A Study of the Utilization of Advanced Composites in Fuselage Structures of Commercial Aircraft

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Final Report

D. J. Watts, P. T. Sumida, B. L. Bunin,
G. S. Janicki, J. V. Walker, and B. R. Fox

Douglas Aircraft Company
Long Beach, California 90846

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D. J. Watts, P.T. Sumida, B. L. Bunin, G. C. Janicki, J. V. Walker, and B. R. Fox

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16. Abstract

A study was conducted to define the technology and data needed to support the introduction of advanced composites in the future production of fuselage structure in large transport aircraft. Fuselage structures of six candidate airplanes were evaluated for the baseline component. The MD-100 was selected on the basis of its representation of 1990s fuselage structure, an available data base, its impact on the schedule and cost of the development program, and its availability and suitability for flight service evaluation. Acceptance criteria were defined, technology issues were identified, and a composite fuselage technology development plan, including full-scale tests, was identified. The plan was based on composite materials to be available in the mid to late 1980s. Program resources required to develop composite fuselage technology are estimated at a rough order of magnitude to be 877 man-years exclusive of the bird strike and impact dynamic test components.

A conceptual composite fuselage was designed, retaining the basic MD-100 structural arrangement for doors, windows, wing, wheel wells, cockpit enclosure, major bulkheads, and interfaces with existing aircraft systems and cabin interior arrangements. A 32-percent weight savings from the existing MD-100 design was realized for this design.

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PREFACE

This final report was prepared by Douglas Aircraft Company, McDonnell Douglas Corporation, under contract NAS1-17416, "Study of Utilization of Advanced Composites in Fuselage Structures of Large Transports." The study was conducted for the Aircraft Composite Structures Technology (ACST) program which is part of the NASA Aircraft Energy Efficiency (ACEE) program. The program was partially funded by the Air Force Wright Aeronautical Laboratory to ensure that the study would be applicable to large military transport aircraft.

The study program was monitored by John Pyle, ACEE Composites Project Office, Langley Research Center, NASA. James Mullineaux, ADPO-AFWAL, was the Air Force Project Manager. D. J. Watts was the Douglas Project Manager.

In addition to the authors, Douglas contributors to this project included M. P. Amason, electromagnetic effects; M. M. Platte, cost analysis; and R. L. Oswald, program administration.

GLOSSARY

A	area
a	half-crack length
(a)	thermal coefficient of expansion
A_1	area under carbon-epoxy stress-strain curve
A_2	area under aluminum stress-strain curve
ADF	automatic direction finder
ADH	adhesive
AMB	ambient
ASSY	assembly
ATC	Air Traffic Control
ATP	authority to proceed
B	bending
BTU	British thermal units
C	compression
c	characteristic length
℄	centerline
℄$_F$	frame centerline
℄$_L$	longeron centerline
Conf	configuration
CRT	cathode ray tube
dB	decibel
DBLR	doubler
DCB	double cantilever beam
deg	degrees
DME	distance measuring equipment
E	elastic modulus
EMI	electromagnetic impulse
ENGG	engineering
FAB	fabricate
FT	feet
FLEX	flexible
FPS	feet per second
FUS	fuselage
FWD	forward
°F	degrees Fahrenheit
G	acceleration
GH_z	gigaHertz
HC	honeycomb
HF	high frequency
HYD	hydraulic
Hz	Hertz
ILS	instrument landing system

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IN.	inch
INS	inertial navigation sytem
INSTL	install or installation
K	stress intensity factor
k	thousand
(k)	thermal conductivity
kPa	1,000 Pascals
KSI	thousands of pounds per square inch
L	longeron
L&R	left and right
l	length
LB	pound
LN_2	liquid nitrogen
MEK	methyl ethyl ketone
MH_z	MegaHertz
MO	months
NDE	nondestructive evaluation
NDI	nondestructive inspection
NDT	nondestructive test
OMEGA	VLF worldwide navigation
P	pressure
P_a	applied load
PLM	plastic laminating mold
Prep	preparation
PROT	protection
PSI	pounds per square inch
R	radius
RH	relative humidity
RT	room temperature
S	shear
SATCOM	satellite communication
SEC	seconds
SHF	super high frequency
SPEC	specimen
STA	station
STRUCT	structure
T	tension
$\bar{t}$	thickness, smeared area
tan	tangent
TBD	to be determined
T/CAS	threat-alert collision avoidance
TEMP	temperature
TYP	typical

U	deflection
UHF	ultra-high frequency
V	velocity
V_c	cruise speed
VHF	very high frequency
VLF	very low frequency
W	panel width
e_1	failure strain of carbon-epoxy
e_2	failure strain of aluminum
μ	micro
π	pi
σ	stress

SUBSCRIPTS

∞	infinity
K_{tc}	shear concentration factor
MAX	maximum

CONTENTS

CONTENTS
(Continued)

SECTION 1
INTRODUCTION

The NASA Aircraft Energy Efficiency (ACEE) composites program has provided the aircraft manufacturer, the FAA, and the airlines with the experience and confidence needed for extensive use of composites in secondary and medium primary structure in future transport aircraft. Secondary and control surface structures made of composites are already in airline service on a production basis, and composite medium primary structures have been introduced for flight service evaluation. Studies to determine the requirements to achieve technological readiness for composite primary wing structures have already been completed under the ACEE wing studies program (References 1 to 3) and key technology issues are currently being addressed under separate contracts.

The composite fuselage structure has significantly different design criteria and structural features from composite wing structures. The wing study findings do not necessarily apply with respect to weight savings, cost, and the programmatic and technical issues involved. The fuselage comprises about 33 percent of the structural weight of a transport aircraft, and weight savings of 25 percent would result in significant benefits in some or all of the following: specific fuel consumption, range, landing field distance, and increased payload.

The objectives of the composite fuselage study are to (1) define the technology and data needed to support an aircraft manufacturer's commitment to utilize composite fuselage structure in future large transport aircraft, and to (2) develop plans for a composite fuselage development program which will supply the needed technology and data. Without the data and a demonstrated technological readiness, commercial and military aircraft operators would be unlikely to accept composite structure for the fuselage.

Two factors strongly influence the amount of technology and data that will be needed to support a commitment to composite fuselage structure:

- Technology for the design and manufacture of conventional fuselage structure has been developed over the past 50 years by a large industry which has invested heavily in test programs, facilities, and equipment, and is supported by the service experience of thousands of aircraft. Regulations have evolved that demand the high level of safety provided by these structures. It is understood that composite fuselage structures will, indeed, require a high level of technology and a proven data base to compete with this mature technology.
- This study is targeted for a 1990s date for a commitment to utilize composites in the fuselage structure. By this time, conventional fuselage construction will be advanced through improvements achieved in aluminum alloys and better manufacturing methods such as adhesive bonding of structure. These advancements do not require a technological breakthrough and are more adaptive to existing facilities and equipment. Corresponding improvements must be attained in the development of the composite fuselage for it to compare favorably with competing systems.

The study was organized to define the issues, assess the state of the art for technology gaps, create a baseline conceptual design, and define composite fuselage technology which will provide the required state of technical readiness. A flow chart for the study tasks is shown in Figure 1-1 and the study schedule is given in Figure 1-2.

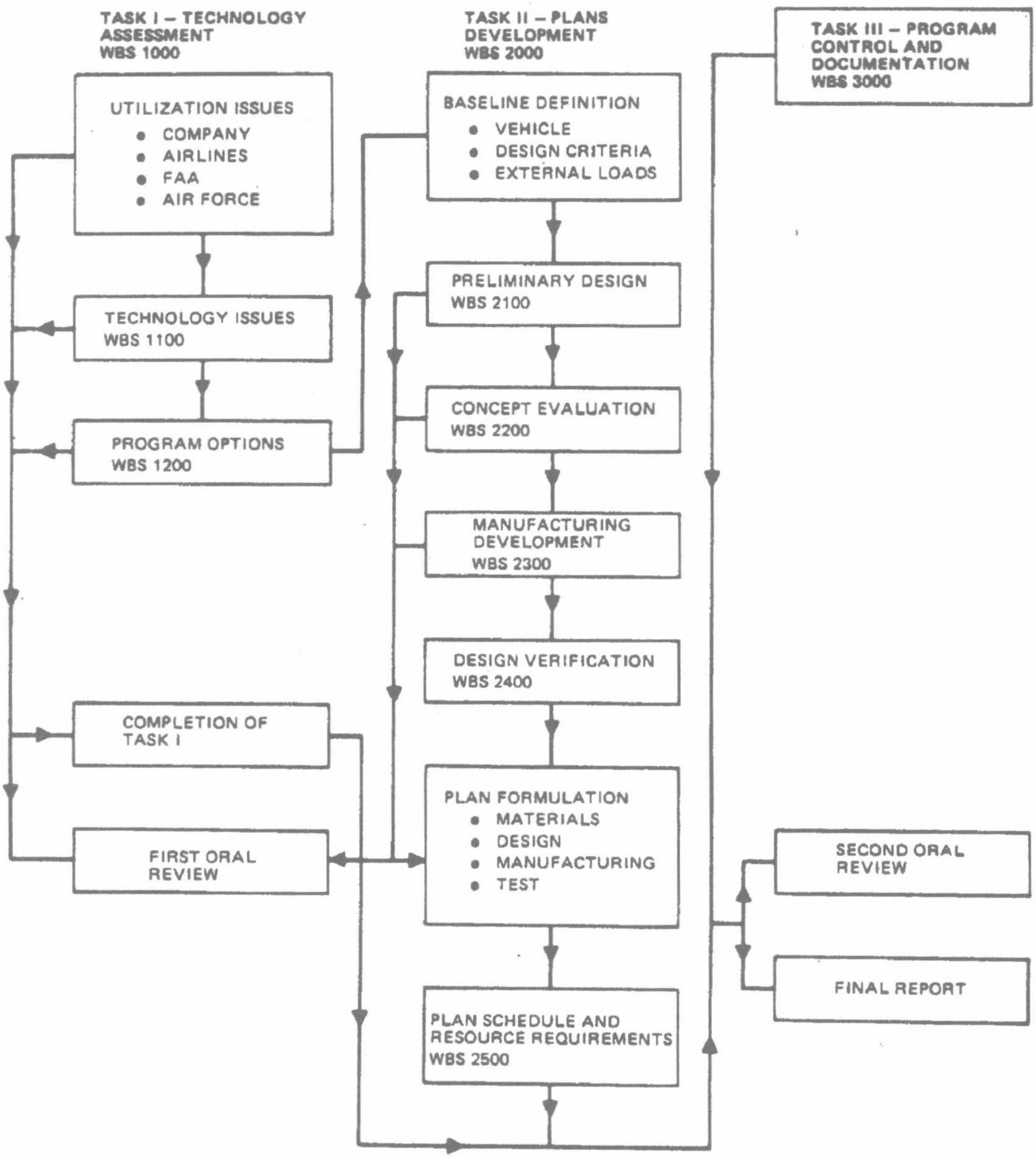

FIGURE 1-1. PROGRAM FLOW CHART

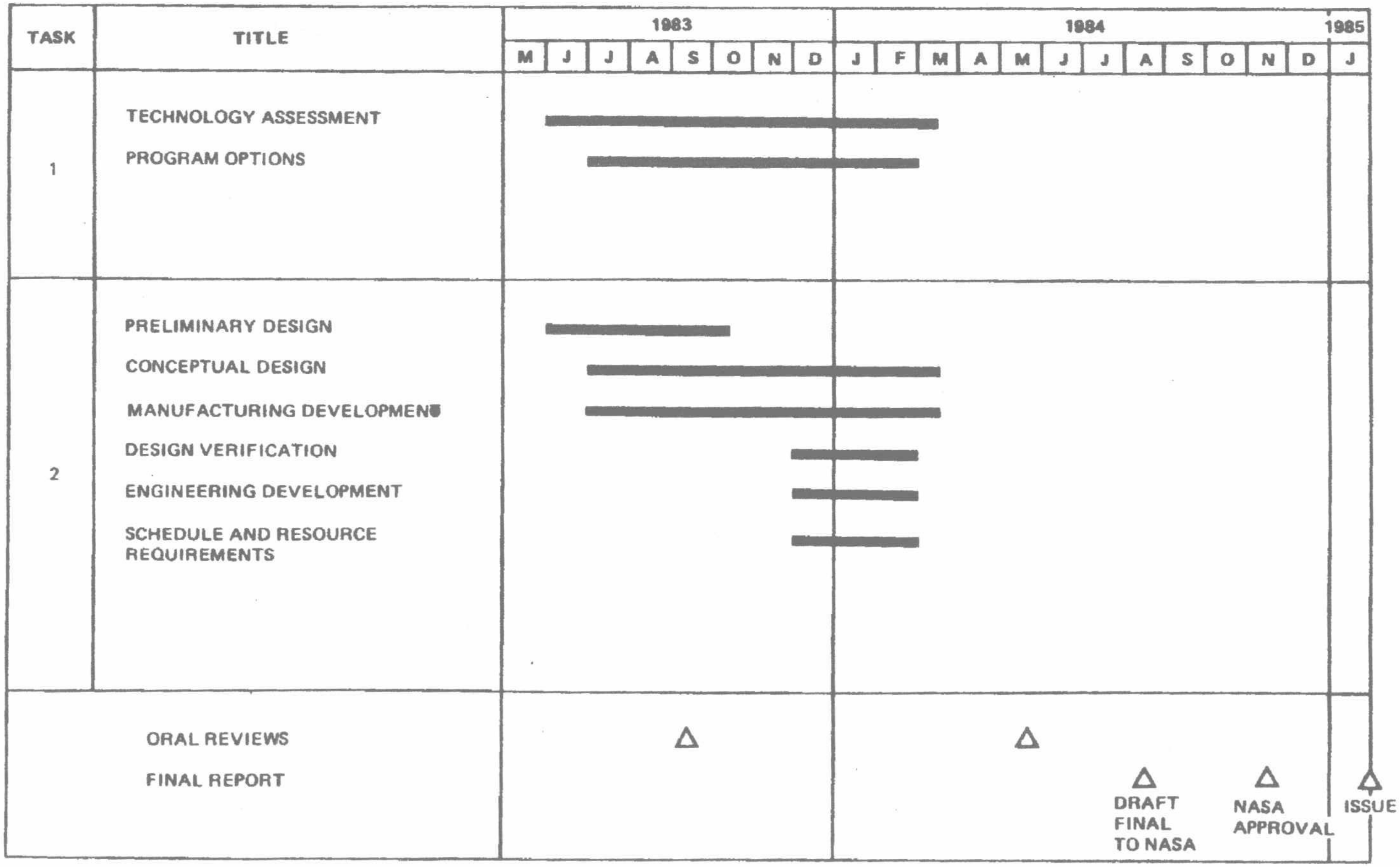

FIGURE 1-2. COMPOSITE FUSELAGE STUDY SCHEDULE

SECTION 2
COMMITMENT TO PRODUCTION

New, large transport aircraft designs are established on the basis of the manufacturer's technology base and the needs of the using commercial airline or military airlift operation. It is not likely that a manufacturer would undertake a major design change such as a composite fuselage structure without a consensus from the airlines or military users. Therefore, in a practical sense, a commitment to production of composite fuselage structure by an aircraft manufacturer is dependent upon its acceptability to the airlines and military users.

Acceptability can be examined on the basis of the benefits to be derived from the change versus the risks encountered in introducing new technology. Potential benefits can be divided into the following areas: (1) reduced manufacturing costs, (2) reduced maintenance costs, (3) longer durability, and (4) improved aircraft performance in terms of range, payload, landing field lengths, and specific fuel consumption.

The risks involved reflect the uncertainties which arise with the introduction of new technology in attaining a high level of structural integrity, achieving projected cost and weight savings, and being able to establish realistic schedules. The seriousness of failure is high; therefore, the probability of failure must be quite low. Table 2-1 summarizes those issues for which the manufacturers, users, and the regulatory agency must have demonstrable evidence of low risk before a production commitment can be made. To put things in the proper perspective, we are talking about decisions affecting the success of a multibillion dollar program. Obviously, these issues will be carefully considered at the highest level of civil and military management.

TABLE 2-1
ACCEPTANCE SUMMARY

	MANUFACTURER	AIRLINES	FAA	MILITARY
STRUCTURAL INTEGRITY FACTORS:				
MATERIAL AND FABRICATION	X	X	X	X
STATIC STRENGTH	X	X	X	X
FATIGUE/DAMAGE TOLERANCE	X	X	X	X
CRASHWORTHINESS	X	X	X	X
FLAMMABILITY	X	X	X	X
LIGHTNING PROTECTION	X	X	X	X
PROTECTION OF STRUCTURE	X	X	X	X
QUALITY CONTROL	X	X	X	X
REPAIR	X	X	X	X
FABRICATION METHODS	X	X	X	X
MILITARY THREATS	X			X

TABLE 2-1
ACCEPTANCE SUMMARY
(CONTINUED)

	MANUFACTURER	AIRLINES	FAA	MILITARY
OPERATIONAL FACTORS:				
RELIABILITY		X		X
MAINTAINABILITY		X		X
INSPECTABILITY		X		X
REPAIRABILITY		X		X
ECONOMIC FACTORS:				
ACQUISITION COSTS		X		X
LIFE–CYCLE COSTS		X		X
WARRANTIES		X		
FACILITIES	X	X		X
EQUIPMENT	X	X		X
PROGRAM RISK FACTORS:				
DESIGN DATA	X			X
PRODUCIBILITY DATA	X			X
SCHEDULE DATA	X	X		X
COST DATA	X	X		X
STAFF EXPERIENCE	X	X		X
AIRLINE ACCEPTANCE	X	X		
FAA ACCEPTANCE	X	X		
MILITARY ACCEPTANCE	X			X

EXISTING EXPERIENCE BASE

A rapidly growing technology base for composite aircraft structure has emerged during the past few years, although it is still insignificant compared with the technology base for conventional aircraft structure. Table 2-2 lists a number of composite applications cited in DoD/NASA Advanced Composites Design Guide. Some of the more significant applications are the control surface and medium primary structural components developed by the NASA ACEE programs, the Boeing 767/757 secondary structure and control surface applications derived from NASA ACEE experience, the Lear Fan all-composite airplane, the Navy AV-8B Harrier wing, and numerous Air Force-sponsored military aircraft programs. Unfortunately, many of the issues related to production of composite fuselage structure for a large transport aircraft still remain unresolved.

TECHNICAL ISSUES

Section 3 of this study is devoted to an assessment of the technical issues. These issues address flight safety design requirements integrated into a durable and producible low-cost design with significant weight savings as an incentive for the commitment to production to be made.

TABLE 2-2
SOME ADVANCED COMPOSITES APPLICATIONS IN AIRCRAFT STRUCTURES

COMPONENT/ APPLICATION	SOURCE	MATERIAL SYSTEM
WING COMPONENTS		
737 SPOILERS	BOEING	CARBON-EPOXY
757 AND 767 SPOILERS	BOEING	CARBON-EPOXY
747 AILERON	BOEING	CARBON-EPOXY
757 AND 767 AILERONS	BOEING	CARBON-EPOXY
757 AND 767 FLAP	BOEING	CARBON-EPOXY
A-7 OUTER WING	VOUGHT	CARBON-EPOXY
L-1011 INBOARD AILERON	LOCKHEED	CARBON-EPOXY
DC-10 AILERON ACCESS DOOR	MCDONNELL DOUGLAS	CARBON-EPOXY
F-18 WING SKINS	MCDONNELL DOUGLAS	CARBON-EPOXY
F-18 WING SLATS	MCDONNELL DOUGLAS	CARBON-EPOXY
F-18 FLAPS	MCDONNELL DOUGLAS	CARBON-EPOXY
AV-8B WING	MCDONNELL DOUGLAS	CARBON-EPOXY
AV-8B FLAPS	MCDONNELL DOUGLAS	CARBON-EPOXY
AV-8B AILERONS	MCDONNELL DOUGLAS	CARBON-EPOXY
B-1 SLAT	ROCKWELL	CARBON-EPOXY
B-1 FLAP	ROCKWELL	CARBON-EPOXY
HiMAT WING AND CANARD	ROCKWELL	CARBON-EPOXY
F-100 WING SKINS	ROCKWELL	BORON-EPOXY
F-111B WING SKIN	VOUGHT	CARBON-EPOXY
LEAR FAN 2100 WING, FLAPS, AILERONS	LEAR-AVIA	CARBON-EPOXY
XFV-12A WING SKIN	ROCKWELL	CARBON-EPOXY
A-10 SLATS, WING LEADING EDGE	FAIRCHILD	CARBON-EPOXY
F-16 WING LOWER SKIN	VOUGHT	CARBON-EPOXY
EMPENNAGE COMPONENTS		
B-1 HORIZ STABILIZER	GRUMMAN	CARBON-EPOXY
A-4 HORIZ STABILIZER	MCDONNELL DOUGLAS	CARBON-EPOXY
F-5 HORIZ STABILIZER	NORTHROP	CARBON-EPOXY
737 HORIZ STABILIZER	BOEING	CARBON-EPOXY
727 ELEVATOR	BOEING	CARBON-EPOXY
T-38 HORIZ STABILIZER	NORTHROP	CARBON-EPOXY
L2100 HS AND VS	LEAR-AVIA	CARBON-EPOXY
AV-8B HS	MCDONNELL DOUGLAS	CARBON-EPOXY
F-18 HS AND VS	MCDONNELL DOUGLAS	CARBON-EPOXY
B-1 VERT STABILIZER	ROCKWELL	CARBON-EPOXY
DC-10 UPPER RUDDER	MCDONNELL DOUGLAS	CARBON-EPOXY
DC-10 VERT STABILIZER	MCDONNELL DOUGLAS	CARBON-EPOXY
L-1011 VERT STABILIZER	LOCKHEED	CARBON-EPOXY
LEAR 2100 HORIZ AND VERT STABILIZER	LEAR-AVIA	CARBON-EPOXY
HiMAT STABILIZER	ROCKWELL	CARBON-EPOXY
F-16 HORIZ AND VERT STABILIZER	GEN DYNAMICS	CARBON-EPOXY
A-10 HORIZ STABILIZER	FAIRCHILD	CARBON-EPOXY
757 RUDDER AND ELEVATORS	BOEING	CARBON-EPOXY
DC-9 RUDDER TAB	MCDONNELL DOUGLAS	CARBON-EPOXY

TABLE 2-2
SOME ADVANCED COMPOSITES APPLICATIONS IN AIRCRAFT STRUCTURES (CONTINUED)

COMPONENT/ APPLICATION	SOURCE	MATERIAL SYSTEM
FUSELAGE COMPONENTS		
FUTURE FIGHTER FUSELAGE FRAME	BOEING	CARBON-EPOXY
757 AND 767 LANDING GEAR DOORS	BOEING	CARBON-EPOXY
DC-10 NOSE LANDING GEAR DOOR	MCDONNELL DOUGLAS	CARBON-EPOXY
F-15 SPEEDBRAKE	MCDONNELL DOUGLAS	CARBON-EPOXY
F-18 SPEEDBRAKE	MCDONNELL DOUGLAS	CARBON-EPOXY
F-18 AVIONICS AND LANDING GEAR DOORS	MCDONNELL DOUGLAS	CARBON-EPOXY
AV-8B FORWARD FUSELAGE	MCDONNELL DOUGLAS	CARBON-EPOXY
AV-8B FUSELAGE CENTER PANEL	MCDONNELL DOUGLAS	CARBON-EPOXY
DC-10 FLOOR BEAMS	MCDONNELL DOUGLAS	CARBON-EPOXY
F-5 SPEEDBRAKE	NORTHROP	CARBON-EPOXY MOLDED
FUSELAGE/WING COMP	NORTHROP	CARBON-EPOXY
B-1 ELECTRONICS BAY DOORS	ROCKWELL	CARBON-EPOXY
B-1 WEAPONS BAY DOORS	ROCKWELL	CARBON-EPOXY
B-1 STRUCTURAL MODE CONTROL VANES	ROCKWELL	CARBON-EPOXY
HiMAT FUSELAGE PANELS	ROCKWELL	CARBON-EPOXY
F-5 FORWARD FUSELAGE	GEN DYNAMICS	CARBON-EPOXY
F-16 FORWARD FUSELAGE	GEN DYNAMICS	CARBON-EPOXY
F-14 MAIN LANDING GEAR DOOR	GRUMMAN	CARBON-EPOXY
A-7 SPEEDBRAKE	VOUGHT AERO	CARBON-EPOXY
LEAR FAN 2100 FUSELAGE	LEAR-AVIA	CARBON-EPOXY
AFT FUSELAGE	VOUGHT	KEV-EPOXY, CARBON-EPOXY

SOURCE: DoD-NASA ADVANCED COMPOSITES DESIGN GUIDE

The regulatory requirements and means of compliance must be defined at the start of a production program to assure a certifiable product and to assess the program certification costs. In general, the basic military specifications and Federal Aviation Regulations apply to the design of composite structures. The Air Force is currently preparing a new damage tolerance specification for composite structure to be used in lieu of the metal structure called for in MIL-A-83444. The FAA has published guidelines for acceptable means of showing compliance with certification requirements for civil aircraft composite structures. The guidelines have recently been revised to reflect the advances made in composite technology, and periodic revisions are expected as the technology matures.

OPERATIONAL ISSUES

The operational issues deal with keeping aircraft in service and are of concern to the airlines and military users. The design features provided by the manufacturer which satisfy the following operational requirements are included in the technical assessment.

- Reliability — Unscheduled time out of service is an extremely high cost factor because of lost revenue and higher capital investment for reserve aircraft. Fleet readiness for military operations is