NUMBER: A44B20232-3

PRINCIPAL INVESTIGATOR: TONY TORNABE

DESCRIPTION:

CONSTRUCTION

[x] DETAIL

[x] GR/EP [ ] G/EP [ ] HYBRID

LENGTH 37.8" HEIGHT 7.32" ave.

TOTAL NUMBER OF PLIES 44

4 NUMBER OF PARTS TYPE CHANNELS

STRAPS

FLYAWAY WEIGHT: 1.86 LBS.

LINEAR FEET - TAPE 3"; 252.7 FT.

BUY/FLY - 1.48

[ ] ASSEMBLY

[ ] BUILT-UP [ ] SANDWICH

LENGTH ___ WIDTH ___ THICKNESS ___

	GR/EP	G/EP	HYBRID	AL.ALY.
NO. OF PARTS				
TYPE				

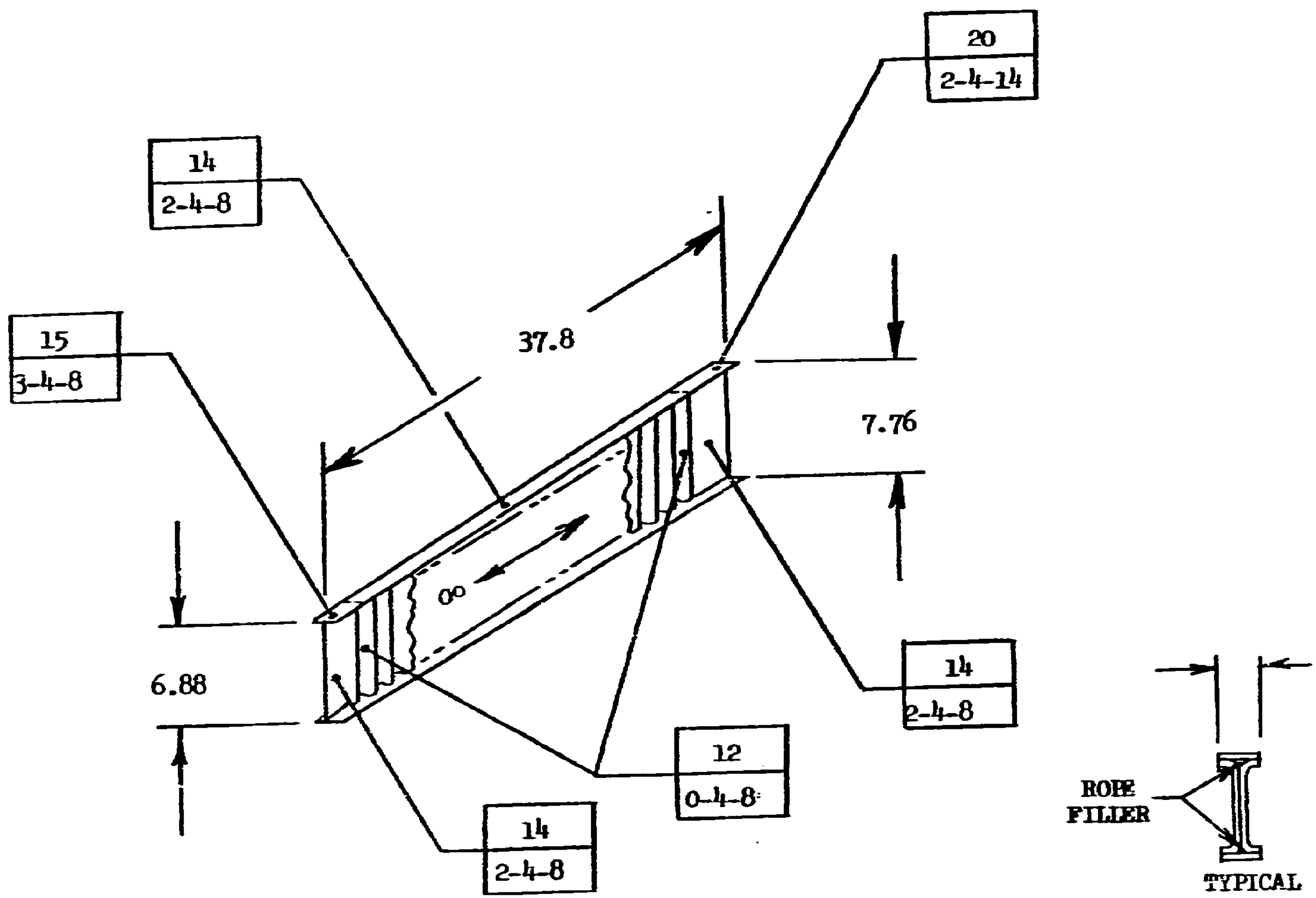
FLYAWAY WEIGHT:

LINEAR FEET - TAPE 3"

12"

BROADGOODS

0986-029W



A44B2032-3 SPAR ASSY.

0986-030W

A44B2032-3

OPERATIONAL DESCRIPTION	GAC ACTUAL UNIT 6	ACCEM EST. UNIT 6 GAC EXPERIENCE LEARNING CURVES	PERCENT DIFFERENCE RELATIVE TO GAC HOURS (1)	ACCEM. EST. UNIT 6 DEFAULT LEARNING CURVES	COMMENTS
LAYUP					
O TOOL PREP & PLY DEPOSITION	22.03	22.45		24.83	
O TRANS TO LAYUP TOOL (STACK)	1.63	1.19		2.85	
O DEBULKING	4.05	1.86		4.46	
O HERO FACTORS	5.04	.31		.75	
O NET TRIM	2.04	1.44		3.45	
	34.79	27.25		36.34	
PART CONSOLIDATION					
O ASSEMBLY OF DETAILS	1.08	1.06		2.59	
O BLEEDER SYSTEM	2.37	.81		1.97	
O VACUUM BAGGING	1.34	.92		2.23	
O AUTOCLAVE O MONITORING O PART REMOVAL	4.16	2.58		6.28	
	8.95	5.37		13.07	
SUB TOTAL HOURS	43.74	32.62		49.41	
ROPE & WEB CORRUGATION	+2.02				
TOTAL HOURS	45.76				
HERO FACTORS	-2.51				
ROPE & CORRUGATION	-2.02				
VACUUM BAG FAB.	- .34				
BLEEDER FAB.	-1.49				
TOTAL HOURS	39.40	32.62	17%		

Note:
(1) based on normalized values.

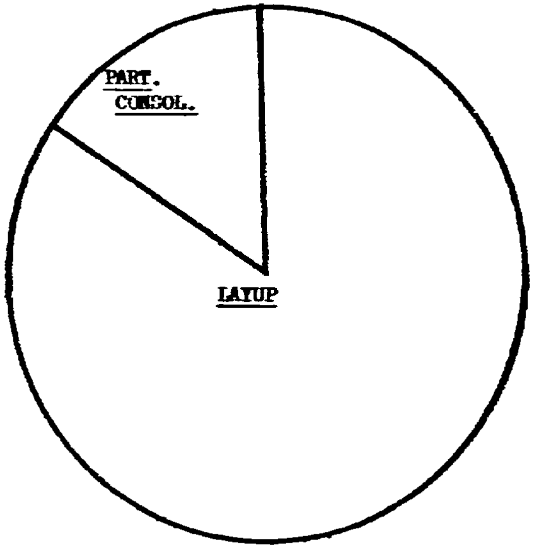
0986-031W

6th

UNIT COST

A44B2032-3

"ACCEM" (NORTHROP)

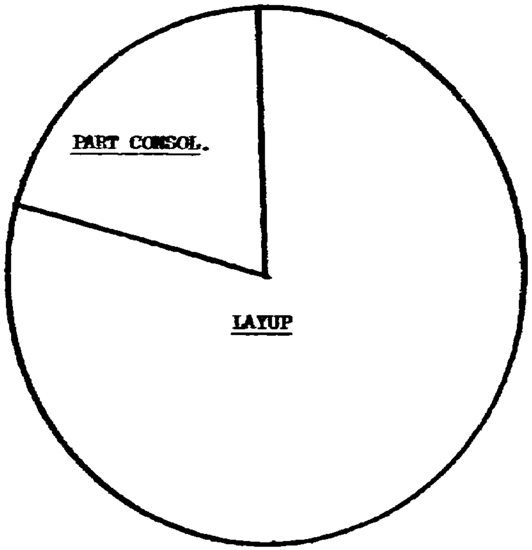


TASK	% OF HOURS
1) LAYUP	84%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	16%
4) FINISHING OPERATIONS	-
TOTAL	100%

* (INCLUDES SET-UP TIME)

0986-032W

ACTUALS (G.A.C.)



TASK	% OF HOURS
1) LAYUP	82%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	18%
4) FINISHING OPERATIONS	-
TOTAL	100%

ADVANCE COMPOSITE COST ESTIMATE

"ACCEM"

DATE 5/26/78

PART NAME: SPAR ASSY.HORIZ.STAB.

PART NUMBER: A44B2056-3

PRINCIPAL INVESTIGATOR: TONY TORNABE

DESCRIPTION:

CONSTRUCTION

☒ DETAIL

☒ GR/EP ☐ G/EP ☐ HYBRID

LENGTH 72.0" HEIGHT 6.47" AVE.

TOTAL NUMBER OF PLIES 32

4 NUMBER OF PARTS TYPE CHANNELS

STRAPS

FLYAWAY WEIGHT: 3.1 LBS.

LINEAR FEET - TAPE 3"; 432.6 FT.

BUY/FLY 1.52

☐ ASSEMBLY

☐ BUILT-UP ☐ SANDWICH

LENGTH ______ WIDTH ______ THICKNESS ______

	GR/EP	G/EP	HYBRID	AL.ALY.
NO. OF PARTS				
TYPE				

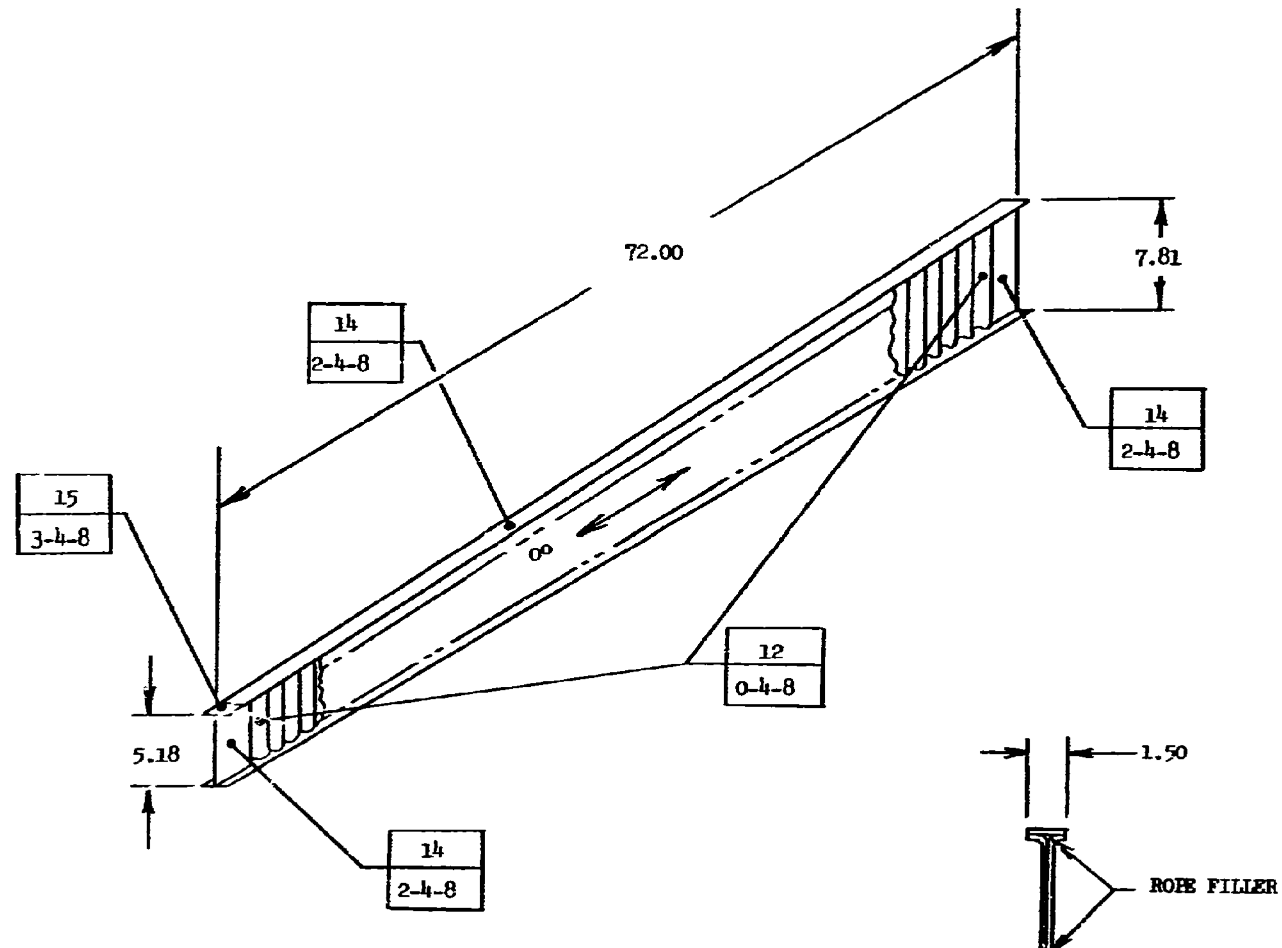
FLYAWAY WEIGHT: ______

LINEAR FEET - TAPE 3": ______

12" ______

BROADGOODS ______

0986-033W



A44B2056-3 SPAR ASSY.

0986-34W

A44B2056-3

OPERATIONAL DESCRIPTION	GAC ACTUAL UNIT 6	ACCEM EST. UNIT 6 GAC EXPERIENCE LEARNING CURVES	PERCENT DIFFERENCE RELATIVE TO GAC HOURS (1)	ACCEM. EST. UNIT 6 DEFAULT LEARNING CURVES	COMMENTS
LAYUP					
O TOOL PREP & PLY DEPOSITION	31.40	33.29		36.81	
O TRANS TO LAYUP TOOL (STACK)	6.53	2.54		6.10	
O DEBULKING	6.29	2.44		5.85	
O BEND FACTORS	10.15	.59		1.41	
O NET TRIM	3.41	2.61		6.26	
	57.78	41.47		56.43	
PART CONSOLIDATION					
O ASSEMBLY OF DETAILS	1.19	1.31		3.19	
O BLEEDER SYSTEM	3.70	.95		2.31	
O VACUUM BAGGING	1.52	1.09		2.66	
O AUTOCLAVE					
O MONITORING	4.16	2.42		3.71	
O PART REMOVAL				2.16	
	10.57	5.77		14.03	
SUB TOTAL HOURS	68.35	47.24		70.46	
ROPE & WEB CORRUGATION	+3.69				
TOTAL HOURS	72.04				
ROPE & CORRUGATION	-3.69				
BEND FACTORS	-5.97				
VACUUM BAG FAB.	-0.49				
BLEEDER FAB.	-2.09				
TOTAL HOURS	59.80	47.24	21%		

0986-035W

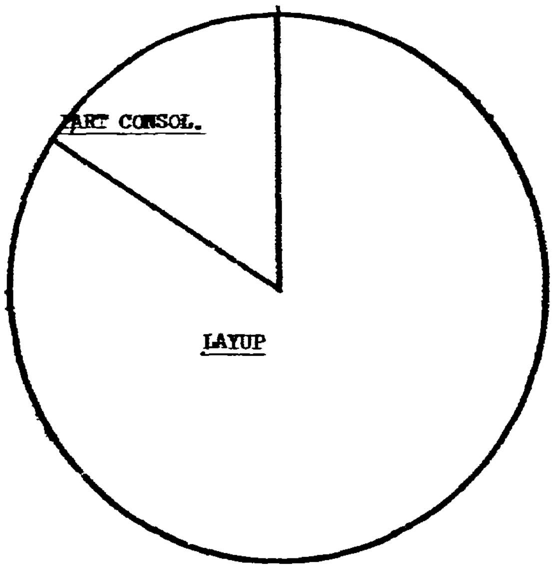
NOTE:
(1) Based on normalized values.

6th

UNIT COST

A44B2056-3

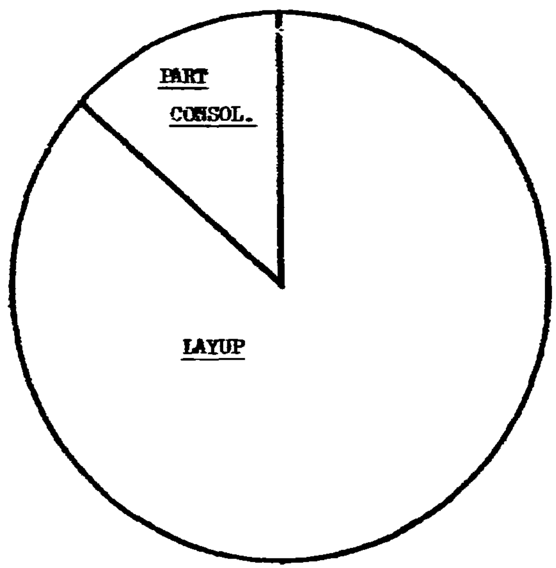
"ACCEM" (NORTHROP)



TASK	% OF HOURS
1) LAYUP	88%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	12%
4) FINISHING OPERATIONS	-
TOTAL	100%

* (INCLUDES SET-UP TIME)

ACTUALS (G.A.C.)



TASK	% OF HOURS
1) LAYUP	87%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	13%
4) FINISHING OPERATIONS	-
TOTAL	100%

C986-036W

ADVANCE COMPOSITE COST ESTIMATE

"ACCEM"

DATE 2/23/78

PART NAME: SPAR ASSY. HORIZ. STAB.

PART NUMBER: A44B2063-3

PRINCIPAL INVESTIGATOR: TONY TORNABE

DESCRIPTION:

CONSTRUCTION

☒ DETAIL ☐ ASSEMBLY

☒ GR/EP ☐ G/EP ☐ HYBRID ☐ BUILT-UP* ☐ SANDWICH

LENGTH 28.25" HEIGHT 10.3" AVE.

TOTAL NUMBER OF PLIES 58

4 NUMBER OF PARTS TYPE CHANNELS, STRAPS

FLYAWAY WEIGHT: 3.4 LBS.

LINEAR FEET - TAPE 3"; 384.3 FT.

BUY/FLY 1.23

LENGTH ______ WIDTH ______ THICKNESS ______

	GR/EP	G/EP	HYBRID	AL.ALY.
NO. OF PARTS				
TYPE				

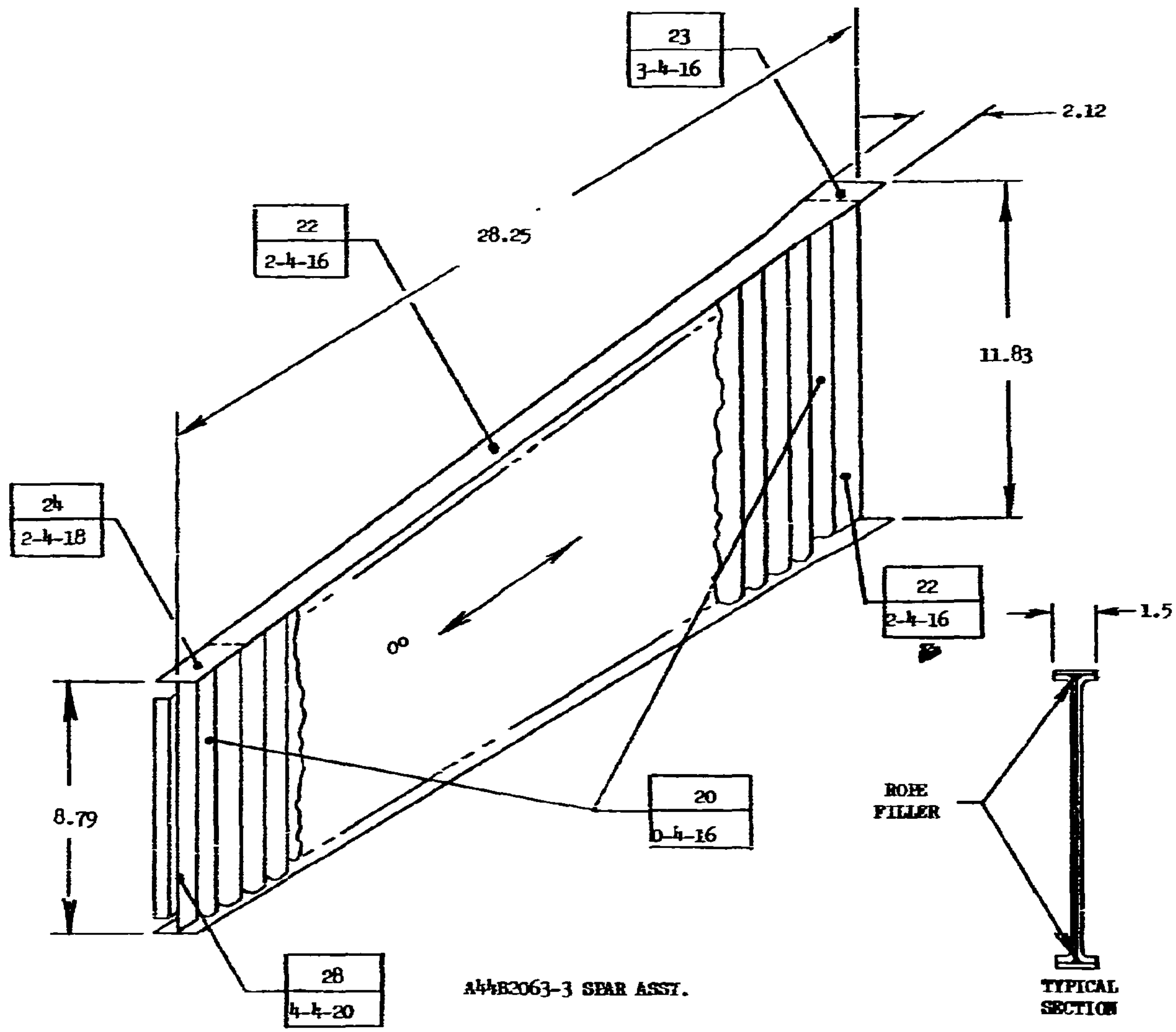
FLYAWAY WEIGHT: ______

*LINEAR FEET - TAPE 3" ______

12" ______

BROADGOODS ______

0986-037W



A44B2063-3 SPAR ASSY.

0986-038W

A44B2063-3

OPERATIONAL DESCRIPTION	GAC ACTUAL UNIT 6	ACCEM EST. UNIT 6 GAC EXPERIENCE LEARNING CURVES	PERCENT DIFFERENCE RELATIVE TO GAC HOURS (1)	ACCEM. EST. UNIT 6 DEFAULT LEARNING CURVES	COMMENTS
LAYUP					
O TOOL PREP & PLY DEPOSITION	28.63	33.89		37.48	
O TRANS TO LAYUP TOOL (STACK)	5.40	1.73		4.17	
O DEBULKING	5.02	1.68		4.02	
O BEND FACTORS	10.00	.38		.92	
O NET TRIM	3.14	1.94		4.65	
	52.19	39.62		51.24	
PART CONSOLIDATION					
O ASSEMBLY OF DETAILS	1.18	1.06		2.59	
O BLEEDER SYSTEM	2.20	.97		2.36	
O VACUUM BAGGING	1.01	.76		1.86	
O AUTOCLAVE					
O MONITORING	4.16	2.25		3.70	
O PART REMOVAL				2.03	
	8.55	5.04		12.54	
SUB TOTAL HOURS	60.74	44.66		63.78	
ROPE & WEB CORRUGATION	+1.13				
TOTAL HOURS	61.87				
BEND FACTORS	-8.78				
VACUUM BAG FAB.	-0.32				
ROPE & CORRUGATION	-1.13				
BLEEDER FAB.	-1.61				
TOTAL HOURS	50.03	44.66	11%		

Notes:
(1) Based on normalized values.

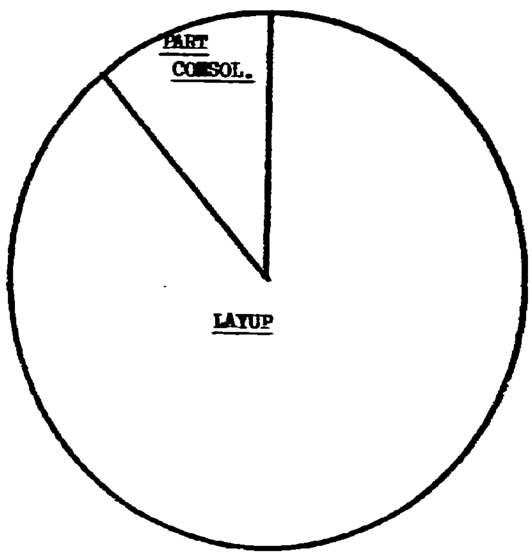
0986-039W

6th

UNIT COST

A44B2063-3

"ACCEM" (NORTHROP)

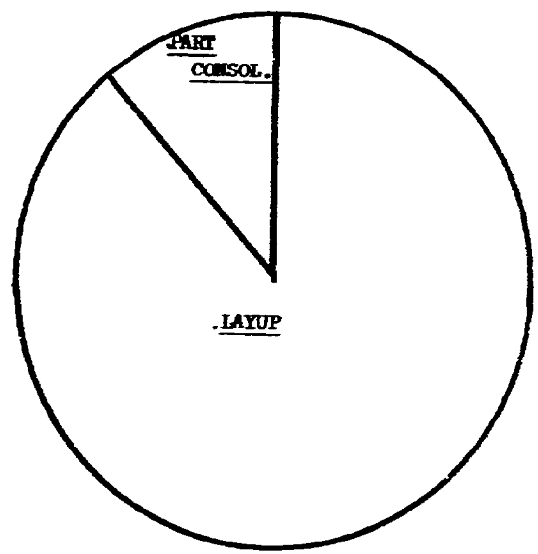


TASK	% OF HOURS
1) LAYUP	89%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	11%
4) FINISHING OPERATIONS	-
TOTAL	100%

* (INCLUDES SET-UP TIME)

0986-040W

ACTUALS (G.A.C.)



TASK	% OF HOURS
1) LAYUP	89%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	11%
4) FINISHING OPERATIONS	-
TOTAL	100%

ADVANCE COMPOSITE COST ESTIMATE

"ACCEM"

DATE 8-25-78

PART NAME: HORIZ. STAB. FRONT SPAR
PART NUMBER: A44B2030-3
PRINCIPAL INVESTIGATOR: TONY TORNABE

DESCRIPTION:

CONSTRUCTION

[X] DETAIL [ ] ASSEMBLY

[X] GR/EP [ ] G/EP [ ] HYBRID [ ] BUILT-UP [ ] SANDWICH

LENGTH 271.½" HEIGHT 3.6" ave.

TOTAL NUMBER OF PLIES 64

½ NUMBER OF PARTS TYPE Channels

Straps

FLYAWAY WEIGHT: 27.0 lbs.

LINEAR FEET - TAPE 3"; 2,373 FT

BUY/FLY 1.17

LENGTH ____ WIDTH ____ THICKNESS ____

	GR/EP	G/EP	HYBRID	AL.ALY.
NO. OF PARTS				
TYPE				

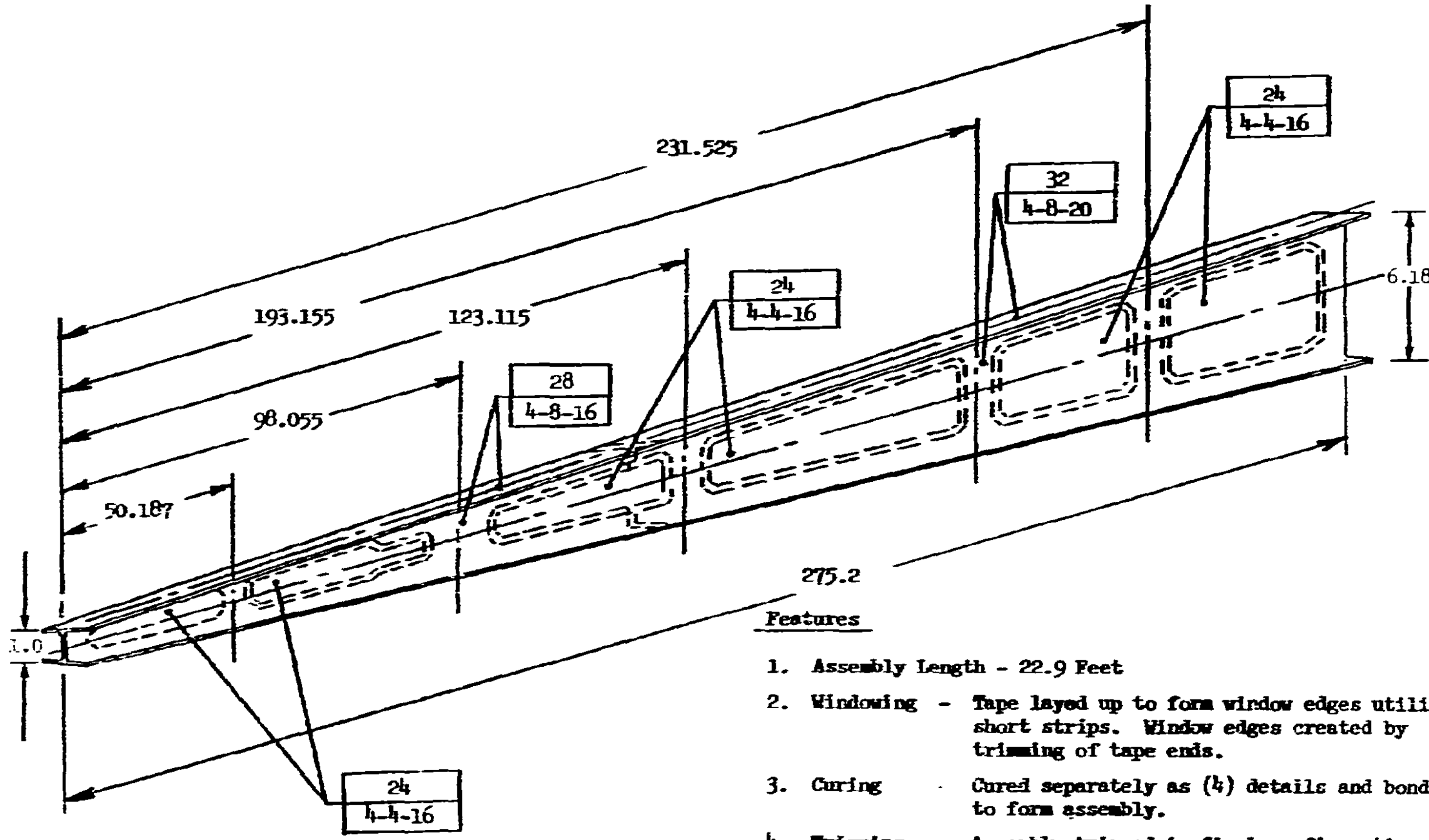
FLYAWAY WEIGHT: ____

LINEAR FEET - TAPE 3" ____

12" ____

BROADGOODS ____

0956-041W



Features

1. Assembly Length - 22.9 Feet
2. Windowing - Tape layed up to form window edges utilizing short strips. Window edges created by trimming of tape ends.
3. Curing - Cured separately as (4) details and bonded to form assembly.
4. Trimming - Assembly trimmed to final configuration after curing.
5. Layup - Variation in web thickness on channels (5).

A44B2030
B-1 HORIZONTAL STAB FRONT SPAR

0986-042W

A44B2030-11 & 13 CHANNELS

OPERATIONAL DESCRIPTION	GAC ACTUAL UNIT 4	ACCEM. EST. UNIT 4 GAC EXPERIENCE LEARNING CURVES	PERCENT DIFFERENCE RELATIVE TO GAC HOURS (1)	ACCEM. EST. UNIT 4 DEFAULT LEARNING CURVES	COMMENTS
LAYUP					
O TOOL PREP & PLY DEPOSITION	126.2	139.0		164.03	
O TRANS TO LAYUP TOOL (STACK)	10.18	4.16		12.25	
O DEBULKING	10.65	8.56		22.68	
O BEND FACTORS	21.06	6.44		17.08	
O NET TRIM	-	-		-	
	168.09	158.16		216.04	
PART CONSOLIDATION					
O ASSEMBLY OF DETAILS	-	-		-	
O BLEEDER SYSTEM	13.60	4.38		11.71	
O VACUUM BAGGING	12.70	3.42		9.15	
O AUTOCLAVE	8.84	4.02		10.76	
O MONITORING					
O PART REMOVAL					
	35.14	11.82		31.62	
TOTAL HOURS	203.23	169.98		247.66	
VACUUM BAG FAB.	- 1.05				
BLEEDER FAB.	-12.38				
TOTAL HOURS	189.80	169.98	10%		

Note:

(1) Based on normalized values.

0986-043W

A44B2030-15 & 17 STRAPS

OPERATIONAL DESCRIPTION	GAC ACTUAL UNIT 4	ACCEM.EST. UNIT 4 GAC EXPERIENCE LEARNING CURVES	PERCENT DIFFERENCE RELATIVE TO GAC HOURS (1)	ACCEM. EST. UNIT 4 DEFAULT LEARNING CURVES	COMMENTS
LAYUP					
O TOOL PREP & PLY DEPOSITION	89.15	88.79		104.70	
O TRANS TO LAYUP TOOL (STACK)	7.93	2.96		7.84	
O DEBULKING	8.62	5.15		13.66	
O BEND FACTORS	-	-		-	
O NET TRIM	-	-		-	
	105.70	96.90		126.20	
PART CONSOLIDATION					
O ASSEMBLY OF DETAILS	-	-		-	
O BLEEDER SYSTEM	9.64	2.39		6.39	
O VACUUM BAGGING	8.78	3.31		8.85	
O AUTOCLAVE	8.84	3.63		9.71	
O MONITORING					
O PART REMOVAL					
	27.26	9.33		24.95	
SUB TOTAL HOURS	132.96	106.23		151.15	
VACUUM BAG FAB.	- 1.45				
BLEEDER FAB.	- 8.99				
TOTAL HOURS	122.52	106.23	13%		

Note:

(1) Based on normalized values.

0936-044W

A44B2030-3 ASSEMBLY

OPERATIONAL DESCRIPTION	GAC ACTUAL UNIT 4	ACCEM. EST. UNIT 4 GAC EXPERIENCE LEARNING CURVES	PERCENT DIFFERENCE RELATIVE TO GAC HOURS (1)	ACCEM. EST. UNIT 4 DEFAULT LEARNING CURVES	COMMENTS
PRE-BONDING					
TOOL PREP.	1.41	-		-	
PREFIT & ASSEMBLY OF DETAILS *	20.85	2.68		7.18	* PARTS ARE 23 FEET LONG. REQUIRING MECHANICAL ASSISTANCE TO HANDLE. PREFITTED, DISASSEMBLED & SHIMMED TO CORRECT TOLERANCE BUILD-UPS.
ADHESIVE APPLICATION,	12.87	9.03		24.16	
VACUUM BAGGING	7.99	4.52		12.09	
	43.12	16.23		43.43	
BONDING CYCLE					
AUTOCLAVE MONITORING				7.15	
PART REMOVAL	5.46	4.45		4.77	
	5.46	4.45		11.92	
FINISHING					
MACHINE ROUTING	11.0	12.35		32.48	
HAND SANDING	2.75	3.37		8.86	
	13.75	15.72		41.34	
SUB TOTAL HOURS	62.33	36.40		96.69	
ROPE ADHESIVE APPL.	5.00				
TOTAL HOURS	67.33				TOTAL HOURS TO FABRICATE (4) DETAIL PARTS. PREFIT ASSEMBLE AND BOND. = 370.43
VACUUM BAG FAB.	- 2.81				
BONDING TOOL PREP.	- 1.41				
ROPE ADHESIVE APPL.	- 5.00				
TOTAL HOURS	58.11	36.40	37%		

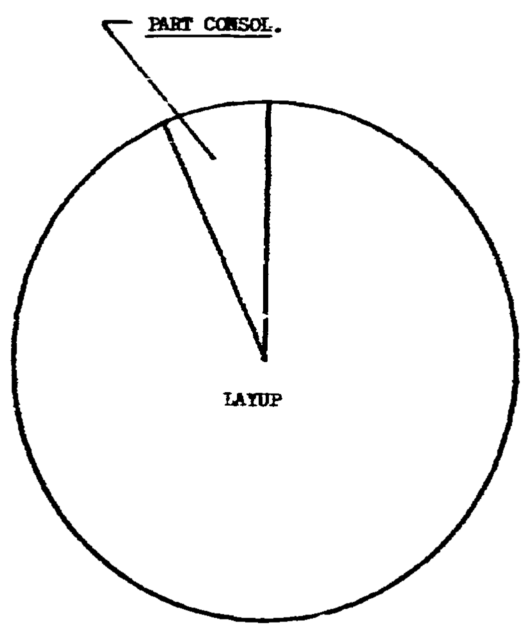
Note:
(1) Based on normalized values.

0986-045W

4 th

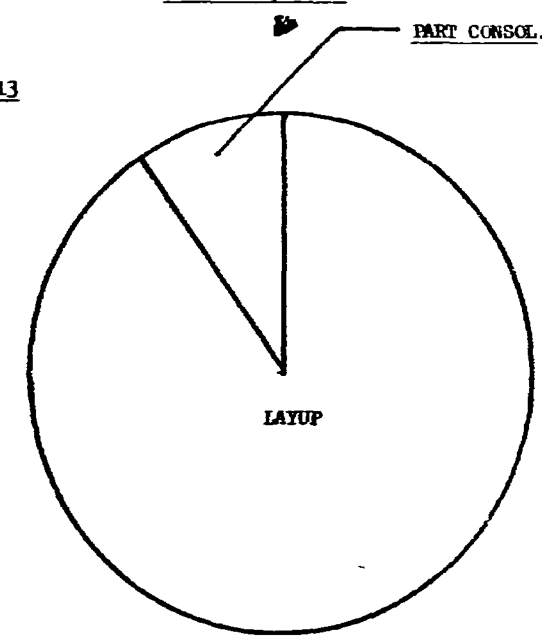
UNIT COST
A44B2030-11 & -13
CHANNELS

"ACCEM" (NORTHROP)



TASK	% OF HOURS
1) LAYUP	93%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	7%
4) FINISHING OPERATIONS	-
TOTAL	100%

ACTUALS (G.A.C.)



TASK	% OF HOURS
1) LAYUP	89%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	11%
4) FINISHING OPERATIONS	-
TOTAL	100%

* (INCLUDES SET-UP TIME)

0986-046W

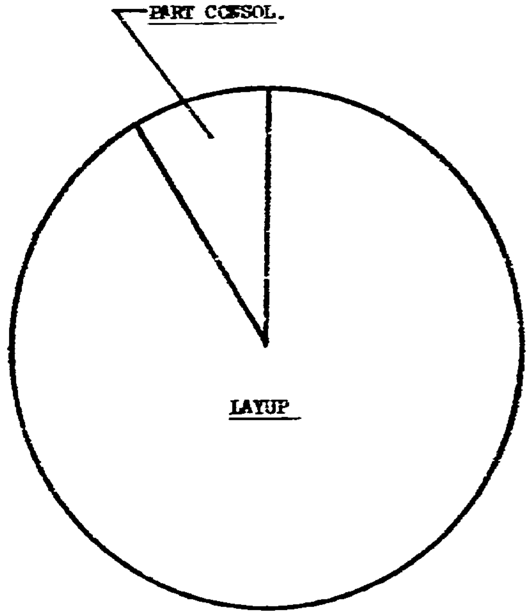
4th

UNIT COST

A44B2030-15 & 17

STRAPS

"ACCEM" (NORTHROP)

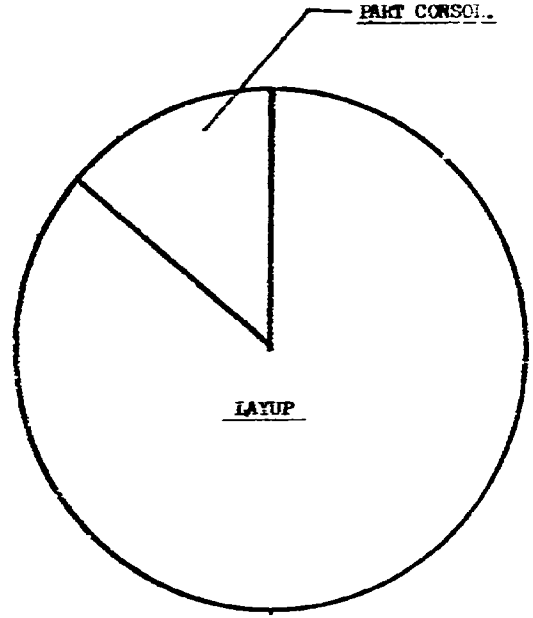


TASK	% OF HOURS
1) LAYUP	91%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	9%
4) FINISHING OPERATIONS	-
TOTAL	100%

* (INCLUDES SET-UP TIME)

0986-047W

ACTUALS (G.A.C.)



TASK	% OF HOURS
1) LAYUP	86%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	14%
4) FINISHING OPERATIONS	-
TOTAL	100%

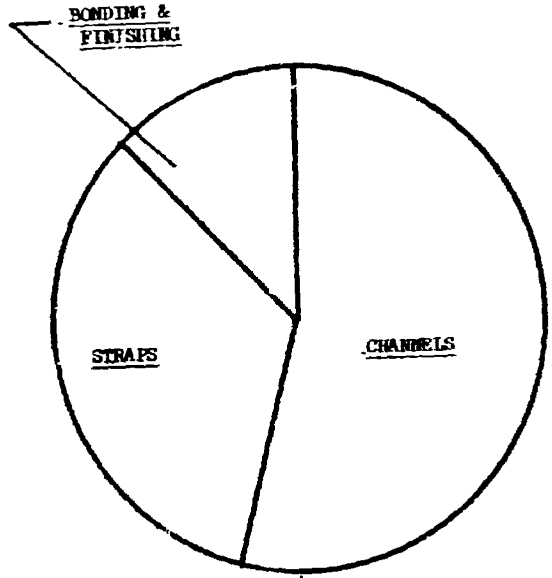
4th

UNIT COST

A44B203C-3

TOTAL COST

"ACCEM" (NORTHROP)

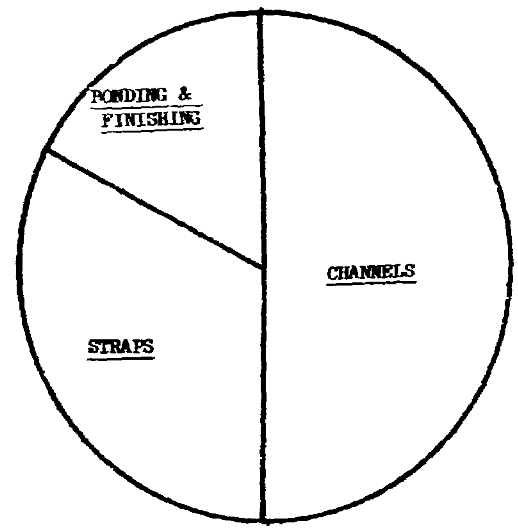


TASK	MANHOURS	% OF HOURS
1) CHANNELS	169.98	54%
2) STRAPS	106.23	34%
3) BONDING & FINISHING	36.41	12%
TOTAL	312.62	100%

* (INCLUDES SET-UP TIME)

0986-048W

ACTUALS (G.A.C.)



TASK	MANHOURS	% OF HOURS
1) CHANNELS	189.80	51%
2) STRAPS	122.52	33%
3) BONDING & FINISHING	58.11	16%
TOTAL	370.43	100%

ADVANCE COMPOSITE COST ESTIMATE

"ACCEM"

DATE 5/25/78

PART NAME: RIB ASSY. HOR'Z. STAB.

PART NUMBER: A44B2024-3

PRINCIPAL INVESTIGATOR: Tony Tornabe

DESCRIPTION:

CONSTRUCTION

☒ DETAIL ☐ ASSEMBLY

☒ GR/EP ☐ G/EP ☐ HYBRID ☐ BUILT-UP ☐ SANDWICH

LENGTH 71.74" HEIGHT 10.5 " LENGTH ______ WIDTH ______ THICKNESS ______

TOTAL NUMBER OF PLIES 62

GR/EP G/EP HYBRID AL.ALY.

4 NUMBER OF PARTS TYPE CHANNELS, STRAPS

NO. OF PARTS

TYPE

FLYAWAY WEIGHT: 7.5 LBS.

LINEAR FEET - TAPE 3"; 1,101

BUY/FLY 1.59

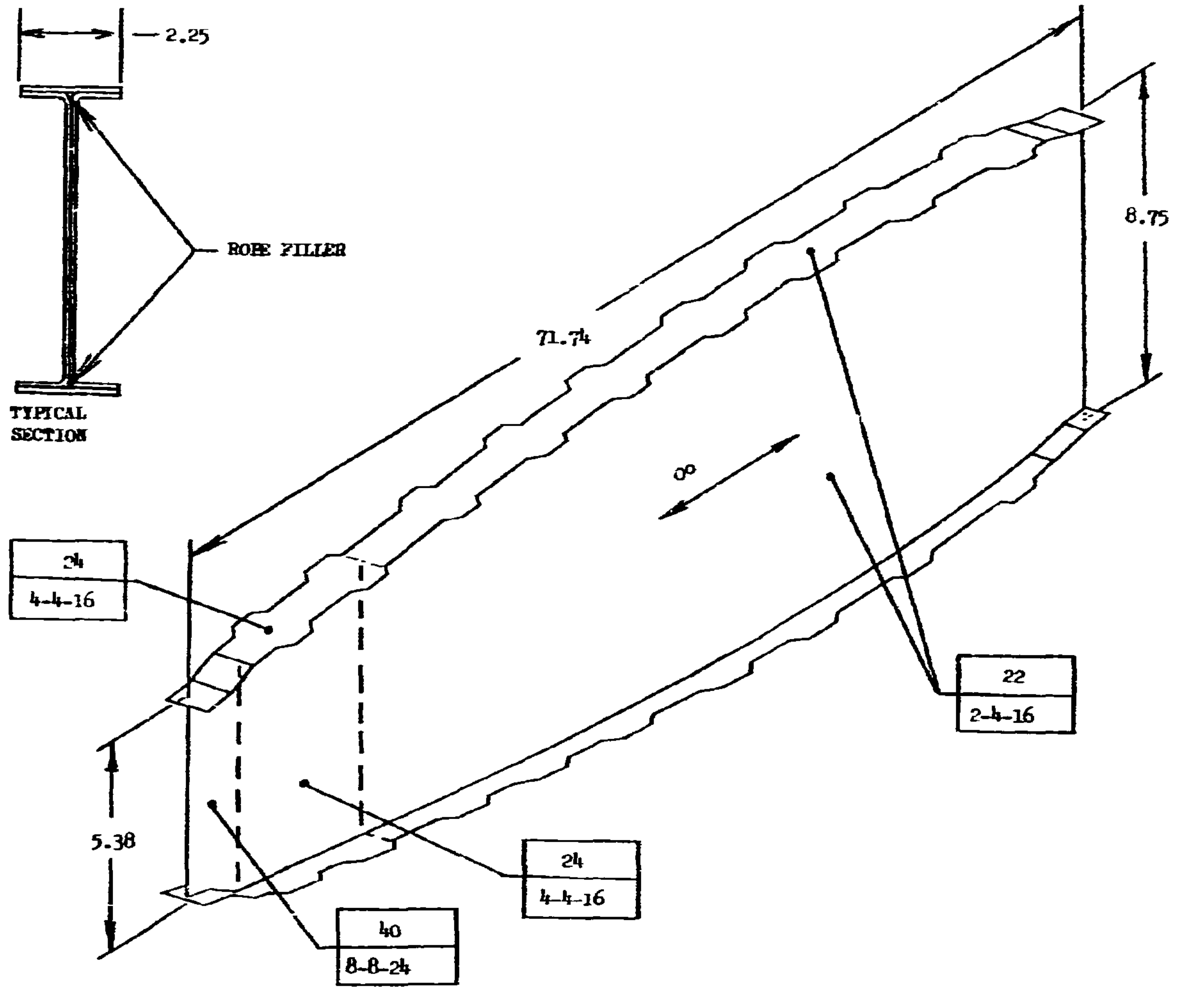
FLYAWAY WEIGHT: ______

LINEAR FEET - TAPE 3" ______

12" ______

BROADGOODS ______

0986-049W



A4432024-3 RIB ASSY.

0986-050W

A44B2024-3

OPERATIONAL DESCRIPTION	GAC ACTUAL UNIT 6	ACCEM EST. UNIT 6 GAC EXPERIENCE LEARNING CURVES	PERCENT DIFFERENCE RELATIVE TO GAC HOURS (1)	ACCEM. EST. Unit 6 DEFAULT LEARNING CURVES	COMMENTS
LAYUP					
O TOOL PREP & PLY DEPOSITION	58.60	68.73		76.02	
O TRANS TO LAYUP TOOL (STACK)	14.43	3.26		7.81	
O DEBULKING	7.07	6.03		14.46	
O BEND FACTORS	6.71	6.68		16.03	
O NET TRIM	6.07	4.29		10.28	
	92.88	89.60		124.60	
PART CONSOLIDATION					
O ASSEMBLY OF DETAILS	1.51	1.57		3.80	
O BLEEDER SYSTEM	2.02	2.88		6.99	
O VACUUM BAGGING	1.85	1.39		3.36	
O AUTOCLAVE					
O MONITORING	4.16	3.49		4.28	
O PART REMOVAL				4.20	
	9.54	9.33		22.63	
SUB TOTAL HOURS	102.42	98.33		147.23	
ROPE ADHESIVE	+1.79				
TOTAL HOURS	104.21				
VACUUM BAG FAB.	-0.44				
BLEEDER FAB.	-1.87				
ROPE ADHESIVE	-1.79				
TOTAL HOURS	100.11	98.33	2%		Note:

(1) Based on normalized values.

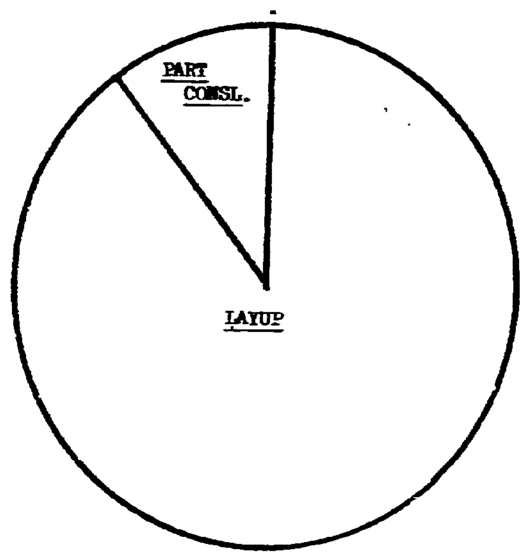
0986-051W

6th

UNIT COST

A44B2024-3

"ACCEM" (NORTHROP)

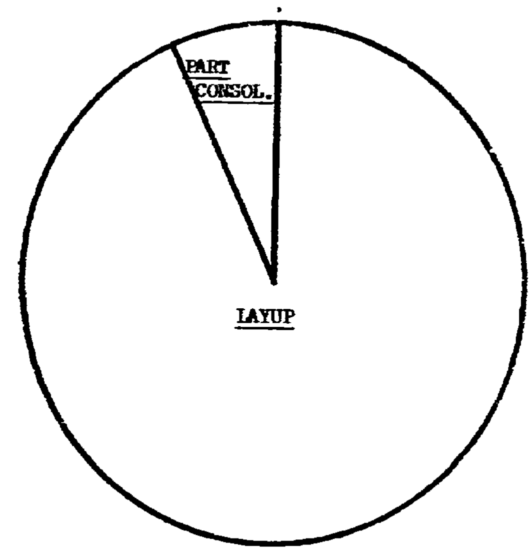


TASK	% OF HOURS
1) LAYUP	91%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	9%
4) FINISHING OPERATIONS	
TOTAL	100%

* (INCLUDES SET-UP TIME)

0986-052W

ACTUALS (G.A.C.)



TASK	% OF HOURS
1) LAYUP	93%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	7%
4) FINISHING OPERATIONS	-
TOTAL	100%

ADVANCE COMPOSITE COST ESTIMATE

"ACCEM" DATE 5/25/78

PART NAME: RIB ASSY. HORIZ. STAB.

PART NUMBER: A44B2027-13

PRINCIPAL INVESTIGATOR: TONY TORNABE

DESCRIPTION:

CONSTRUCTION

☒ DETAIL ☐ ASSEMBLY

☒ GR/EP ☐ G/EP ☐ HYBRID ☐ BUILT-UP ☐ SANDWICH

LENGTH 41.83" HEIGHT 2.5" LENGTH ____ WIDTH ____ THICKNESS ____

TOTAL NUMBER OF PLIES 18 ✓

GR/EP G/EP HYBRID AL.ALY.

1 NUMBER OF PARTS TYPE CHANNEL NO. OF PARTS

TYPE

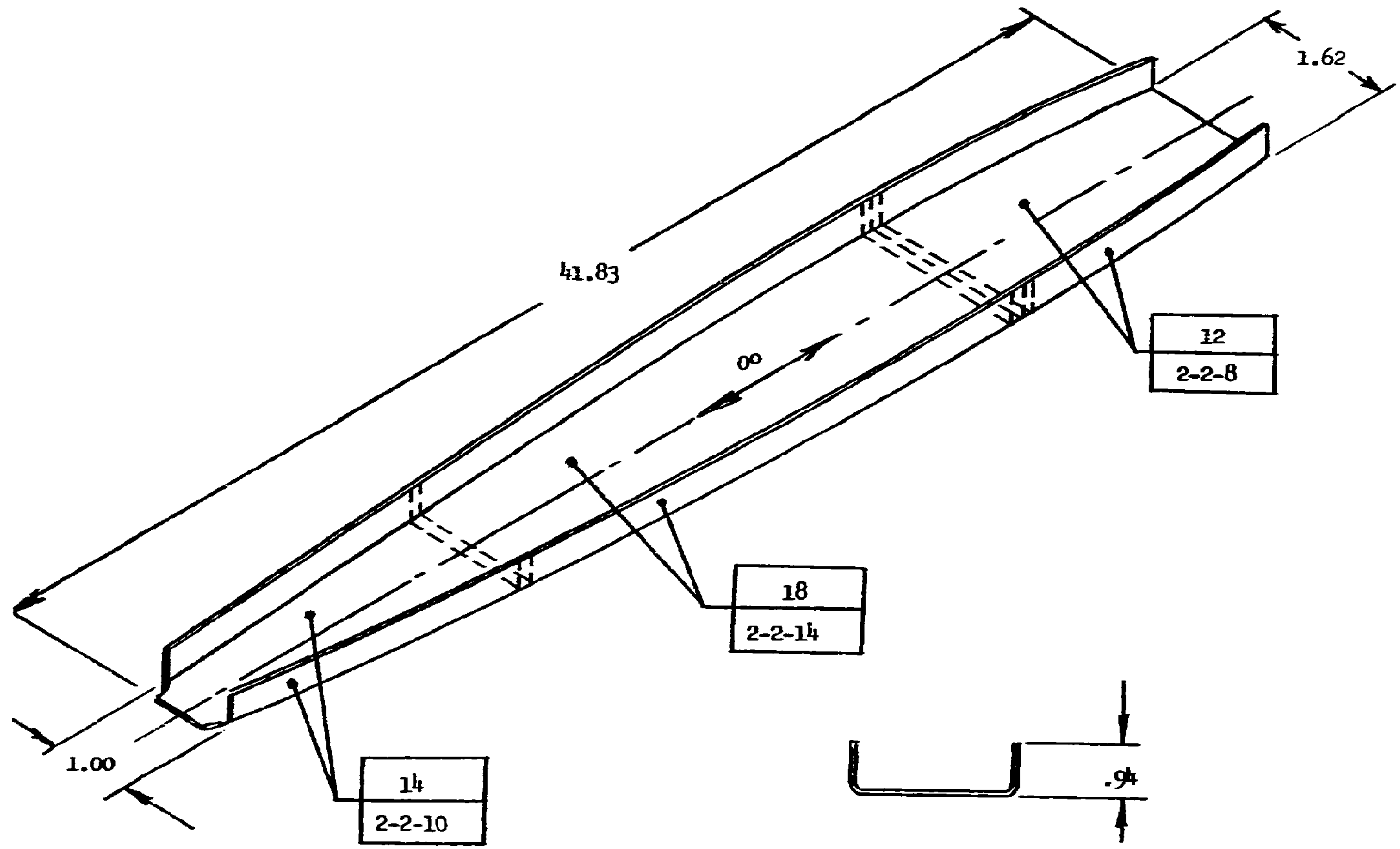
FLYAWAY WEIGHT: 0.66 LBS. FLYAWAY WEIGHT: ____

LINEAR FEET - TAPE 3"; 86.0 FT. LINEAR FEET - TAPE 3": ____

BUY/FLY 1.42 12": ____

BROADGOODS ____

0986-053W



A44B2027-13 RIB ASSY.

0986-054W

A44B2027-13

OPERATIONAL DESCRIPTION	GAC EXPERIENCE UNIT 4	ACCEM EST. UNIT 4 GAC EXPERIENCE LEARNING CURVES	PERCENT DIFFERENCE RELATIVE TO GAC HOURS (1)	ACCEM EST. UNIT 4 DEFAULT LEARNING CURVES	COMMENTS
-LAYUP					
o TOOL PREP & PLY DEPOSITION	9.80	9.98		11.75	
o TRANS TO LAYUP TOOL (STACK)	1.60	.47		1.25	
o DEBULKING	1.75	.75		1.98	
o BEND FACTORS	2.26	2.08		5.50	
o NET TRIM	1.0	.71		1.87	
	16.41	13.99		22.35	
-PART CONSOLIDATION					
o ASSEMBLY OF DETAILS	0	0		1.11	
o BLEEDER SYSTEM	.45	.21		.59	
o VACUUM BAGGING	1.06	.65		1.85	
o AUTOCLAVE					
o MONITORING	4.16	1.68		3.66	
o PART REMOVAL				1.12	
	5.67	2.54		8.33	
TOTAL HOURS	22.08	16.53		30.68	
VACUUM BAG FAB	-.38				
BLEEDER FAB	-.41				
TOTAL HOURS	21.29	16.53	22%		

Note:

(1) Based on Normalized values.

0986-055W

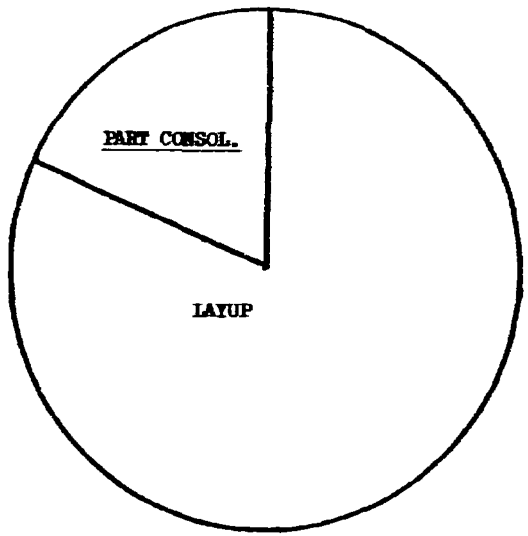
4 th

UNIT COST

A44B2027-13

"ACCEM" (NORTHROP)

(PART CONSOL.)

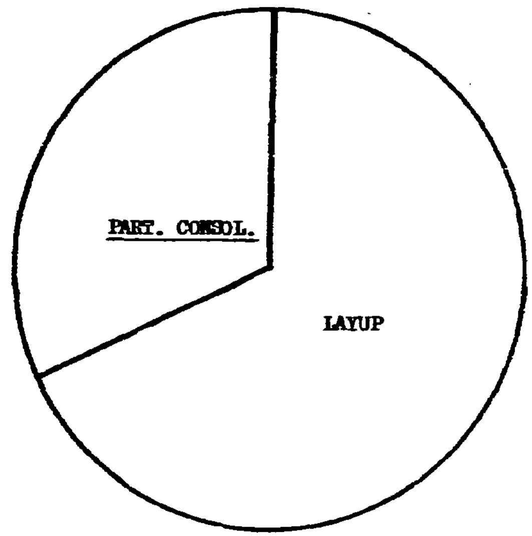


TASK	% OF HOURS
1) LAYUP	83%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	17%
4) FINISHING OPERATIONS	-
TOTAL	100%

* (INCLUDES SET-UP TIME)

0986-056W

ACTUALS (G.A.C.)



TASK	% OF HOURS
1) LAYUP	73%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	27%
4) FINISHING OPERATIONS	-
TOTAL	100%

ADVANCE COMPOSITE COST ESTIMATE

"ACCEM"

DATE 9-19-78

PART NAME: Fairing, Wing Center

PART NUMBER: A51B21003

PRINCIPAL INVESTIGATOR: Tony Tornabe

DESCRIPTION:

CONSTRUCTION

☐ DETAIL

☐ GR/EP ☐ G/EP ☐ HYBRID

LENGTH ______ HEIGHT ______

TOTAL NUMBER OF PLIES ______

NUMBER OF PARTS TYPE ______

FLYAWAY WEIGHT: ______

LINEAR FEET - TAPE 3"; ______

12" ______

☒ ASSEMBLY

☐ BUILT-UP ☒ SANDWICH

LENGTH 78" WIDTH 36" THICKNESS 1" Ave.

	GR/EP	G/EP	HYBRID	Paper Base Phenolic Resin
NO. OF PARTS	1	[illegible]		5
TYPE	SKIN			CORE

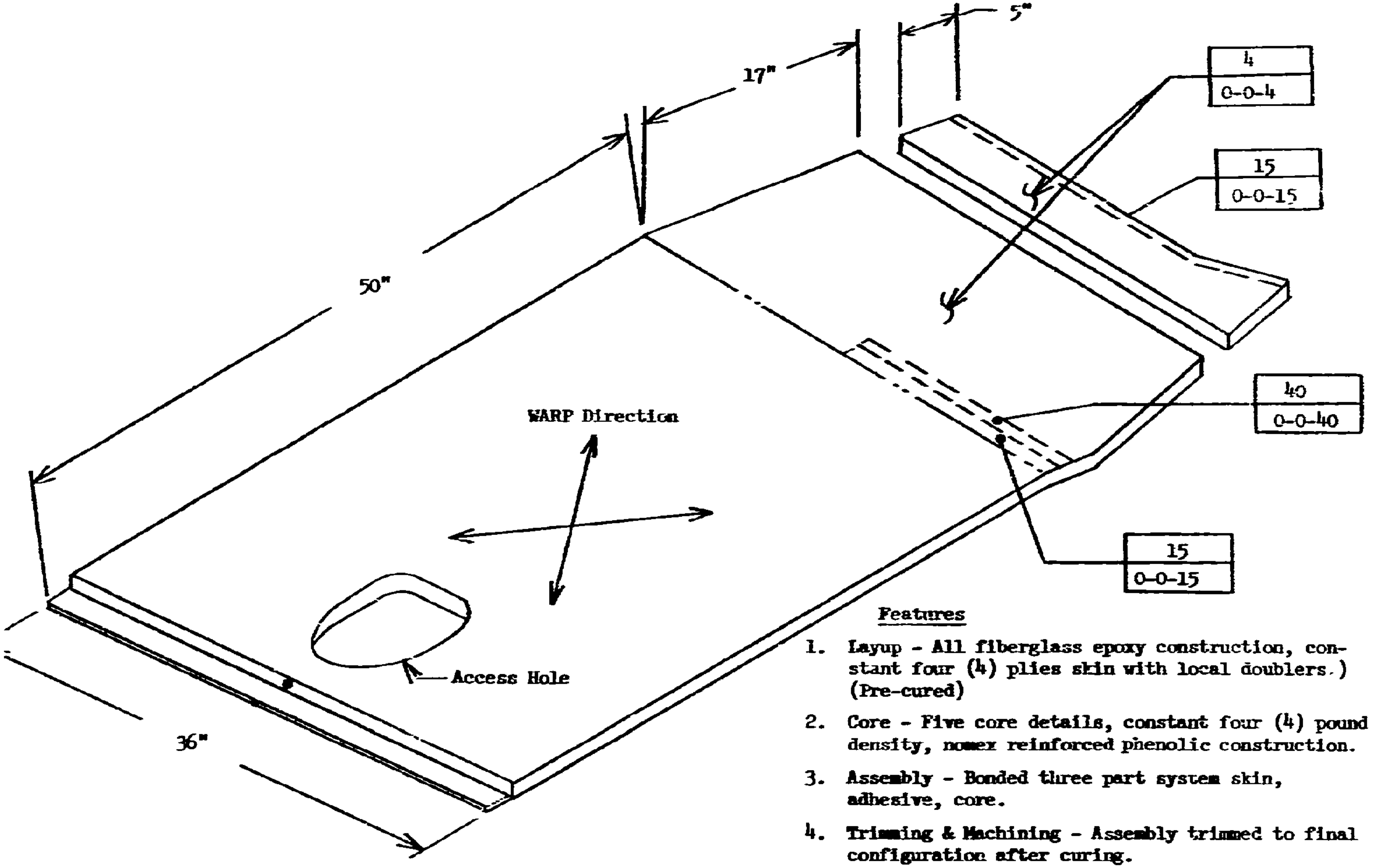
FLYAWAY WEIGHT: 19.0 lbs

LINEAR FEET - TAPE 3" ______

BUY/FLY 1.33

BROADGOODS 158 Ft^2

0986-057W



Features

1. Layup - All fiberglass epoxy construction, constant four (4) plies skin with local doublers.) (Pre-cured)
2. Core - Five core details, constant four (4) pound density, nomex reinforced phenolic construction.
3. Assembly - Bonded three part system skin, adhesive, core.
4. Trimming & Machining - Assembly trimmed to final configuration after curing.

A51B21003
F-14 WALKWAY FAIRING

0986-058W

A51B21003 Skin

OPERATIONAL DESCRIPTION	GAC ACTUAL UNIT 564	ACCEM EST. UNIT 564 GAC EXPERIENCE LEARNING CURVES	PERCENT DIFFERENCE RELATIVE TO GAC HOURS (1)	ACCEM. EST. UNIT 564 DEFAULT LEARNING CURVES	COMMENTS
LAYUP					
O TOOL PREP & PLY DEPOSITION	3.71	3.11		3.38	
O TRANS TO LAYUP TOOL (STACK)	-	-		-	
O DEBULKING	3.30	2.00		2.23	
O BEND FACTORS	1.18	.31		.35	
O NET TRIM	-	-		-	
	8.19	5.42		5.96	
PART CONSOLIDATION					
O ASSEMBLY OF DETAILS	-	-		-	
O BLEEDER SYSTEM	1.68	.53		.59	
O VACUUM BAGGING	1.40	.56		.62	
O AUTOCLAVE					
O MONITORING	4.1	1.22		.73	based on 2 part/cycle
O PART REMOVAL	-	-		.62	
	7.18	2.31		2.56	
SUB TOTAL HOURS	15.37	7.73		8.52	
VACUUM BAG FAB.	-0.140				
BLEEDER FAB.	-0.811				
TOTAL HOURS	14.42	7.73	46%		

NOTE:

(1) BASED ON NORMALIZED VALUES.

0986-059W

A51B21993 CORE & ASSEMBLY

OPERATIONAL DESCRIPTION	GAC ACTUAL UNIT 564	ACCEM EST. UNIT 564 GAC EXPERIENCE LEARNING CURVES	PERCENT DIFFERENCE RELATIVE TO GAC HOURS (1)	ACCEM. EST. UNIT 564 DEFAULT LEARNING CURVES	COMMENTS
HONEYCOMB CORE PREPARATION					
SAWING *	2.43	.74		.68	* Additional mfg. operations are required for for total sawing time.
POLYGLYCOL **	-	.88		.82	
FLAT MACHINING ***	7.28	1.06		.98	
STEP CUT MACHINING	.62	.61		.56	** Not req'd,core is stabilized by co-cured assembly.
SCARF CUT MACHINING	.56	.54		.50	
CUTOUT MACHINING	.11	.15		.14	
HAND FORMING	.17	.19		.18	*** The manhour is based on a minimum of four (4) passes, to achieve fina thickness.
SET-UP	.11	.27		.25	
	11.28	4.44		4.11	
PRE-BONDING					
TOOL PREP.	1.14	-		-	
PREFIT & ASSEMBLY OF DETAILS	.76	.70		.77	
ADHESIVE APPLICATION	1.25	3.63		4.04	
VACUUM BAGGING	1.40	.77		.86	
	4.55	5.10		5.67	
BONDING CYCLE					
AUTOCLAVE					
MONITORING	3.50	1.12		.73	
PART REMOVAL				.51	
	3.50	1.12		1.24	
FINISHING					
MACHINE SAWING	.12	.38		.41	
HAND SANDING	.13	.26		.29	
	.25	.64		.70	Note:
SUB TOTAL HOURS	19.59	11.30		11.73	(1) Based on normalized values.
VACUUM BAG FAB.	- .14				
BONDING TOOL PREP.	- 1.14				
	18.31	11.30	38%	11.73	

0986-060W

"ACCEM" (NORTHROP)

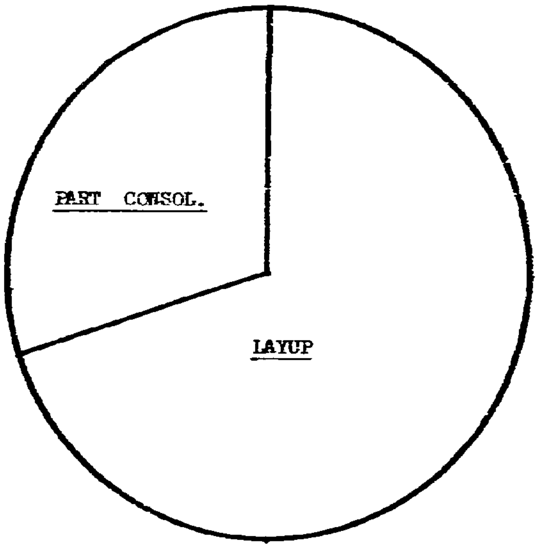
ACTUALS (G.A.C.)

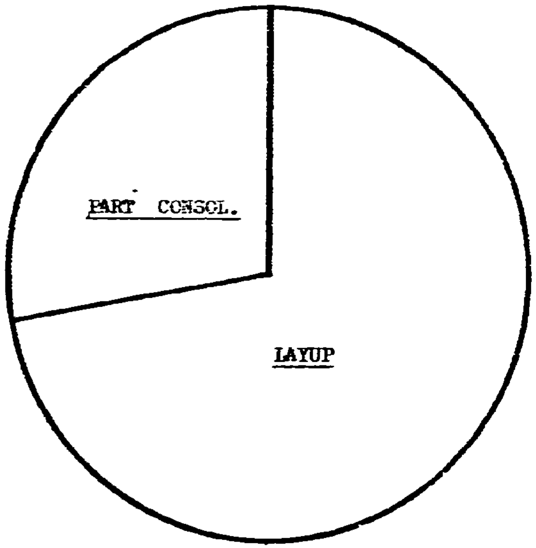
564th

UNIT COST

A51B21003-11

Skin





"ACCEM" (NORTHROP)

TASK	% OF HOURS
1) LAYUP	70%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	30%
4) FINISHING OPERATIONS	-
TOTAL	100%

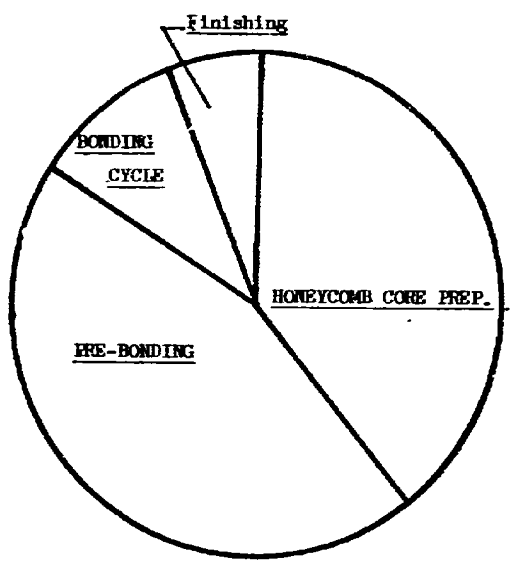
ACTUALS (G.A.C.)

TASK	% OF HOURS
1) LAYUP	72%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	28%
4) FINISHING OPERATIONS	-
TOTAL	100%

* (INCLUDES SET-UP TIME)
0986-061W

564th
UNIT COST
A51B21003-7
Assembly

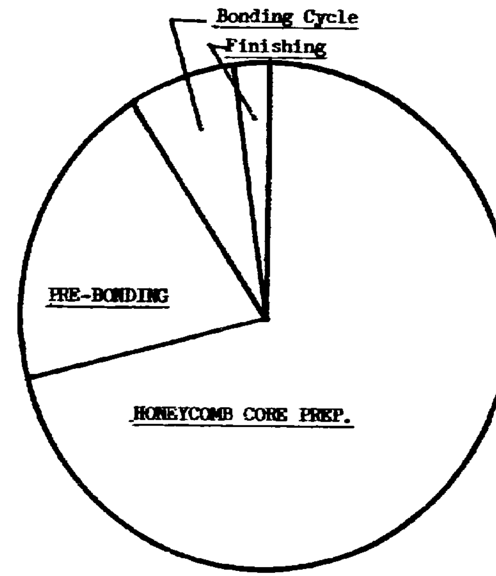
"ACCEM" (NORTHROP)



TASK	% OF HOURS
1) HONEYCOMB CORE PREP.	39%
2) PRE-BONDING	45%
3) BONDING CYCLE	10%
4) FINISHING	6%
TOTAL	100%

* (INCLUDES SET-UP TIME)

ACTUALS (G.A.C.)



TASK	% OF HOURS
1) HONEYCOMB CORE PREP	71%
2) PRE-BONDING	20%
3) BONDING CYCLE	7%
4) FINISHING	2%
TOTAL	100%

0986-062W

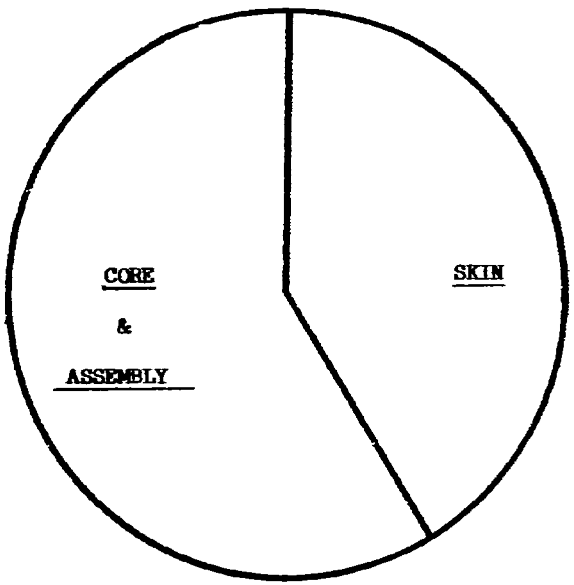
564th

UNIT COST

A51B21003

TOTAL COST

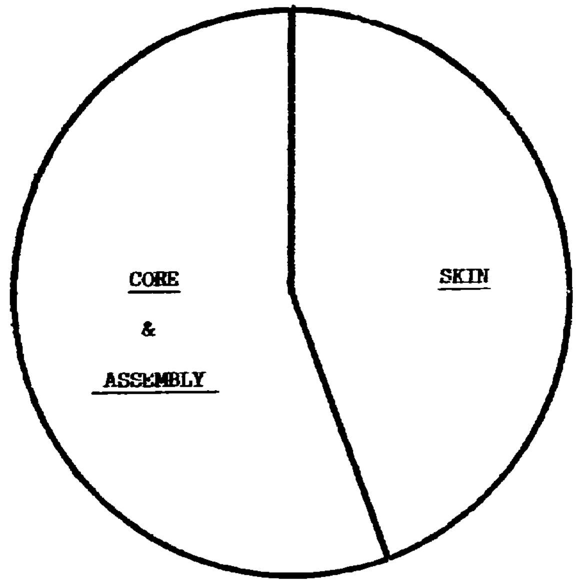
"ACCEM" (NORTHROP)



TASK	MANHOURS	% OF HOURS
1) SKIN	7.73	41%
2) CORE & ASSEMBLY	11.30	59%
TOTAL	19.03	100%

*(INCLUDES SET-UP TIME)

ACTUALS (G.A.C.)



TASK	MANHOURS	% OF HOURS
1) SKIN	14.42	44%
2) CORE & ASSEMBLY	18.31	56%
TOTAL	32.73	100%

0986-063W

ADVANCE COMPOSITE COST ESTIMATE

"ACCEM"

DATE 10-30-78

PART NAME: Fairing, Stores Closure Skin

PART NUMBER: A51B23108

PRINCIPAL INVESTIGATOR: Tony Tornabe

DESCRIPTION:

CONSTRUCTION

[x] DETAIL

[ ] GR/EP [x] G/EP [ ] HYBRID

LENGTH 20.6" HEIGHT 13"

TOTAL NUMBER OF PLIES 54

1 NUMBER OF PARTS TYPE Skin

FLYAWAY WEIGHT: 3.91 lbs

LINEAR FEET - TAPE 3"; ______

BUY/FLY 1.46

BROADGOODS 14,592 in²

[ ] ASSEMBLY

[ ] BUILT-UP [ ] SANDWICH

LENGTH ______ WIDTH ______ THICKNESS ______

	GR/EP	G/EP	HYBRID	AL.ALY.
NO. OF PARTS				
TYPE				

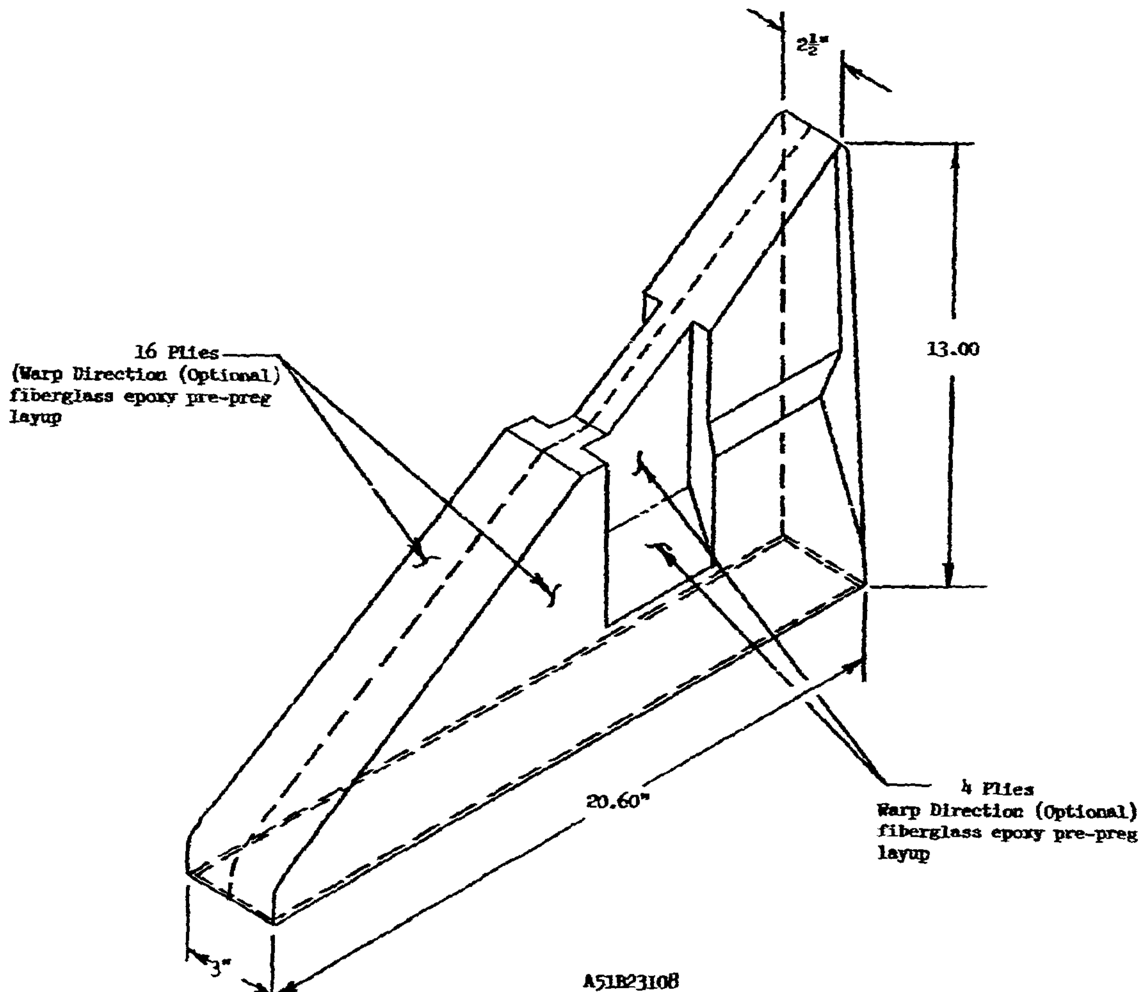
FLYAWAY WEIGHT: ______

LINEAR FEET - TAPE 3" ______

12" ______

BROADGOODS ______

0986-064W



A51B23108
Fairing, Stores Closure Skin

0986-065W

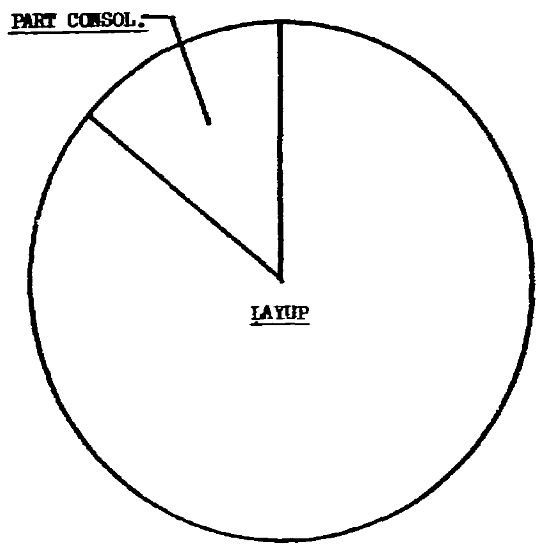
A51B23108 FAIRING

OPERATIONAL DESCRIPTION	GAC ACTUAL UNIT 282	ACCEM. EST. UNIT 282 GAC EXPERIENCE LEARNING CURVES	PERCENT DIFFERENCE RELATIVE TO GAC HOURS (1)	ACCEM. EST. UNIT 282 DEFAULT LEARNING CURVES	COMMENTS
LAYUP					
O TOOL PREP & PLY DEPOSITION	4.03	3.02		3.12	
O TRANS TO LAYUP TOOL (STACK)	-	-		-	
O DEBULKING	1.80	.88		1.10	
O BEND FACTORS	1.43	.27		.34	
O NET TRIM	-	-		-	
	7.26	4.16		4.56	
PART CONSOLIDATION					
O ASSEMBLY OF DETAILS	-	-		-	
O BLEEDER SYSTEM	.25	.07		.08	
O VACUUM BAGGING	.21	.21		.26	
O AUTOCLAVE					
O MONITORING	1.08	.67		.64	
O PART REMOVAL				.21	
	1.54	.95		1.19	
SUB TOTAL HOURS	8.80	5.11		5.75	
VACUUM BAG FAB.	- .02				
BLEEDER FAB.	- .12				
TOTAL HOURS	8.66	5.11	41%		Note: (1) based on normalized values.

0986-066W

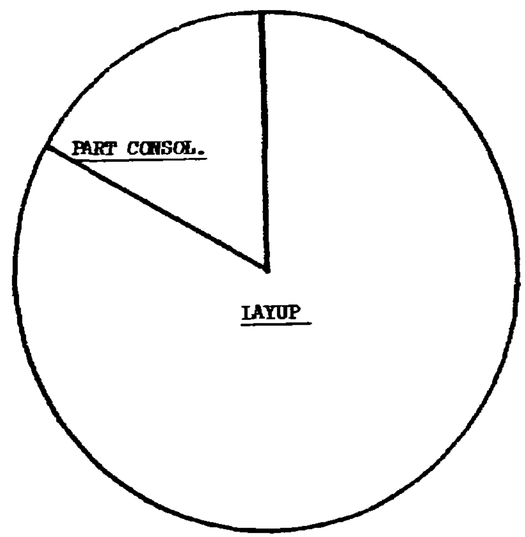
A51B23108 FAIRING
282nd
UNIT COST
LOT SIZE 25

"ACCEM" (NORTHROP)



TASK	% OF HOURS
1) LAYUP	86%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	14%
4) FINISHING OPERATIONS	-
TOTAL	100%

ACTUALS (G.A.C.)



TASK	% OF HOURS
1) LAYUP	84%
2) HONEYCOMB CORE PREP.	-
3) PART CONSOLIDATION	16%
4) FINISHING OPERATIONS	-
TOTAL	100%

:0986-067W

APPENDIX B

SAMPLE "ACCEM" COMPUTER DATA

ADVANCED COMPOSITE COST ESTIMATE

ESTIMATOR: TONY TORNABE DATE: 05/25/78

ESTIMATE NUMBER:

PART NAME: RIB ASSY,HORIZ,STAB

PART NUMBER: A44B2027-13

INPUT FORMS	QUANTITY
LAYUP	1
HONEYCOMB CORE OPERATION	0
PART CONSOLIDATION	1
FINISHING OPERATIONS	0
COST PROJECTIONS	1

0986-069W

LAYUP

PART NAME: RIB ASSY,
PART NUMBER: -13
LAYUP TOOL NOT = CURING TOOL
NO. OF DEBULKING OPERATIONS: 2

QTY: 1
TRIM ALLOWANCE: 0.50
TYPE OF BAG: DISPOSABLE

	MATERIAL DATA	
	DENSITY	COST
GRAPHITE--3" TAPE	0.000400	45.00
GRAPHITE--12" TAPE	0.000400	45.00
GRAPHITE--WOVEN	0.000880	93.00
FIBERGLASS--3" TAPE	0.000540	8.70
FIBERGLASS--12" TAPE	0.000540	8.70
FIBERGLASS--WOVEN	0.001040	9.30

					BEND DATA			PLY DESCRIPTION		RECT		NON-RECT		MATL		
LD	#P	LH	DT	TH	LENGTH	CR	FW	ORI	CT	LENGTH	WIDTH	AREA	DIST	F	T	WD
2	0	1	2	6	83.70	446.0	1.50	45	8	0.0	0.0	141.0	32.0	1	1	3.
2	0	1	2	6	83.70	446.0	1.50	90	2	0.0	0.0	141.0	41.8	1	1	3.
2	0	1	2	6	83.70	446.0	1.50	0	2	0.0	0.0	141.0	4.6	1	1	3.
2	0	1	2	6	55.10	446.0	1.50	45	2	0.0	0.0	93.0	22.0	1	1	3.
2	0	1	2	6	56.00	446.0	1.50	45	4	0.0	0.0	61.0	15.8	1	1	3.

0986-070W

LAYUP

FACTORY STANDARD HOURS	SET-UP	RUN	
CLEAN LAYUP TOOL	0,0	0,001	
POSITION MYLAR	0,0	[illegible]	
PLY DEPOSITION	0,050	[illegible]	
TRANS TO LAYUP TOOL	0,0	[illegible]	
CLEAN CURING TOOL	0,0	[illegible]	
APPLY RELEASE AGENT	0,0	[illegible]	
TRANS TO CURING TOOL	0,0	[illegible]	
SUBTOTAL	0,050	[illegible]	
DEBULKING (DISP BAG)	0,020	0,135	
TOTAL LAYUP	0,070	1,322	
BEND FACTOR HOURS		0,374	
MATERIAL	USAGE (SQ.IN.)	SCRAP (SQ.IN.)	PERCENT SCRAP
GRAPHITE--3" TAPE	2801,55	679,55	32,02
	WEIGHT	COST	
GRAPHITE--3" TAPE	0,85	38,20	

0988-071W

PART CONSOLIDATION

CYCLE NO.: 1
PART NAME: SPAR ASSEMBLY
PART NUMBER: A44B2027(-13) QTY: 1

COMPONENT DETAIL PARTS

PART NAME	PART NO.	QTY
RIB ASSY.	-13	1

VACUUM BAGGING: DISPOSABLE
RESIN BLEED PLIES-TO-BLEEDER RATIO: 2.2
BAGGING AREA: 281.00 SEALING/CLAMPING PERIMETER: 95.00

CURING TOOL: AUTOCLAVE

0986-072W

PART CONSOLIDATION

FACTORY STANDARD HOURS	SET-UP	RUN
SET UP	0.070	
BEFORE CURE		
APPLY POROUS FILM		0.003
APPLY BLEEDER PLIES		[illegible]
APPLY NONPOROUS FILM		[illegible]
APPLY VENT CLOTH		[illegible]
INSTALL VACUUM FTGS		[illegible]
INSTALL THERMOCPLS		[illegible]
APPLY SEAL STRIPS		[illegible]
APPLY DISPOSABLE BAG		[illegible]
SEAL EDGES		[illegible]
CONNECT VACUUM LINES		[illegible]
SMOOTH BAG DOWN		[illegible]
CHECK SEALS		[illegible]
REMOVE VACUUM LINE		[illegible]
CHECK CHAMBER AUTO.		[illegible]
LOAD LAYUP IN AUTO.		[illegible]
CONNECT VACUUM LINES		[illegible]
CONNECT T.C. LEADS		[illegible]
CHECK FOR LEAKS		[illegible]
CLOSE DOOR		[illegible]
DURING CURE		
SET RECORDERS		[illegible]
CYCLE CHECK		[illegible]
SHUT DOWN		[illegible]
REMOVE CHARTS		0.003
AFTER CURE		
OPEN DOOR		[illegible]
RELEASE T.C. LEADS		[illegible]
RELEASE VAC. LINES		[illegible]
REMOVE PART FR AUTO.		[illegible]
REMOVE DISP. BAG		[illegible]
REMOVE THERMOCOUPLES		[illegible]
REMOVE VACUUM FTGS		[illegible]
REMOVE PROCESS MATL		[illegible]
REMOVE LAYUP & ASIDE		[illegible]
CLEAN TOOL		[illegible]
TOTAL HOURS	0.070	0.496

0986-073W

TOTAL FACTORY LABOR STANDARD HOURS

FACTORY STANDARD HOURS	SET-UP	RUN
LAYUP	0.070	1.322
HONEYCOMB CORE PREP	0.0	0.0
PART CONSOLIDATION	0.070	0.456
FINISHING OPERATIONS	0.0	0.0
TOTAL HOURS	0.140	1.779

0986-074W

COST PROJECTION

PRODUCTION COST ESTIMATE AT UNIT NO.(4
AVERAGE LOT SIZE 5.
LINEAR UNIT CURVE

PROJECTION FACTORS	T1,VAR	CURVE SLOPE
LAYUP	1?.78	7?.?0 %
HONEYCOMB CORE PREP	[illegible]	[illegible]
PART CONSOLIDATION	[illegible]	[illegible]
FINISHING OPERATIONS	1.00	?9.00 %

LABOR RATES	$/HR
FACTORY LABOR	10.00
QUALITY CONTROL	10.00
TOOLING	10.00
MFG ENGINEERING	10.00
ENGINEERING	10.00
GRAPHIC SERVICES	10.00

SUPPORT FUNCTIONS	BASE	FACTORS
QUALITY CONTROL	[illegible]	0.??
TOOLING	[illegible]	[illegible]
MFG ENGINEERING	[illegible]	[illegible]
ENGINEERING	[illegible]	[illegible]
GRAPHIC SERVICES	[illegible]	[illegible]
SUPPORT MATERIAL	[illegible]	0.30

OVERHEAD RATES	
FACTORY LABOR	1.?00
QUALITY CONTROL	[illegible]
TOOLING	[illegible]
MFG ENGINEERING	[illegible]
ENGINEERING	[illegible]
GRAPHIC SERVICES	[illegible]
MATERIAL	[illegible]
ADMINISTRATIVE	0.?00

0986-075W

COST PROJECTION

UNIT COST ESTIMATE AT T 4

COST ELEMENT	STD. HRS	T 4 HRS	DOLLARS	
FACTORY LABOR				
"ACCEM" ESTIMATED HOURS FOR NET TRIMMING (HAND CALCULATION)		0.71	7.10	
LAYUP	1.33	[illegible]	[illegible]	
HONEYCOMB CORE PREP	0.0	[illegible]	0.0	
PART CONSOLIDATION	0.46	[illegible]	[illegible]	
FINISHING OPERATIONS	0.0	[illegible]	0.0	
TOTAL FACTORY LABOR	1.79	[illegible]	[illegible]	
		16.53	165.30	
SUPPORT LABORS				
QUALITY CONTROL		[illegible]	[illegible]	
TOOLING		[illegible]	[illegible]	
MFG. ENGINEERING		[illegible]	[illegible]	
ENGINEERING		[illegible]	[illegible]	
GRAPHIC SERVICES		[illegible]	[illegible]	
TOTAL SUPPORT LABOR			[illegible]	
LABOR OVERHEAD				
FACTORY LABOR			[illegible]	
QUALITY CONTROL			[illegible]	
TOOLING			[illegible]	
MFG. ENGINEERING			[illegible]	
ENGINEERING			[illegible]	
GRAPHIC SERVICES			[illegible]	
TOTAL OVERHEAD			[illegible]	
TOTAL LABOR			~~[illegible]~~	968.98
MATERIAL				
PRODUCTION MATERIAL			[illegible]	
SUPPORT MATERIAL			[illegible]	
MFG. ALLOWANCE			[illegible]	
OVERHEAD			[illegible]	
TOTAL MATERIAL			[illegible]	
ADMINISTRATIVE OVERHEAD			155.98	
TOTAL COST			~~[illegible]~~	1,202.97

	WEIGHT
LAYUP	0.85
HONEYCOMB CORE PREP	0.0
TOTAL	0.85

0986-076W

REFERENCES

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3. "ACCEM" Computer Program and Input Data Sets

☆U.S.Government Printing Office: 1979 — 657-002/60