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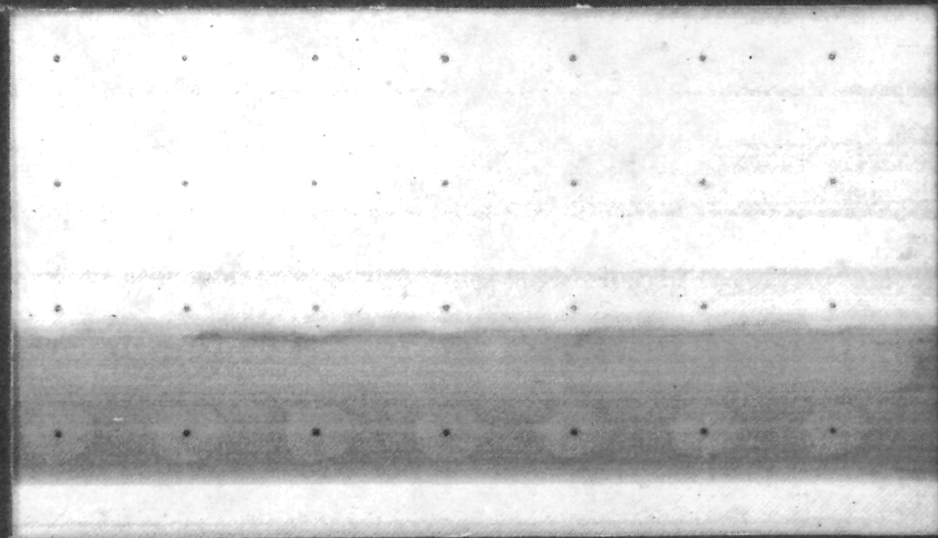

DOUGLAS AIRCRAFT COMPANY

MCDONNEL

CORPORATION

NASA Contractor Report 145382-1

Advanced Composites Wing Study Program
Volume 1–Executive Summary

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1.0 INTRODUCTION AND BACKGROUND

A study of advanced composite materials to reduce weight of commercial transport aircraft is one of many areas being investigated by the NASA and industry under the Aircraft Energy Efficiency (ACEE) program. The overall objective of the ACEE program is to improve the energy efficiency of air transportation and conserve petroleum fuel..

The objective of the Wing Study is to plan the required effort leading to commitment of extensive advanced composite use in large primary wing structures of commercial transports entering service in 1985 to 1990.

The United States commercial airlines consumed approximately 233-million barrels of fuel in 1977. With current jet fuel at about 40 cents/gallon, fuel costs have become the largest single contributor to airline direct operating costs. As a result, the conservation of fuel has become important from the standpoint of airline cost reduction as well as energy conservation. A third important consideration is the significant impact of foreign oil imports on the U.S. balance of payments.

Technology improvements present opportunities to save fuel. The shaded bands in Figure 1 show the potential gains in the fuel efficiency to be expected from the various technologies and in the time frames now judged by Boeing to be appropriate. It is apparent that some major improvements are in the offing, including advanced structural materials. The large upper shaded band shows an estimate of the combined effect of all technology improvements on fuel saving.

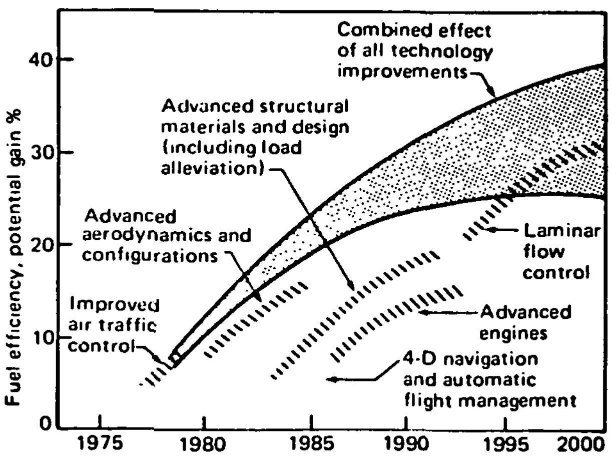


Figure 1. Technology Benefits

Use of composite materials for primary structure offers the potential for up to 25% structural weight reduction and 12% to 15% fuel reduction (figure 2). In terms of direct operating cost (DOC), Figure 3, the 25% weight savings converts to a reduction in DOC of 11%.

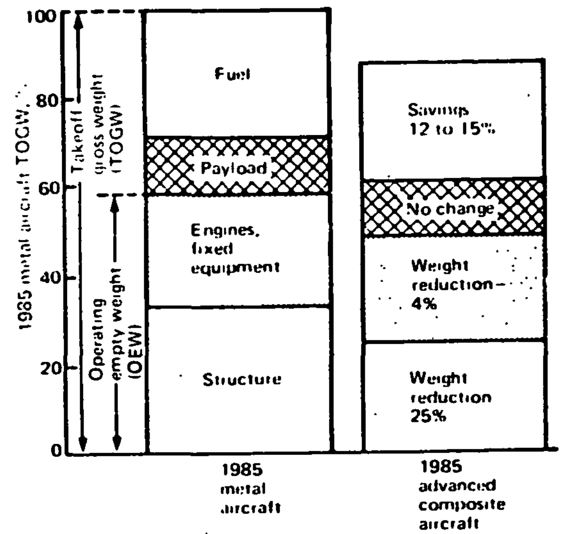


Figure 2. Advanced Composites Weight Reduction and Fuel Savings

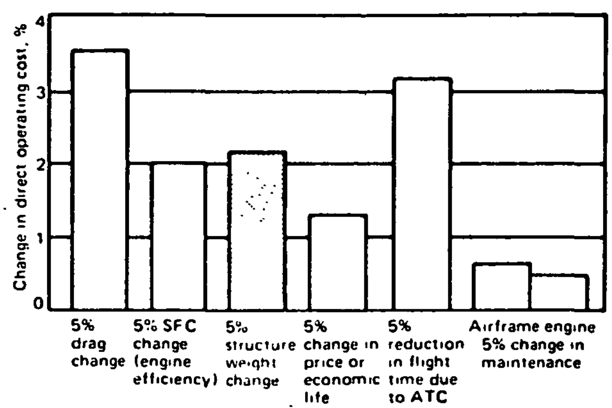


Figure 3. Structural Weight/DOC Relationship

At Boeing, several advanced composite components, Figure 4, are currently being evaluated as production options. These components are limited to secondary and lightly loaded primary structure. To gain large weight savings, future efforts must be directed to areas of highly loaded primary structure, e.g., the wing. Structural weight comprises 58% of the operational empty weight and the wing makes up 35% of the structural weight (figure 5).

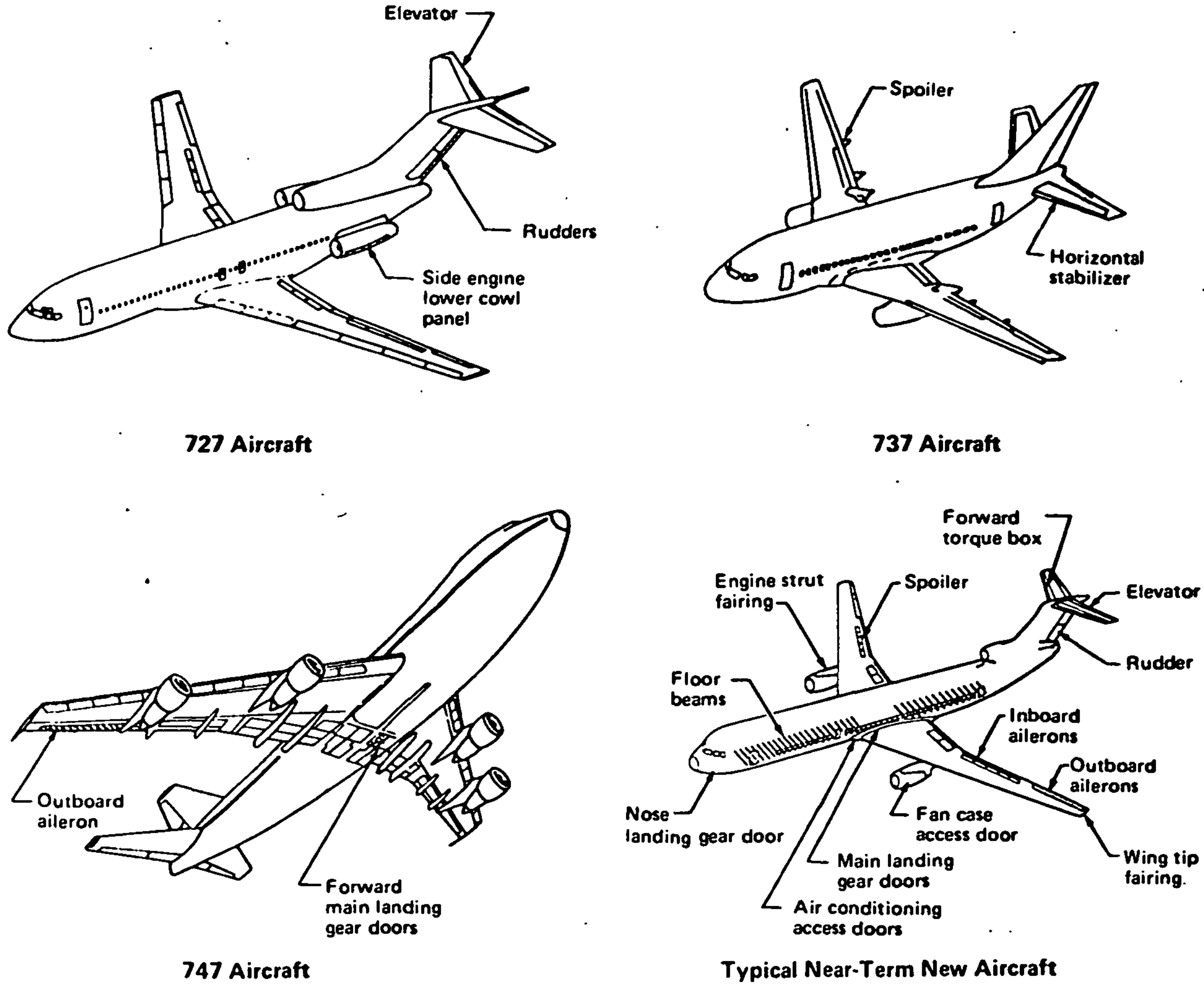
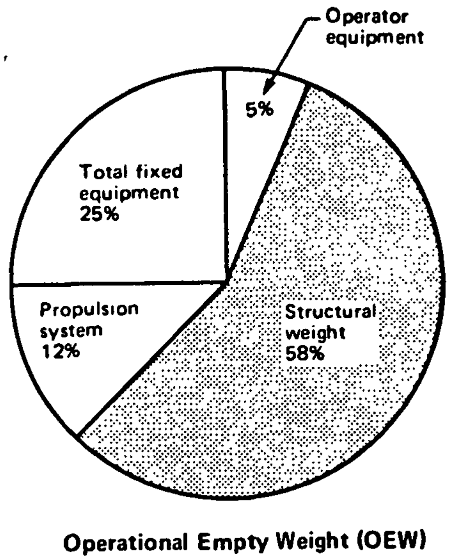


Figure 4. Potential Production Components



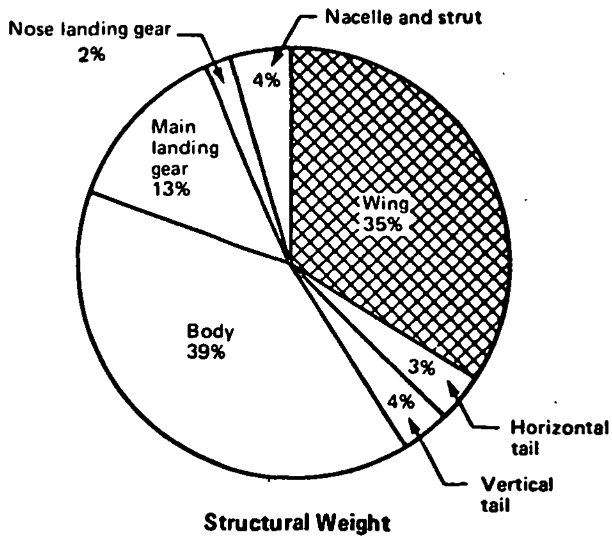


Figure 5. Typical Transport Weight Distribution

The Boeing Company has estimated that the program delineated in this summary will require an expenditure of approximately 2,500,000 manhours over a period of 7 years. The estimate includes manhour requirements regardless of funding sources, and makes assumptions as to the usability of relevant data that might be available from other programs either now completed or planned concurrently with the recommended Wing Program. The estimate was prepared for planning purposes only, and does not represent a Boeing Company commitment.

This Advanced Composites Wing Study Program is an essential step in establishing the development necessary to commit advanced composite materials for commercial production of highly loaded primary airplane structures by the mid-1980s.

2.0 WING STUDY GROUND RULES

Ground rules were established early to form a program framework. The first ground rule was a production readiness date of 1985 supporting extensive use of advanced composites in wings of commercial aircraft entering service in the 1985 to 1990 time frame.

Maximum use of advanced composites in the wing box was the next ground rule, with emphasis to be placed on the use of graphite/epoxy materials. The conceptual design was concentrated on the primary structural box; consideration also was given to interfacing control surfaces and installation of systems. Consistent with this maximum-use ground rule, a weight reduction goal of 25% from current aluminum design was established, based upon results from on-going programs (figure 4).

Cost is an essentail element in a production commitment. It was, therefore, established that the advanced composites wing costs must be competitive with aluminum wing costs. A production-rate ground rule of eight airplanes per month was selected to assist in identifying facility needs.

It was recognized that evolutionary material system developments (similar to those for steel and fiberglass) could be expected. These developments are both desirable and logical. It also was recognized that the capital investments required to implement a production decision would be extremely large and are expected to be an order of magnitude larger than the advanced composite development costs. For the purpose of this study, neither of these factors was considered to be a constant.

3.0 WING STUDY APPROACH

Boeing's approach to the Wing Study consisted of a closely integrated effort among the technical, manufacturing, and management functions. This approach is illustrated in Figure 6. This ensures consideration of all facets of contemporary composite technology and is consistent with The Boeing Company process for a production commitment.

A conceptual baseline metal wing for an anticipated 1985 transport, Figure 7, was established to provide a common point of comparison. The selected baseline design consisted of a wing for a wide-body aircraft having a takeoff gross weight of 136 080 kg (300 000 lb) and wing characteristics of 45.72m (150 ft) span, advanced airfoil, and structural box weight of 10 433 kg (23 000 lb). All evaluations and comparisons were made relative to this wing box.

A conceptual advanced composite design then was defined in detail sufficient to identify projected requirements in all areas. Design and producibility requirements were considered. The principal thrust was to develop concepts exploiting manufacturing advantages of advanced composites to produce low-cost structure. Thus, manufacturing suitability was emphasized equally with structural efficiency during the development of concepts.

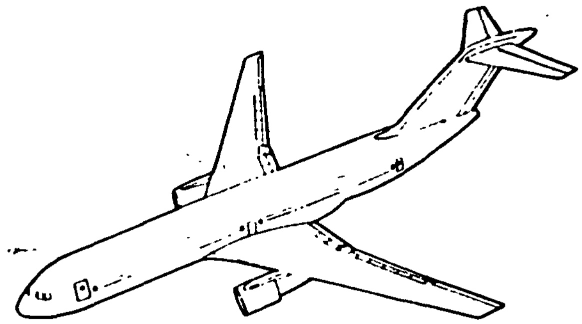


Figure 7. Baseline Airplane

A preliminary evaluation considering various forms of wing structure assembly and component definition was performed to focus efforts on concepts meaningful to the study goals. Considered were (1) planform, (2) cross-section, (3) substructure, and (4) skin panel concepts. Relative rankings of each are summarized in Figure 8.

The results of the design/producibility evaluations were utilized to define an advanced composite baseline design suitable for conducting the technical assessment task. In each case, the concept rated number one was used.

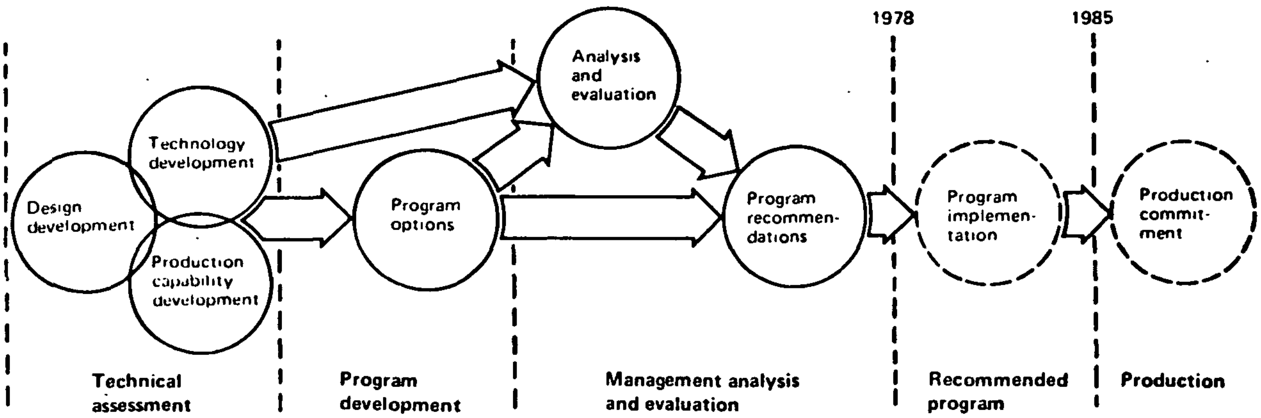


Figure 6. Wing Study Approach

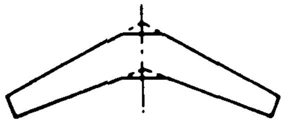
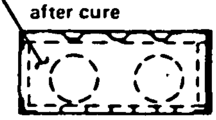
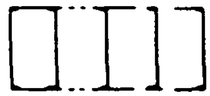
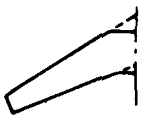
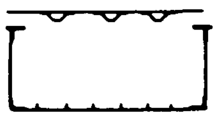
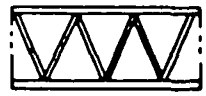
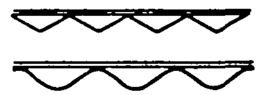
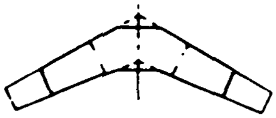
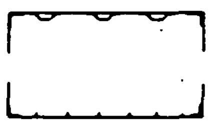
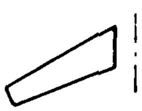
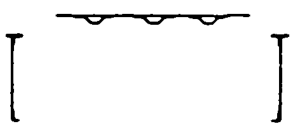
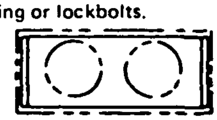
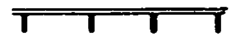
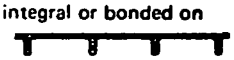
General configuration (planform) concept	General configuration (cross-section) concept	Substructure configuration concept	Skin panel configuration concept
1. Full-span skin • Can accommodate either ℄ or side-of-body sweep break  Rank: 3	1. One-piece box  Rank: 4	1. Multispar • Solid laminate or sandwich spars, cocured or bonded  Rank: 2	1. Sandwich • Aluminum or nonmetallic cores  Rank: 3
2. Half-span skin  Rank: 4	2. One-piece lower box  Rank: 3	2. Truss rib • Trusses prefabricated from pultruded sections, assembled by bonding  Rank: 4	2. Single face sandwich  Rank: 5
3. Center section • Splice location variable  Rank: 2	3. Split box  Rank: 2	3. Post • Posts prefabricated, installed during box assembly into fittings in covers  Rank: 3	3. Built-up stiffeners • Stiffeners can be integral or bonded onto skin • Y, J, Z shapes common  Rank: 2
4. Side-of-body  Rank: 1	4. Built-up box  Rank: 1	4. Solid rib • Ribs—built up or sandwich. Installed by bonding or lockbolts.  Rank: 1	4. Blade stiffeners • *Solid blades, integral* or bonded on  • Built-up blades, integral or bonded on  Rank: 1
			5. Hats • Built up or solid laminate, integral, or bonded on  Rank: 4

Figure 8. Design/Producibility Evaluation

Technology development and production capability needs were determined by comparing identified technology requirements to the anticipated state-of-the-art level. This anticipated level was determined through a comprehensive examination of technology disciplines to assess the current state-of-the-art and then adding projected results of on-going programs. These results are contained in Section 4.0.

The baseline aluminum wing was used to establish basic structural requirements and criteria for the advanced composite wing design. Evaluations of the advanced composite technical needs were made relative to this metal baseline wing box, which served as a check and focal point to verify that all needs had been identified. In many instances, the differences in material properties require a different development treatment. The identification of these differences constituted an important output of the study. Some of these requirements reflected the certification requirements identified in the draft FAA Advisory Circular.

In addition to technology requirements, FAA certification criteria and airline acceptance of graphite-epoxy structure are essential prior to production go-ahead. Therefore, certification and service acceptance were considered in the analysis and evaluation of program risks.

After determining the needs for technology, design, and production capability, several options were identified. The options involved various approaches for gaining the knowledge, experience, and information required to support cost decisions and certification requirements. Each option was evaluated to determine how it would satisfy requirements and its cost and schedule implications. An option then was selected for the required development program that will integrate and validate technology design and production development. The option was selected as a part of the recommended development program, which is described in Paragraph 4.4.

4.0 WING STUDY RESULTS

A summary of the Wing Study results is presented in the following text. Detailed discussions of these results are contained in Volume II (CR 145382-2), Final Report.

4.1 TECHNICAL ASSESSMENT

The technical assessment was divided into three, highly integrated tasks, i.e., design, technology, and production capability development.

Design Assessment - Assessment of the baseline design indicated that the design philosophy and/or approach in several areas must receive thorough investigation prior to a production commitment. Key areas requiring investigation are:

- Validation of the producibility study
- Structural detail development
- Lightning protection
- Fuel and other system compatibility development
- Finishes and sealing development
- Inspection and repair development
- Damage tolerance design development

Technology Assessment--Evaluation and reduction of the extensive data generated in the technology evaluation resulted in identification of the most critical concerns and information needs of advanced composite wing development. The evaluation reconfirmed previously recognized areas requiring development and led to establishment of priorities.

A list was made containing approximately 250 items of information needs that must be considered at the time of a production commitment. The current state-of-the-art review resulted in the identification of past and presently planned programs contributing to these information needs. A summary of these results is shown in Figure 9.

Engineering technology required for advanced composites wing primary structural box design	Contribution of existing programs to Boeing technology base: ACEE programs														Extent of existing technology base
	727 elevator	737 stabilizer	DC-10 rudder	DC-10 fin	L-1011 aileron	L-1011 fin	Air Force programs	Navy programs	NASA R&T	Boeing IR&D	Boeing new product development	7/7/7 components	747 components	Industry	
Material and process specification	X	X					X			X	X	X	X	X	2
Associated material and processes	X	X					X		X	X	X	X	X	X	2
Loads technology		X													1
Flutter technology		X					X		X						1
Material properties	X	X							X	X	X		X		3
Environmental effects	X	X						X	X		X	X	X	X	3
Damage tolerance	X	X					X		X	X					3
Durability/Repeated loads	X	X					X		X	X			X	X	3
Component strength data	X	X		X		X	X		X	X	X	X	X	X	3
Structural analysis methods	X	X							X	X	X	X	X	X	3
Structural testing technology	X	X		X		X	X	X	X	X					2
Weights and performance prediction	X	X									X	X	X		1
Fuel-effects and fire safety							X	X	X						3
Flight controls	X	X													1
Electromagnetic technology	X	X	X			X	X	X		X	X	X	X	X	3
Repair technology		X					X		X						3

Existing technology base: (1) Significant (2) Moderate (3) Limited

Figure 9. Boeing Advanced Composites Engineering Technology Assessment

One of the first observations in the search for critical technology was that the most severeiy impacted disciplines were those influenced by a significant change in meterial properties or characteristics, or affected by the manufacturing process. For example, the electrical resistance of graphite/epoxy material is about 1000 times that of aluminum. This is a principal reason why electromagnetic effects have become a major technological concern, whereas loads analysis technology, primarily concerned with mass and stiffness of the structure, is relatively unaffected. Technology elements identified as major concerns and that must be addressed are:

- Damage tolerance
- Durability/repeated loads
- Electromagnetic effects
- Environment
- Material improvement

Production Capability Assessment -A standard manufacturing plan that considered the unique aspects of composite materials and their producibility was developed, based upon the design producibility evaluations (Figure 8). This plan then was used to develop tooling, facility, and process plans for production requirements identification.

Cost was considered key to the selection of a manufacturing process or method, and cost studies were performed for all major wing components. Typical of these studies are the relative cost comparisons for fabricating the spars and ribs shown in Figure 10. Other portions of the design were treated in a similar manner.

A summary of the production capability assessment is shown in Figure 11. The right-hand column of the figure indicates areas requiring considerable development, as noted by "3". A limited base exists for quality assurance and a moderate base exists for detail fabrication and assembly functions. Future efforts must address development of these functions.

Production process	Relative cost
Ribs	
Hand layup–autoclave cure	1.0
Hand layup–elastomeric aided autoclave cure	0.9
Hand layup–captive elastomeric-autoclave cure	0.9
Filament wind–autoclave cure	0.8
Mechanized kitting–elastomeric die molding/cure	0.7
Compression molding	0.7
Spars	
Hand layup–autoclave cure	1.0
Hand layup–elastomeric aided autoclave cure	1.0
Hand layup–captive elastomeric mold-oven cure	0.9
Mechanized layup–diaphragm press-mold cure	0.7
Thermoplastic molding	0.9
Filament winding–elastomeric aid to autoclave cure	0.7

Figure 10. Typical Cost Producibility Evaluation

Major Conclusions--These technical assessments resulted in two major conclusions:

- Development and flight service of a full-scale, primary structural component is required to:
  - Integrate and validate design and manufacturing methods
  - Establish facility requirements
  - Validate fabrication costs
  - Ensure airline participation
  - Ensure in-depth FAA involvement
- A laboratory test program is required to provide an advanced composite data bank consistant with MIL Standards for metal structure.

Both activities are required to support a production commitment.

Technology item	NASA ACEE programs						Other programs								Extent of existing technology base
	727 elevator	737 stabilizer	DC-10 rudder	DC-10 fin	L-1011 aileron	L-1011 fin	Air Force programs	Navy programs	NASA R&T	Boeing IR&D	Boeing new product development	747 components	7J7 components	Industry	
Detail fabrication															
Tapered shape pultrusion										X	X				2
Sandwich panel pultrusion										X	X	X	X		2
Large shape pultrusion										X	X				2
Contoured shape pultrusion										X	X				3
Cocuring	X	X	X	X	X	X	X	X	X	X	X	X	X	X	1
Filament winding							X	X	X	X	X		X	X	2
Thermoplastic forming							X	X	X	X				X	2
Compression molding	X	X							X	X		X	X		2
Conv GR/EP machining	X	X								X	X	X		X	1
Laser and water jet trimming					X		X			X				X	2
TI prebond treatment	X	X								X	X	X	X		2
Assembly processes															
New fastener concepts				X		X	X							X	3
Advanced composites fasteners	X	X				X	X	X		X		X		X	2
Titanium rivets	X					X		X		X				X	2
Titanium nutplates	X									X					3
Blind fasteners		X					X			X		X		X	2
GR/EP hole prep improvement	X	X	X	X	X	X	X			X	X	X	X	X	2
GR/EP metal hole prep	X	X	X	X	X	X	X			X	X	X	X	X	2
Hole quality allowables										X					3
Dust collection	X	X					X			X		X	X	X	2
Corrosion protect/sealing	X	X					X			X		X		X	2
Materials															
Improved prepregs	X	X					X	X	X	X	X	X	X	X	1
Pultrusion prepregs							X	X		X	X			X	2
Adhesives	X	X					X	X	X	X	X	X	X	X	2
Thermoplastic composite							X	X	X	X	X			X	3
Chopped fiber molding							X	X	X	X	X			X	2
Preplied broadgoods							X		X	X				X	2
Lightning strike protect	X	X			X		X	X	X		X	X	X	X	2
Exterior finishes	X	X									X	X			2
Tooling concepts															
Mechanized layup					X	X	X								3
Tooling advancements	X	X					X		X	X		X			2
Compression molding										X		X		X	2
Elastomeric mold/cocure	X	X		X	X	X		X	X	X	X	X	X	X	2
Captive elastomeric mold			X				X							X	3
Integrally heated dies			X				X			X				X	2
Inflatable mandrels							X							X	2
Quality assurance															
Material acceptance improvement	X	X					X		X	X	X			X	2
Cure monitoring			X							X					3
In-line process control															3
NDI methods	X	X	X	X	X		X	X	X	X	X	X	X	X	2
Large contoured panel NDT							X								3
Maintenance and repair procedures	X	X	X	X	X	X	X	X	X	X	X	X	X	X	2

Level of contribution (1) Significant (2) Moderate (3) Limited

Figure 11. Boeing Production Capability Assessment Summary

4.2 PROGRAM OPTIONS

Based upon the results of the technical assessment task, it was concluded that development and test of a full-scale advanced composite wing is required prior to production commitment. The Boeing Company has available several aircraft options to provide maximum program flexibility. Four options that address many of the technical and production requirements were identified and studied. These options, shown in Figure 12, are:

- Option A - 737 wing box, ground test
- Option B - 737 wing box, ground test
  707 outboard wing flight service
- Option C - Two 737 wing box/center sections, ground test
  737 wing, flight service
- Option D - 727 wing box/center sections, ground test
  727 wing, flight service

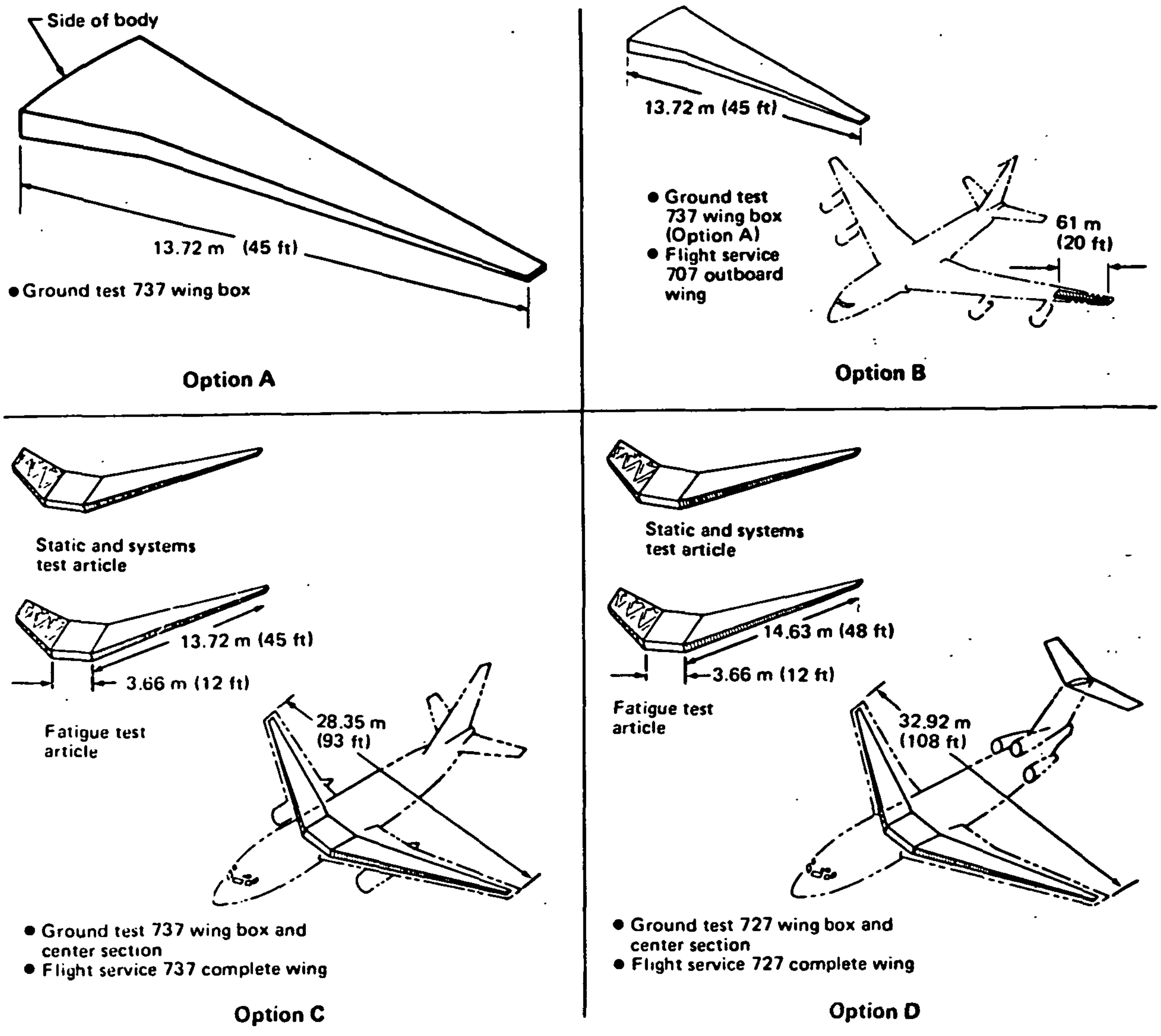


Figure 12. Available Program Options

4.3 ANALYSIS AND EVALUATION

Evaluation of the four program options were based upon an analysis of the risk, cost, and benefits of each option in respect to the production readiness ground rule. The evaluations were subdivided into technical, production, and airline acceptance categories. Certification considerations were included in the technical category and cost considerations under the production and airline acceptance categories. The results of the evaluations are summarized in Figure 13.

A final evaluation comparing relative cost was made. The results are shown in Figure 14. Options A and B provide major building blocks, but do not fully support production readiness by 1985. Options C and D support the 1985 date at acceptable risk levels.

4.4 RECOMMENDED PROGRAM

The Boeing Company recommends a three-element program involving hardware (Option C), technology, and production capability development. Each element is essential to establishing production readiness and user confidence.

The 82-month program, as shown in Figure 15, includes a 12-month flight service period. Based

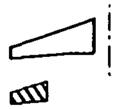
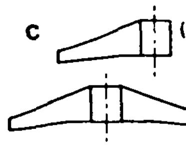
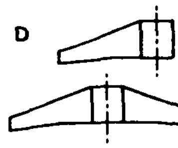
	A 	B 	C (2) 	D (2) 
Technical evaluation				
Provide development in detail sufficient to ensure freedom from major faults?	Minimum	Minimum	Yes	Yes
Provide design data to support production design?	Minimum	Same as (A) plus fight experience	Yes	Yes
Provide FAA certified hardware?	No–data base only	Yes–limited	Yes	Yes
Risk evaluation	High	Moderate	Low	Low
Production evaluation				
Validate production manufacturing plan?	No–limited use of production methods	Same as (A)	Yes–some use of production methods	Same as (C)
Establish required cost data?	No	No	Limited	Limited
Risk evaluation	High	High	Low	Low
Airline acceptance evaluation				
Provide substantiation of weights?	Yes	Yes	Yes	Yes
Provide substantiation of operational costs?	No	Limited	Partially	Partially
Provide flight experience for in-service system validation?	No	Yes	Yes	Yes
Risk evaluation	High	Moderate	Low	Low

Figure 13. Option Evaluation Analysis

Option	Description	Relative cost	Technical risk	Production risk	Airline acceptance risk	Chance of a successful program leading to a production commitment
A	737 outboard wing ground test	1.0	High	High	High	Poor (building block)
B	Option A + 707 partial wing flight test	1.4	Moderate	High	Moderate	Marginal
C	737 ground test + tip-to-tip flight test	2.1	Low	Low	Low	Good
D	727 ground test + tip-to-tip flight test	2.4	Low	Low	Low	Good

Figure 14. Option Evaluation Summary

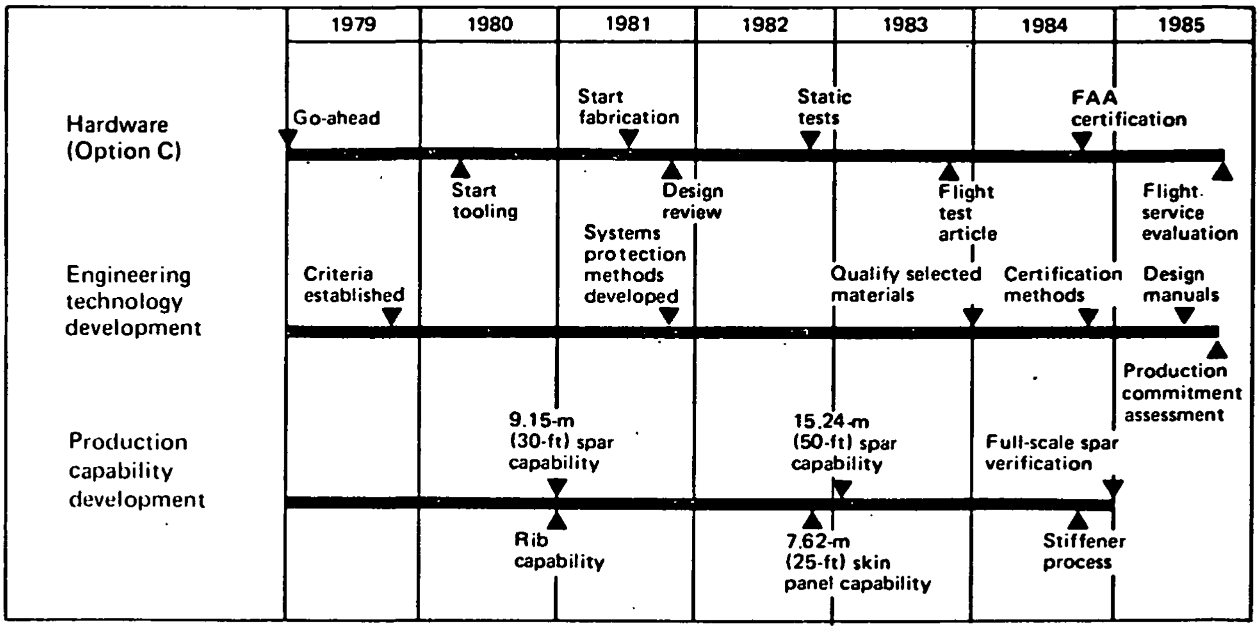


Figure 15. Recommended Program Schedule (Option C)

upon a January 1979 go-ahead and upon parallel efforts for all three elements, production readiness would be established in October 1985.

Hardware Element--This element includes development, design, test, and flight service of a 737 aircraft incorporating advanced composites in the wing structure. It contains two ground test articles (left and center wing sections) and one flight service article (left, center and right wing sections). The element also provides means for validating the technology and production capability developments. Figure 16 illustrates typical developments to be validated.

The requirement for two ground test articles was determined by:

- Production readiness date of 1985
- Need to have strain survey data to validate math models
- Undesirability of adding probable effects of ultimate load testing to the results of damage growth and residual strength testing

Test article relationship and general phasing are shown in Figure 17.

Flight service provides benefits that are key to the establishment of advanced composites as a viable commercial production option. These benefits are:

- Deeper FAA involvement in certification of advanced composites
- Basic airline participation ensured
- Structure subjected to day-to-day commercial airline service

Technology Development–Technology development providing information required to proceed with advanced composite wing design in the mid-1980s was identified for five major areas:

- Damage tolerance
- Durability/repeated loads
- Electromagnetic effects
- Materials improvement
- Environment

These areas are of first priority in terms of needed technical information.

The key areas of damage tolerance that will be addressed are:

- Flaw types and criticality
- Material and configuration sensitivity to different flaw types
- Growth types and rates of all flaw varieties
- Moisture and temperature influence upon criticality and growth rate of any designated flaw

737 WING HARDWARE PROGRAM	Fabrication processes					Assembly methods				Quality assurance			
	Filament winding	Automated layup	Pultrusion	Elastomeric die molding	Automated prepreg cutting	Hole preparation	Fastening systems	Sealant and application	Automated assembly—spar	Receiving inspection	In-process controls	Cure monitoring	Automated NDI
Ground test article No. 1 (static)	X			X		X	X			X		X	
Ground test article No. 2 (fatigue)	X	X		X	X	X	X			X	X	X	
Flight service article	X	X	X	X	X	X	X	X		X	X	X	

Figure 16. Production Capability Development Validation

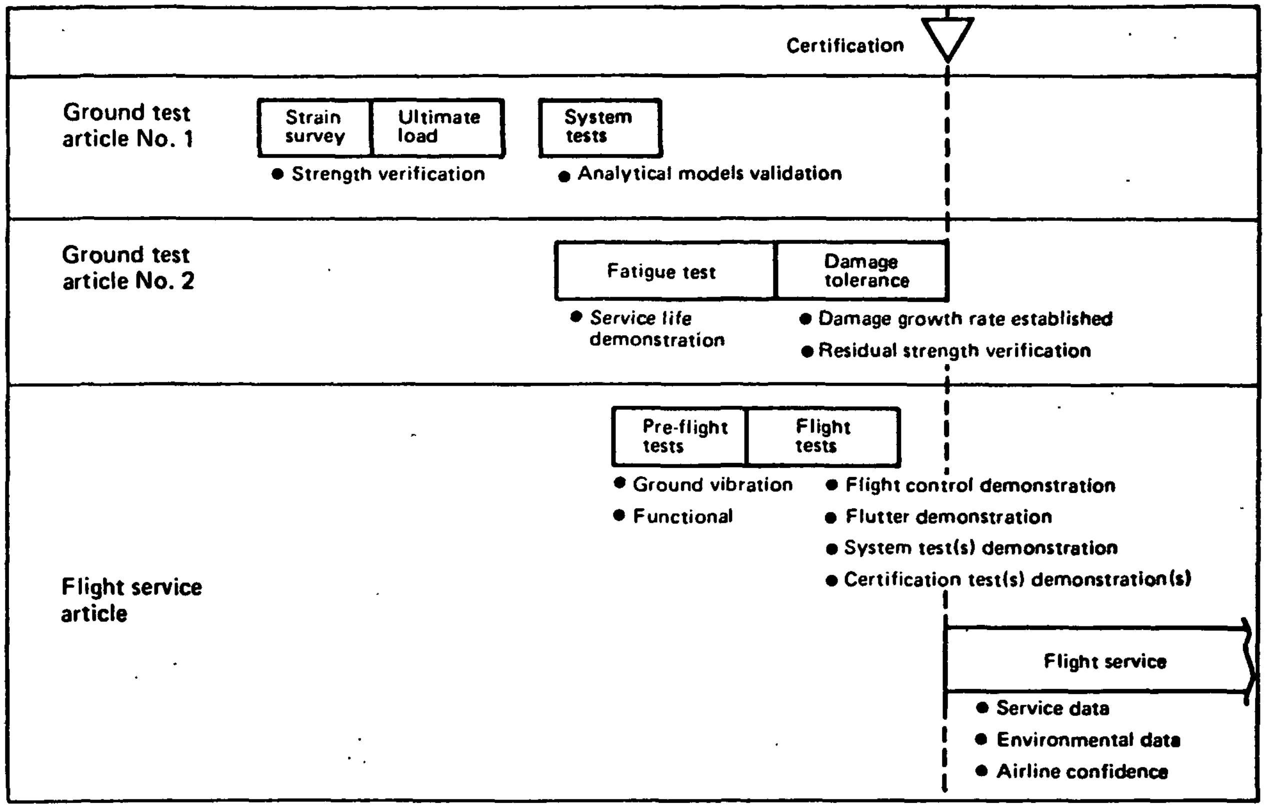


Figure 17. Test Article Relationships

Damage tolerance development for each of these areas will include extensive testing that characterizes material flaw types and criticality, and assessment of configuration influence upon design. Following wing structure inspection capability assessment and availability of resultant data, a damage tolerance criteria and acceptance procedure for certification will be prepared.

An area associated with material fracture and flaw characteristics is durability or repeated loads characteristics and will require:

- Durability assessment of structural details
- Analysis methodology relating to detailed structural information, materials data base, and an accumulative damage model

Therefore, basic material durability/fatigue characteristics will be developed, as well as fatigue characteristics of generic structural details. In association with the wing hardware development, configuration effects of specific critical structural details (e.g., splices and joints) will be realistically assessed. Key to this analysis concept is the accumulated damage model. A significant amount of work will be related to this model development and to incorporating into it the influencing factors of R-ratio, stress magnitude, cycle sequence, and environment.

Key elements of electromagnetic technology are fuel ignition hazards from both lightning strike and fuel electrification during fueling, structural damage from lightning, attached strokes, swept strokes, current paths, and induced transients. Areas that will be developed are:

- Electromagnetic protection associated with electrostatic discharge
- Electromagnetic discharge
- Power system return paths

The program also will develop adequate information pertaining to:

- Electrical bonding

- Circuit immunity enhancement
- Joint conductivity
- Material compatibility of both conductive and nonconductive areas

In the area of environmental effects, the program will address each of the effects separately and in combination. To be considered are:

- Temperature
- Moisture
- Fuel
- Systems fluid (e.g., Skydrol)

For short-term test, development will quantify the methodology required for material screening and degradation assessment. Therefore, testing will include flight, ground, and laboratory exposure and quantification of each degradation parameter. From these data, analysis capability will be developed to scale from coupons to structural details, to structural elements, to subcomponents, and finally, to full-scale component. This capability will avoid full-scale environmental testing of the full-scale aircraft component. This research at the element level will permit appropriate subcomponent testing to be combined with the hardware portion of the program to provide the final step in the scale-up procedure.

Some of the characteristics obtained from each of the five major technical areas will supply requirements for material improvements. The development program will consider:

- Hybrids (mixtures of glass, graphite, and Kevlar)
- Other thermal-setting resin systems
- Thermoplastics
- Formulation modifications

These are needed to improve toughness and interlaminar tension, resistance to environment, application cost effectiveness, and potential fiber containment. This testing will range from the effect of any of the properties at the coupon level to the component level, in a manner similar to that discussed under environmental effects.

Production Capability Development—A series of trade studies was conducted to determine the most cost-effective fabrication and assembly processes for wing-box spars, ribs, and skin panels. This was followed by definition of production capability. It was determined that mechanized production methods must be developed if advanced composite structure is to be cost competitive with metal structure. Three specific areas were identified to support production capability development: quality assurance, fabrication processes, and assembly methods.

Quality assurance methods that will be developed include:

- Material acceptance improvements
- In-process adaptive controls
- Skin panel cure monitoring
- Automated nondestructive inspection methods

Fabrication processes that will be developed to support production of an advanced composite wing are:

- Filament winding of long structural shapes
- Large panel automated layup machine
- Tapering, thick-sandwich pultrusion
- Structural component elastomeric die molding
- Automated prepreg cutting center
- Improved prepreg materials

Assembly method mechanization development will include:

- Hole preparation
- Fastening systems
- Sealant and sealant application
- Automated assembly machine for fastened components

Boeing's many past development programs provide an experience base for determining the associated costs and the development required to provide information for cost-effective production application of advanced composites. This will provide a high degree of confidence in the costs and schedules developed for the Advanced Composites Wing Program.

The wing hardware portion of the program will provide the opportunity to see the effectiveness of this development applied to full-scale components. With these technology and production needs addressed, the technical information will be available to proceed with wing production hardware.

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16. Abstract

This report outlines the effort necessary for the contractor to achieve a state of production readiness for the design and manufacturing of advanced composite wing structure in the contractor's facilities. Volume II (CR 145382-2) contains detailed discussions of the Wing Study Program results.

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