APPLICATION OF COMPOSITE MATERIALS AND NEW DESIGN CONCEPTS FOR FUTURE TRANSPORT AIRCRAFT

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Abstract

The application of advanced technologies and the use of innovative aircraft design concepts show the potential for significant improvement in the fuel efficiency of future transport aircraft envisioned for operation in the mid to late-1990s. This paper reviews recent preliminary design system studies of transport aircraft featuring cost/benefit analyses of advanced technology and new vehicle design concepts. Emphasis is directed toward the use of graphite epoxy composite materials in the primary and secondary structures of transport aircraft. The data on aircraft design concepts include preliminary design studies of Advanced Civil/Military Aircraft (ACMA) aircraft and innovative configurations. The aircraft design parameters include cruise Mach numbers of 0.75 to 0.80, design payloads from 330,000 to 772,000 lbs, and range from 3,500 to 4,000 nautical miles.

I. Introduction

Projected mission requirements, the application of advanced technologies, and the use of innovative design concepts will all influence future transport aircraft. The increasing costs of developing new aircraft has tended to direct attention to derivatives of current aircraft. On the other hand, the dramatic rise in fuel prices since 1973 has provided the motivation for serious consideration of innovative aircraft design concepts and the use of advanced technologies aimed at increased fuel efficiency. Through the years, the aircraft industry and government agencies such as the Air Force, Navy, and NASA have worked jointly in many programs in the development and timely application of advanced technologies. These include, for example, the NASA/Industry Advanced Transport Technology (ATT) program in the early 1970s (References 1,2), the NASA Aircraft Energy Efficiency (ACEE) Program (References 3-8), and Air Force projects including the ASD Design Options Studies and others (References 9,10). These programs have identified supercritical wing, advanced composite materials, advanced turbofan engines, active controls, prop-fan propulsion, and laminar flow control as technologies that show the most significant potential benefits and which merit acceleration of technology readiness (Reference 11).

As the size of the transport aircraft has increased, advances in technology, as previously described, have permitted continuing improvements in performance and economics; however, further improvements are likely to be obtained in smaller increments (Reference 12). This result has fostered consideration of innovative aircraft design approaches as a means of providing larger incremental improvements in performance and economics of large cargo aircraft.

One of the more recent innovative design concepts that also features the use of advanced technologies is the Lockheed-patented concept of the Spanloader, in which the cargo is carried in the wing (References 13,14). Continuing activities in preliminary design and system studies of innovative aircraft design concepts have been reported for industry- and government-funded projects (References 15-21).

Since the extensive activity in the application of advanced technologies and innovative design concepts precludes any attempt to review the status of all on-going work, this paper is limited to two specific areas: (1) recent cost/benefit studies of the application of graphite epoxy composites to an Advanced Civil/Military Aircraft, and (2) design system studies of a multi-body aircraft design concept.

II. Study Approach

The results presented in this paper cover two separate design system studies with somewhat different technology assumptions and mission parameters. Therefore, to avoid confusion, the discussion in section III, Results of Design Studies, will first cover the cost/benefit studies of graphite epoxy composite materials to ACMA type transports including the technology and mission assumptions. The multibody aircraft design study will be reviewed next along with its technology and mission assumptions. Inherent in the technical approach to each study is a basic procedure in which the particular technology advance in a given aircraft design is compared to a reference aircraft design without the technology advance. For example, in the graphite epoxy composite materials cost/benefit study, an aluminum-structure aircraft configured to perform the mission requirements is used as a reference; otherwise, the aluminum-structure aircraft includes all other advanced technologies. This procedure is used to determine the singular effect of a given technology advance on the performance and economics of the aircraft. The identical procedure is used in the multibody study in which the reference is a single-body aircraft designed to perform the required mission.

The primary element of the design studies is the Lockheed Generalized Aircraft Sizing and Performance (GASP) program. The functioning of this computer program is dependent on a number of basic inputs common to all aircraft types, such as mission requirements, geometric characteristics, and engine data. Inputs must also be developed which define any particular characteristics of the aircraft type being sized. These inputs will be discussed later for each of the two studies.

In the design studies, the aircraft are configured to satisfy a given figure of merit or optimization parameter. For the study of graphite epoxy composite materials, the optimization parameter is minimum 20-year life cycle cost (LCC), and for the multibody study the parameter is minimum direct operating cost (DOC).

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III. Results of Design Studies

Composite Materials Aircraft

The advanced technology assumptions include a technology readiness date of 1990 corresponding to an inservice operational date of 1995, and technology applications include:

- Supercritical aerodynamics
- Active controls, including relaxed static stability
- Turbofan propulsion - NASA E^3 technology
- Graphite epoxy composites materials in primary and secondary structure

Mission requirements, listed below, are assumed to be representative of an Advanced Civil/Military Aircraft candidate mission:

- 331,000-pound design payload
- 3500 nautical mile range at design payload
- 0.80 Mach cruise speed
- 34,000-foot initial cruise altitude
- 9,500-foot or less takeoff distance

Comparable economics for all study aircraft are provided by application of the following cost constraints:

- January 1980 dollars
- Fuel cost of one dollar per gallon
- 900 flight hours per year utilization rate
- 200-unit production quantity
- 200-aircraft fleet size
- 20-year operational cycle

The reference aluminum material and composite material aircraft are sized to accomplish identical mission requirements, thus providing comparisons based on equal airlift capability. A significant input to the GASP program for the graphite epoxy composite material study is the material weight factors with base values of one being used for the aluminum structure aircraft. Material weight factors are developed for each of the various major structural components, such as wing and fuselage. An aircraft is first sized and weighed based on aluminum structure; then the advanced material is substituted for the aluminum in each component. The material weight factor for this component is then defined as the ratio of the weight of the advanced material component to the weight of the aluminum component. The procedure is shown in Figure 1.

As stated previously, the aircraft optimization parameter used is minimum 20-year military life cycle cost (LCC). Each aircraft sized by GASP is input into the economic model, where the two elements of LCC, acquisition cost and 20-year operating cost, are defined for the aircraft fleet. To reflect properly the material and labor costs associated with the development, production, and operation of advanced material aircraft, material and labor cost factors are required for input to the economic model. The factors adjust the aluminum material costing methodology within the model to provide advanced material RDT&E, production, and operational cost data using value engineering methods. A typical development of both the material and labor cost factors for a graphite epoxy wing is shown on Figure 2.

The technology weight factors for graphite epoxy composite structures include the experience acquired in the design, fabrication, ground test, and flight tests of various component structures on aircraft, including the NASA ACEE/Industry program described by Dr. Robert W. Leonard (Reference 5), the Lockheed L-1011 vertical tail under NASA development, a section of the C-5 leading-edge slat fabricated in both boron and graphite composites under Air Force funding, and leading-edge sections for the C-141 aircraft fabricated in composite structures under Air Force funding.

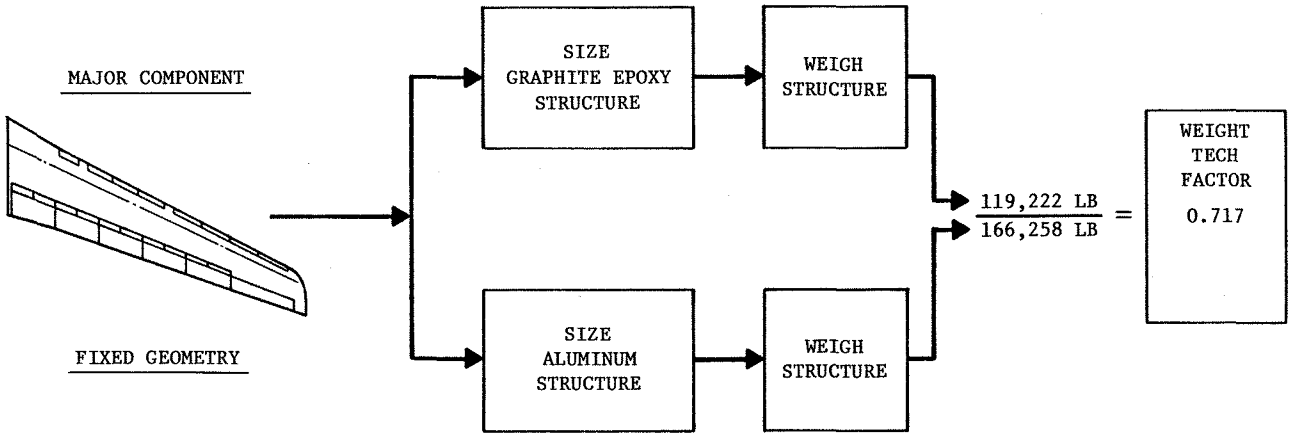
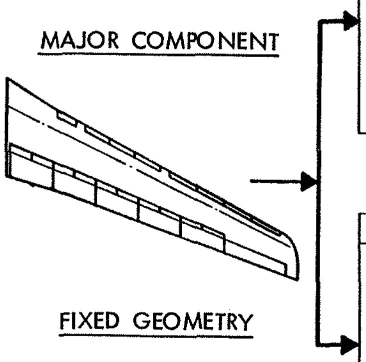


Figure 1. Weight Technology Factor Definition



LABOR COST FACTOR

$$\frac{\left[\frac{\text{G.E. PROD. HRS}}{\text{LB}}\right]}{\left[\frac{\text{ALUM. PROD. HR}}{\text{LB}}\right]} = \frac{\left[\frac{\text{G.E. PROD. HRS + ALUM. PROD. HRS}}{\text{G.E. WING WT.}}\right]}{\left[\frac{\text{ALUM. PROD. HRS}}{\text{ALUM. WING WT}}\right]} = \frac{1.88}{1.74} = 1.08$$

MATERIAL COST FACTOR

$$\frac{\left[\text{G.E. WING COST PER LB}\right]}{\left[\text{ALUM. WING COST PER LB}\right]} = \frac{\left[\frac{[\text{G.E. MAT. WT}]\ [\$/\text{LB}]\ +\ [\text{ALUM. MAT. WT}]\ [\$/\text{LB}]}{\text{G.E. WING WT}}\right]}{\left[\frac{[\text{ALUM. MAT. WT}]\ [\$/\text{LB}]}{\text{ALUM. WING WT}}\right]} = \frac{82.87}{24.37} = 3.40$$

ALUMINUM @ 4.5/6.0 $/LB
GRAPHITE EPOXY @ 30 $/LB

Figure 2. Labor and Material Cost Technology Factors

The cost factors are derived from the following material prices:

Material	Price Dollars per Pound Sheet Stock	 Shape Stock
Aluminum	4.50	6.00
Graphite Epoxy	30.00	30.00

Additional information on Lockheed experience in composite materials and details of the application of graphite epoxy materials to an ACMA type of transport are contained in a recent AIAA publication (Reference 22).

The aluminum structure aircraft shown in Figure 3 is used as the reference from which the benefits of graphite epoxy composite structures in the aircraft are determined. The aircraft performs the mission described previously and the configuration is optimized for minimum 20-year life cycle cost. With these guidelines, the wing aspect ratio is 7.77, and the aircraft gross weight is 1,066,000 pounds. The 20-year life cycle cost for a 200-aircraft fleet is $282.5 million in 1980 dollars.

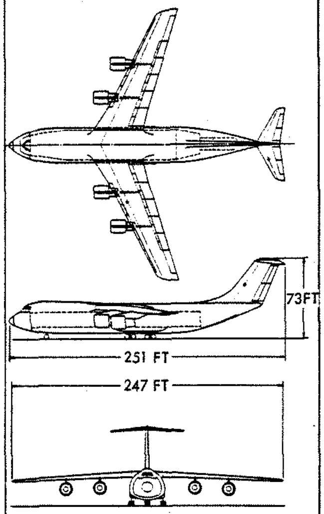
CHARACTERISITCS		GENERAL ARRANGEMENT
SPEED - MACH	0.80	
PAYLOAD - LB	331,000	
RANGE - NM	3,500	
LIFE CYCLE COST - $M	282.5	
ACQUISITION COST - $M	118.0	
OPERATING COST - $M	164.5	
GROSS WEIGHT - LB	1,066,000	
BLOCK FUEL WT - LB	246,000	
OPERATING WT - LB	463,300	
STRUCTURE WEIGHT - LB	359,800	
WING WEIGHT - LB	166,300	
FUSELAGE WEIGHT - LB	129,000	
EMPENNAGE WEIGHT - LB	15,000	
WING ASPECT RATIO	7.77	
WING AREA - SQ FT	7,866	
EMPENNAGE AREA - SQ FT	2,222	
THRUST - LB/ENGINE	66,160	
TON-MILES/LB-FUEL	2.35	

Figure 3. Aluminum Structure Baseline Aircraft

Following the methodology just described, the graphite epoxy composite aircraft is developed from design of its major components and the determination of the material weight factors relative to the aluminum structure aircraft. This process is based on previous Lockheed advanced design experience and includes the percent utilization of advanced materials for major components of the aircraft, as shown in Figure 4. It should be noted that the highest percentage of composites utilization, about 80 percent, is realized for the wing and empennage, whereas the percentage for the fuselage is relatively low at 31 percent. The relatively low utilization in the fuselage results at this point in time from total reliance on the use of aluminum in the fuselage main frames and carry-through structure to accommodate the high loads from the wing, the landing gear, and the empennage. As shown on the figure, the resulting utilization for the total aircraft is 53 percent graphite epoxy composite materials. The weight and cost technology factors based on the design data show, for example, that a graphite epoxy wing with the same planform geometry is 71.7 percent as heavy as the aluminum aircraft wing. The material and labor costs are 3.4 and 1.08, respectively, higher than for the aluminum aircraft.

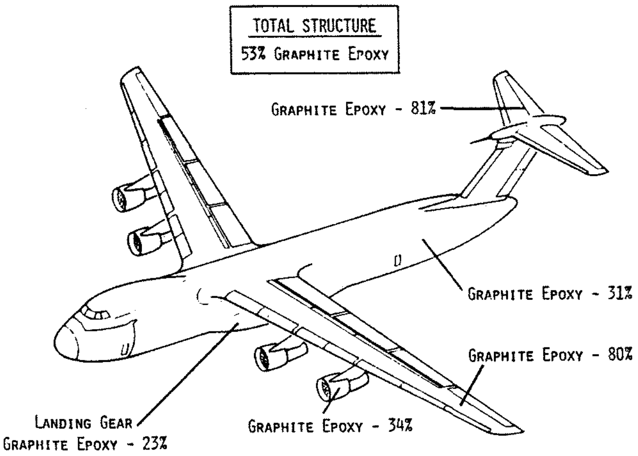
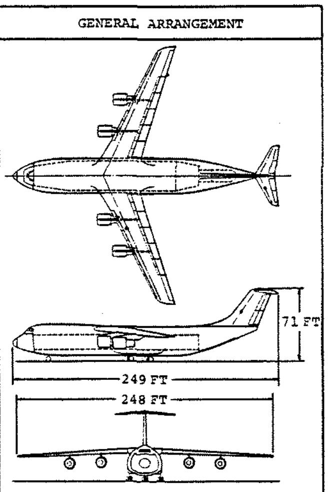


Figure 4. Material Usage Summary - Graphite Epoxy Aircraft

Inputting the technology factors into the GASP program and optimizing the design parameters for minimum life cycle cost result in the aircraft shown in the general arrangement drawing, Figure 5. From a total configuration standpoint, a comparison of the aluminum aircraft in Figure 3 with the graphite epoxy aircraft in Figure 5 shows an increase in aspect ratio of 12 percent for the graphite epoxy aircraft. All other dimensions are about the same for the two aircraft; however, not shown, is a decrease of 15 percent in wing area of the graphite epoxy aircraft.

CHARACTERISTICS	
SPEED - MACH	0.80
PAYLOAD - LB	331,000
RANGE - NM	3,500
LIFE CYCLE COST - $M	250.8
ACQUISITION COST - $M	114.2
OPERATING COST - $M	136.6
GROSS WEIGHT - LB	910,000
BLOCK FUEL WT - LB	206,500
OPERATING WT - LB	350,900
WING ASPECT RATIO	8.84
WING AREA - SQ FT	6,710
EMPENNAGE AREA - SQ FT	1,767
THRUST - LB	55,250
TON-MILES/LB-FUEL	2.81

GENERAL ARRANGEMENT



MATERIAL USAGE - POUNDS

COMPONENT	GRAPHITE EPOXY	ALUM. & OTHER	TOTAL WEIGHT
WING	86,551	21,710	108,261
FUSELAGE	35,363	71,442	106,805
EMPENNAGE	7,241	1,531	8,771
NACELLE & PYLON	2,971	5,768	8,739
LANDING GEAR	6,012	20,129	26,141
TOTAL STRUCTURE	138,138	120,580	258,717

53% COMPOSITE MATERIAL

Figure 5. Graphite Epoxy Structure Aircraft

Cost/Benefit Comparison of Aluminum and Graphite Epoxy Materials

The major performance, weight, and cost benefits that are a direct result of graphite epoxy composite material technology are given on Figure 6. These benefits are illustrated in terms of percent increase and/or decrease of various comparison parameters with reference to the baseline aluminum aircraft.

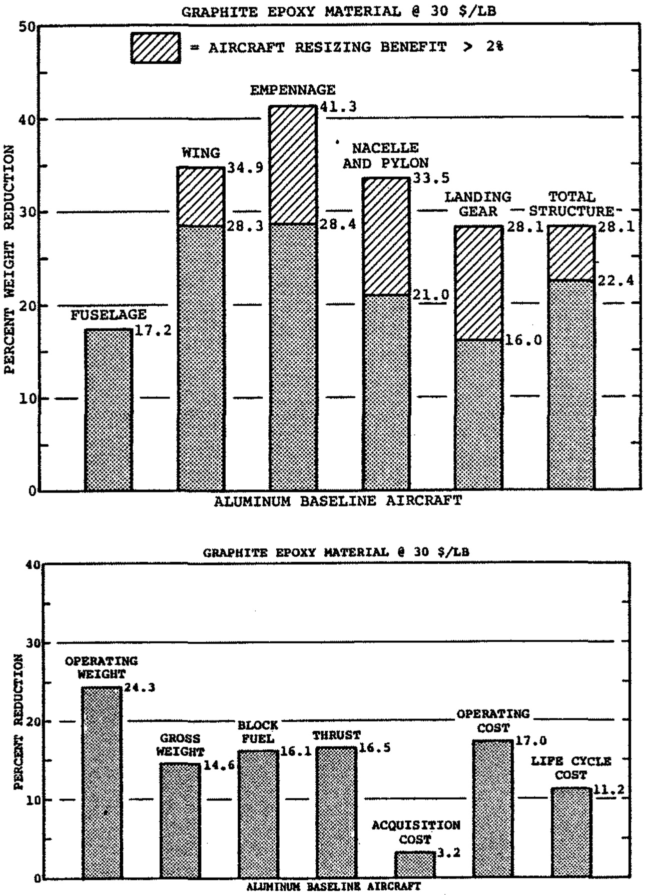


Figure 6. Graphite Epoxy Aircraft Benefit Summary.

The total structural weight of the GEC aircraft is 28.1 percent less than that of the baseline aluminum aircraft. The wing is a major contributor to this weight reduction, with its weight being reduced by 34.9 percent. All structural components except the fuselage realize a significant benefit from the aircraft resizing that results from the reduced aircraft gross weight. For example, approximately 19 and 31 percent, respectively, of the wing and empennage weight saved is a result of the area and load reductions provided by resizing.

The 14.6 percent reduction in gross weight is a product of both the operating and block-fuel weight reduction. The operating weight reduction is primarily influenced by the reduction in structural weight. The block-fuel weight is influenced by both weight reduction and the increase in wing aspect ratio. As noted earlier, the graphite epoxy aircraft has a wing aspect ratio of 8.84, compared with 7.77 for the baseline aluminum aircraft. This increase in aspect ratio provides an improved cruise efficiency, and thus a reduction in fuel consumption.

Of the two primary elements of life cycle cost, acquisition and operating cost, the first is shown to decrease 3.2 percent and the second is shown to decrease by 17.0 percent. The combination of these two elements results in an 11.2 percent reduction in life cycle cost.

In the previously cited report on composite materials (Reference 22), it is concluded that the significant potential benefits from the application of graphite epoxy composite materials cannot be achieved by the 1995-2000 time period without significant government development funding from NASA and Air Force programs to achieve the necessary technology readiness. The NASA ACEE Large Composite Primary Aircraft Structures program has as its objective the development of technology readiness of large components of transport aircraft. Therefore, it is of great concern to the aircraft industry to see this activity eliminated in the NASA FY83 planned budget.

Multibody Aircraft Design

Studies of large span-distributed-loading aircraft, in which the cargo is carried entirely in the wing, have shown the potential for cost reduction and performance improvement through reduction in structural weight. These improvements are more pronounced for payloads ranging from 600,000 pounds to over 1 million pounds (References 23-26). This design concept, however, has the disadvantage that the aircraft require very wide runways and taxiways not presently available at existing airports. The requirement for these wide runways and taxiways results from the need to support the payload all the way to the wingtips.

An interesting alternative to the span-distributed-load concept is the multi-body concept wherein the payload is carried in separate bodies located on the wing outboard of the wing centerline. Preliminary Lockheed studies of a two-body arrangement show a reduction in wing-root bending moments and the synergistic effects of the resulting reduction in wing weight on the performance of the aircraft (Reference 21). Multibody designs that emphasize parts commonality in the fuselage and empennage should result in reduced first cost and lower overall operating costs.

Many technical unknowns, however, exist concerning this type of aircraft. Basic questions that arise relate to the wing efficiency obtainable, structural characteristics, and stability and control behavior. Moreover, wind tunnel data on multibody aircraft are minimal, giving rise to numerous uncertainties when standard analytical methods are used to design multibody concepts. Lockheed has recently completed a NASA-sponsored study of multibody aircraft that provides some guidance in the above areas (Reference 27,28). This paper summarizes the highlights of this study.

An inservice date of 1990 to 1995 is assumed, thus allowing for the incorporation of those technologies expected to be mature and available for production usage in 1985. Included in these technologies are supercritical aerodynamics, relaxed static stability, and advanced structural materials. Graphite epoxy composite is the principal material used for all secondary structure and empennage primary structure. Wing and fuselage structures are selectively reinforced with boron epoxy composite material.

The aircraft are sized to provide the minimum direct operating cost (DOC) configuration when transporting 771,620 pounds over a distance of 3500 nautical miles at a cruise speed of Mach 0.80. Direct operating cost data are based on 1981 dollars and a fuel cost of 1.30 dollars per gallon. Other mission parameters include a takeoff distance of 10,500 feet, an initial cruise altitude of 32,000 feet, and a maximum approach speed of 150 knots. The payload is transported on a single-level cargo floor, within civil containers 8 by 8 by 10 or 20 feet in width, height, and length, respectively. Revenue payload (design payload minus container tare weight) design density is 10 pounds per cubic foot. A cargo compartment minimum pressure is maintained equivalent to an altitude of 18,000 feet.

Two baseline aircraft are configured in this study. A multibody aircraft shown in Figure 7 has two fuselage bodies located at approximately 28 percent wing semispan. The singlebody aircraft shown in Figure 8 is designed to provide a reference base to which the multibody aircraft is compared. The multibody and the singlebody baseline aircraft were subjected to a rigorous theoretical analysis to assure concept technical feasibility, to identify those areas where additional investigations are required, and to provide the data from which performance and cost comparisons can be made (Reference 27).

SPEED	0.80 MACH
PAYLOAD	771,618 LB
RANGE	3,500 NM
OPERATING WT.	739,100 LB
GROSS WT.	1,964,600 LB
BLOCK FUEL	379,500 LB
ASPECT RATIO	10.74
DOC	10.57 ¢/ATNM @ 1.30$ PER GAL.

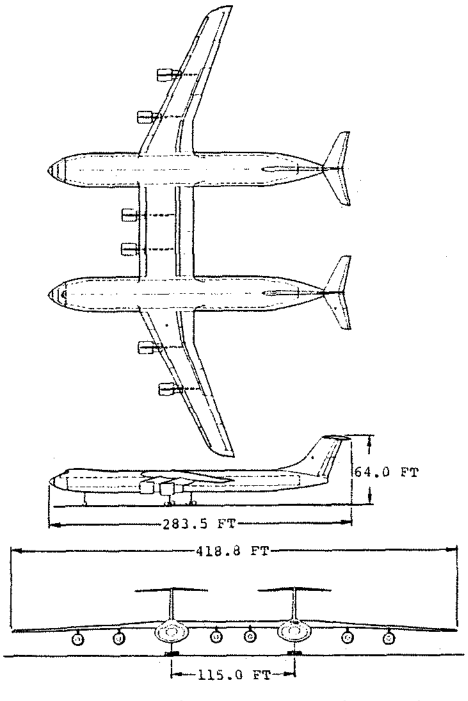


Figure 7. Multibody Baseline Aircraft

SPEED	0.80 MACH
PAYLOAD	771,618 LB
RANGE	3,500 NM
OPERATING WT.	820,900 LB
GROSS WT.	2,111,700 LB
BLOCK FUEL	434,200 LB
ASPECT RATIO	8.93
DOC	11.93 ¢/ATNM @ 1.30$ PER GAL

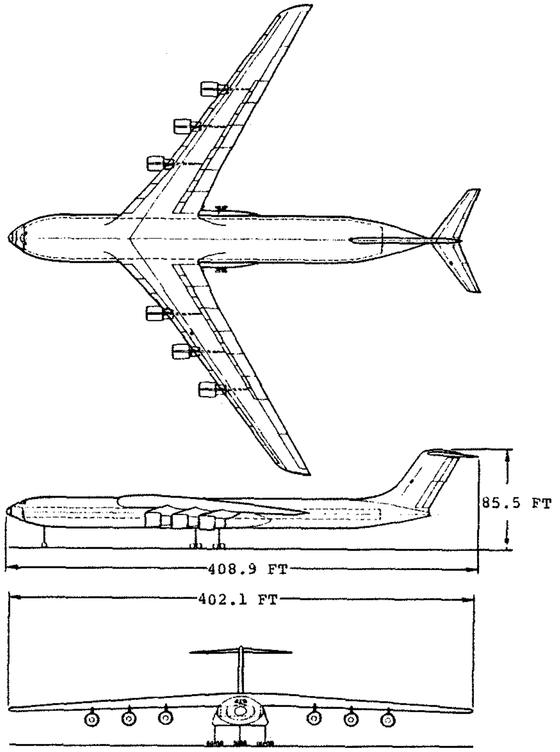


Figure 8. Singlebody Baseline Aircraft

Multibody/Singlebody Comparison

As discussed previously, the basic advantage of the multibody concept is the reduction in the wing-root bending moments compared with a singlebody configuration, and the synergistic effects of the resulting reduction in wing weights on the performance of the aircraft. The variation of wing bending moments from wing root to wingtip displayed in Figure 9 show a reduction in wing-root bending moment of 51 percent for the multibody aircraft at the 2.5g cruise flight condition. For the 2.0g downbending taxi condition, the reduction is 49 percent.

The wing span load distributions and resulting span efficiencies used for the multibody aircraft and the singlebody comparison aircraft are given on Figure 10. In the absence of a transonic code capable of modeling the aerodynamics of off-centerline bodies, initial estimates of spanloading and efficiency were made using the Hess subsonic code and the Vorlax Vortex Lattice method (Reference 29,30). Both of these methods provided a singlebody span load and efficiency less than those achieved by existing singlebody aircraft. Consequently, the singlebody data were adjusted to provide known achievable values of span efficiency by assuming a reduction in the lift loss. Assuming that the same inaccuracy existing in the multibody data, a corresponding adjustment was made to its load distribution to provide the data given in Figure 10.

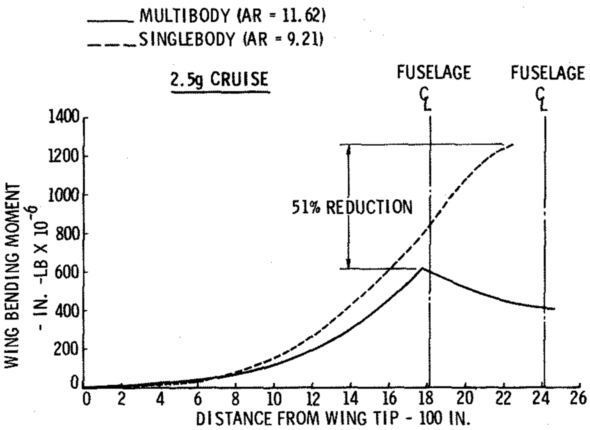


Figure 9. Up Bending Moment Comparison

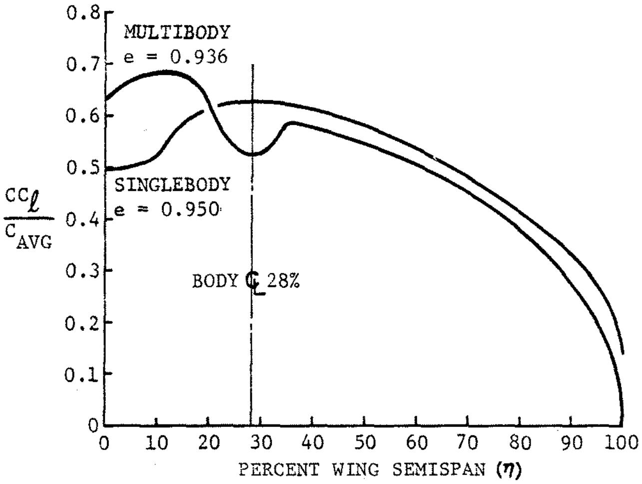


Figure 10. Span Efficiency and Load Distribution - Adjusted Vorlax Code Data

Subsequent wind tunnel test data substantiate the validity of the span-efficiency values defined by this analytical method for the multibody aircraft (Reference 28).

In the drag buildup for each aircraft, the data are referenced to a trapezoidal wing area derived by an extension of the outer wing leading and trailing edges to intersection points with the aircraft centerline (Reference 28). For better comparison of these drag levels, some of the more important drag items are given in Figure 11 in terms of equivalent parasite area ($D/q = C_DS$). The data in Figure 11 show the drag level of the basic fuselage of the multibody aircraft to be greater than that of the singlebody fuselage. However, adding the gear pod to the singlebody aircraft, which is not required by the multibody aircraft, increases the drag level of the singlebody aircraft fuselage. This comparison results in the singlebody fuselage drag being about 10 percent higher than that for the multibody fuselage.

Profile, induced, and total drag comparisons are also given in Figure 11 and are 13.6, 17.1, and 15.1 percent less, respectively, for the multibody aircraft. The induced drag of the multibody aircraft reflects the counterbalancing influence of its higher wing aspect ratio and lower span efficiency.

EQUIVALENT PARASITE AREA (D/q FT.^{2})	SINGLEBODY	MULTIBODY
FUSELAGE DATA		
BASIC FUSELAGE	53.87	58.45
BASIC FUSELAGE + GEAR POD	64.96	58.45
AIRCRAFT DATA		
PROFILE	207.5	179.3
INDUCED	139.4	115.6
TOTAL	369.2	313.5

Figure 11. Equivalent Parasite Area Comparison

To provide comparison data for the multibody and singlebody aircraft, certain revisions were made to both baseline aircraft. For example, the baseline multibody aircraft wing required an outer wing weight increase of 4500 pounds to provide wing stiffness to achieve an adequate flutter margin. In addition, both aircraft have been resized to optimize the thrust and wing loading to provide the required takeoff distance. This is accomplished by a reduction in cruise power setting. The characteristics of the revised aircraft are provided in Figure 12 to allow comparison of the multibody design concept with a singlebody aircraft. The data in Figure 12 are arranged so that the incremental percentage change given in the third column is the multibody increment referenced to the singlebody.

AIRCRAFT TYPE → / ↓ DATA ITEM	SINGLEBODY (SB)	MULTIBODY (MB)	* Δ%
Wing			
Aspect Ratio	9.21	11.62	+26.2
Area - SQ. FT.	16,862	14,409	-14.5
Sweep - Degree	35	25	-28.6
Loading - LB./SQ.FT.	122.5	134.3	+9.6
Span - FT.	394.0	409.1	+3.8
Weight - LB.	276,630	251,920	-8.9
Weight - LB./SQ.FT.	16.41	17.48	+6.5
Fuselage			
Length - FT.	365.9	261.2	-28.6
Width - FT.	40.2	31.5	-21.6
Height - FT.	25.3	19.7	-22.1
Weight - LB.	231,610	236,520	+2.1
Weight - LB/SQ.FT.	7.02	6.42	-8.5
Floor Height Above Ground-FT.	25.50	17.74	-30.4
Empennage			
Area - SQ.FT.	3,268	3,545	+8.5
Weight - LB.	17,160	17,940	+4.5
Weight - LB./SQ.FT.	5.25	5.06	-3.6
Propulsion			
Engines - Number	6	6	
Thrust/Eng. - LB.	75,860	67,010	-11.7
System Wt. - LB.	120,280	105,090	-12.6
Cruise Power Setting	0.92	0.88	-4.3
Landing Gear			
Max. Tread Width - FT.	55.7	127.2	+128.4
Weight - LB.	94,530	66,650	-29.5
Aircraft Weight - 1000 LB.			
Structure	641.0	591.7	-7.7
Operating	829.3	763.0	-8.0
Fuel	514.8	445.5	-13.6
Gross	2,115.7	1,980.1	-6.4
Performance			
Cruise L/D	21.81	24.05	+10.3
Block Fuel - 1000 LB.	430.4	372.2	-13.5
Ton NM/GAL. Fuel	21.04	24.31	+15.5
Ferry Range - NM	5,374	5,431	+1.1
Economic			
Aircraft Price - $M	305.8	275.1	-10.1
DOC - ¢/ATNM @ 1.30 $/GAL	11.91	10.56	-11.3

$$* \Delta\% = 100 \left[\frac{MB - SB}{SB} \right]$$

Figure 12. Comparison Aircraft Data Summary

As shown in Figure 12, the significant percentage changes of the multibody as compared to the singlebody include: an increase in wing aspect ratio of 26 percent, a reduction in engine thrust of 11.7 percent, and a reduction in structure weight of 7.7 percent. With the increase in cruise L/D of 10 percent and reduced structure weight, the block fuel is reduced by 13.5 percent and the gross weight reduced 6.4 percent. The unit price of the multibody aircraft is 10 percent lower, which includes RDT&E, production, and other costs such as engines and warranties. The lower aircraft price and block fuel consumption results in a reduced direct operating cost, DOC, of 11.3 percent for the multibody aircraft.

From an operations standpoint, the multibody has a cargo floor height of 17.7 feet as compared with 25.5 feeet for the singlebody. Thus, the multibody is more compatible with existing ground loading equipment. For the large payload considered, although the quantity of equipment and personnel required for simultaneous loading of the multibody fuselages are increased, it is expected that the loading/unloading time can be significantly reduced, thereby reducing the turnaround time and increasing the utilization of the aircraft.

Wind tunnel test results demonstrate that reasonable span efficiencies can be obtained for multibody aircraft of the type illustrated in Figure 13. However, a correlated transonic code that is capable of multibody analysis is required to optimize the wing design.

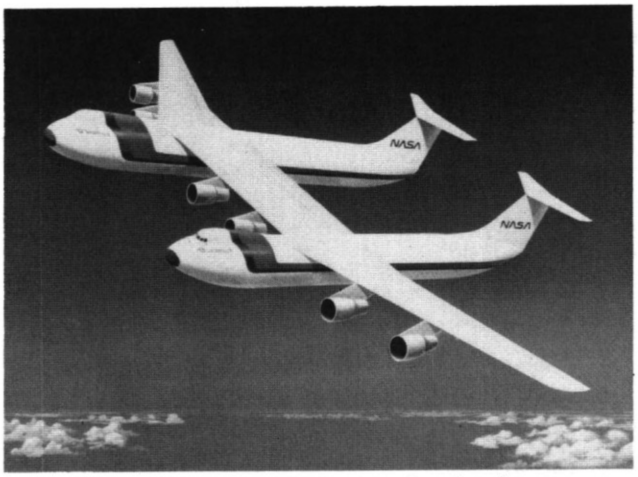


Figure 13. Very Large Payload Air Cargo Transport Aircraft

IV. Conclusions

System design studies of large cargo transport aircraft envisioned for operation in the 1995-2000 time period show significant potential benefits in reduced aircraft weight and improved performance and operating costs as a result of the utilization of graphite epoxy composite materials in primary and secondary structures. The potential benefits from the full utilization of graphite epoxy composites structure, compared with an equivalent aluminum-structure aircraft show a 24 percent reduction in operating weight, 16 percent reduction in fuel, 16.5 percent reduction in engine thrust, 17 percent reduction in operating costs, 11 percent reduction in life cycle costs, and a 3 percent reduction in acquisition costs.

System design studies of multibody aircraft with an inservice operation date of 1990-1995 show improvements in performance and costs compared with a singlebody aircraft. Compared with the singlebody aircraft, the multibody shows an increase in cruise L/D of 10 percent, a reduction in structure weight of 7.7 percent, a reduction of block fuel of 13.5 percent, a reduction in gross weight of 6.4 percent, a reduction in unit price of 10 percent, and a reduction in DOC of 11.3 percent.

From an operations standpoint, the 17.7 foot cargo floor height of the multibody aircraft, which is 7.8 feet lower than the singlebody aircraft, makes it more compatible with existing ground loading equipment. For the large payload considered, it is expected that the loading/unloading time can be significantly reduced, thereby reducing the turnaround time and increasing the utilization of the multibody aircraft.

Wind tunnel test results indicate that reasonable span efficiencies can be obtained for multibody aircraft of the type considered in this study. However, additional transonic analysis correlated with wind tunnel testing is required to optimize the wing-body configuration for multibody design concepts.

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