A REVIEW OF UNCONVENTIONAL AIRCRAFT DESIGN CONCEPTS

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Abstract

The need for improved aircraft performance and efficiency has provided the motivation for consideration of unconventional design concepts for aircraft envisioned for operation in the 1990-2000 time period. Advances in technology permit continuing improvements in aircraft performance and economics but unconventional design concepts show the potential for larger incremental improvements in aircraft efficiency. The paper reviews preliminary design system studies of unconventional aircraft including span-distributed loading, multi-body, wing-in-ground effect, flatbed and transonic biplane design concepts. The data include a comparison of the performance and economics of each concept to that for conventional designs. All of the design concepts reviewed incorporate appropriate advanced technologies. The aircraft design parameters include Mach numbers from 0.30 to 0.95, design payloads over 1 million pounds, and design ranges up to 5,500 nautical miles.

I. Introduction

Aeronautical engineers are motivated to consider unconventional aircraft design concepts in order to achieve a particular performance or operational improvement such as drag reduction, increased useful load, short airfield capability and/or combinations thereof. External influences such as the fuel crisis of the early 1970's provided the impetus for a number of approaches toward the achievement of aircraft fuel efficiency including Very Large Aircraft, VLA, air cargo concepts and variable and fixed geometry designs for normal 200 to 400 passenger-sized aircraft. The fuel crisis also provided the motivation for a concerted effort within NASA, the Air Force, and industry on the application of advanced technologies for the improvement in aircraft fuel efficiency. This effort includes the NASA Aircraft Energy Efficiency (ACEE) Program (References 1 - 4). Advanced technologies including supercritical wing, advanced composite materials, advanced turbofan and propfan propulsion and laminar flow control have been identified in these programs as those that show the most significant potential benefits and which merit acceleration toward technology readiness (References 5 - 8). As will be discussed later, the selected application of these advanced technologies enhances the performance of unconventional aircraft design concepts as well.

There have been two AIAA Very Large Vehicle Conferences: the first in Arlington, Virginia in April 1979 (References 9 - 11) and the second in May 1982 in Washington, D.C. (References 12 - 14). These conferences covered a very broad range of vehicles including lighter-than-airships, surface effects ships, marine systems, nuclear-powered aircraft, hydrogen-fueled aircraft, and other air vehicles (Reference 9). Review papers covering design concepts and advanced technologies for large cargo aircraft have been presented at several conferences of the International Forum for Air Cargo (References 15 - 16).

This paper presents the results of preliminary design system studies of Very Large Aircraft, VLA, and for the more normal 200 to 400 passenger-sized aircraft. Design concepts reviewed include span distributed loading, multi-body, wing-in-ground effect, flatbed, and transonic biplane. The data include a comparison of the performance and economics of each concept to that for an equivalent conventional design. All design concepts incorporate appropriate advanced technologies. The aircraft design parameters include Mach numbers from 0.30 to 0.95, design payloads over 1 million pounds, and ranges up to 5,500 nautical miles.

This paper is intended as a brief summary of some unconventional design concepts, and only highlights of the study results and technical issues are presented. The reader is provided with references to more detailed reports on the design studies of the concepts.

II. Systems Technical Approach

The results presented in this paper cover a wide range of unconventional design concepts with different mission parameters and advanced technology assumptions employed in the preliminary design system studies. Inherent in the technical approach to each study is a procedure in which the particular unconventional aircraft design is compared to a reference aircraft design without use of the unconventional design feature. In each case the unconventional design aircraft and the reference aircraft are sized to provide identical performance capabilities of design cruise Mach number, payload, range, and airfield performance. It should be noted, however, that in the case of the wing-in-ground effects (WIG) aircraft where the tactical requirement to fly at extremely low altitude combined with the proposed power augmented ram lift system makes for a comparison with a high altitude cruise reference aircraft less meaningful, although such comparison data are available in Reference 17.

In order to provide a consistent data base from which the several design concepts can be compared, use is made in the Lockheed studies of the Generalized Aircraft Sizing and Performance (GASP) computer program. This program accounts for the interaction of the design constraints and technical disciplines involved in the aircraft design process such as mission requirements, geometric characteristics, engine data, and aerodynamic parameters. The GASP program is designed to calculate drag coefficients and weight on a component basis, integrate the results into complete aircraft drag and weight, select the propulsion system size by matching (or mismatching to optimize the aircraft for a given field length) cruise thrust requirements, determine the aircraft sized for the

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mission, and iterate the process until the defined mission parameters are satisfied. The GASP program has sufficient flexibility to permit the use of adjusting factors representing changes in the level of technology for various technology performance areas such as airfoil and materials technology. GASP has been used in a number of previous studies (References 8, 12, 15, and 17) to synthesize aircraft for design variables, such as wing loading, aspect ratio, cruise power setting, Mach number, range, payload, and field performance, and to define aircraft optimized to figures-of-merit such as minimum direct operating cost, gross weight, acquisition cost, and fuel usage.

III. Results of System Studies

Very Large Aircraft

One of the more significant events in the evolution of Very Large Aircraft concepts is the span distributed loading design in which the cargo is carried in the wing. By distributing the payload along the wing span, the structural weight of the wing is reduced as a result of the compensating effects of aerodynamic lift and inertia of the wing. Pioneering work by Lockheed in 1979 resulted in the spanloader configuration shown in Figure 1.

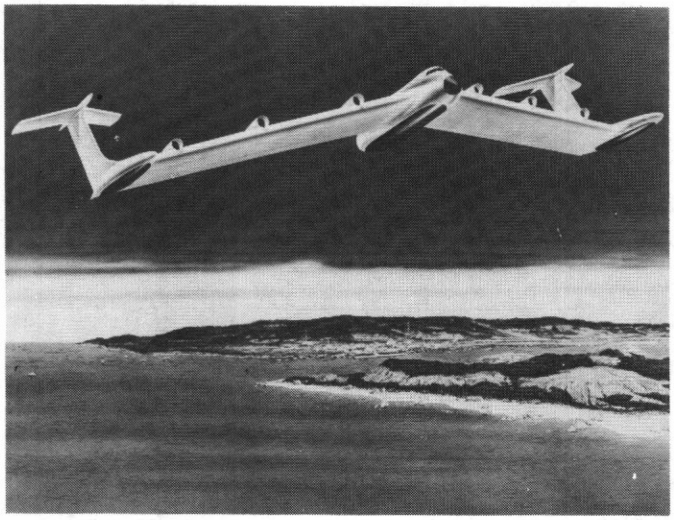


Figure 1. Lockheed Spanloader Design Concept

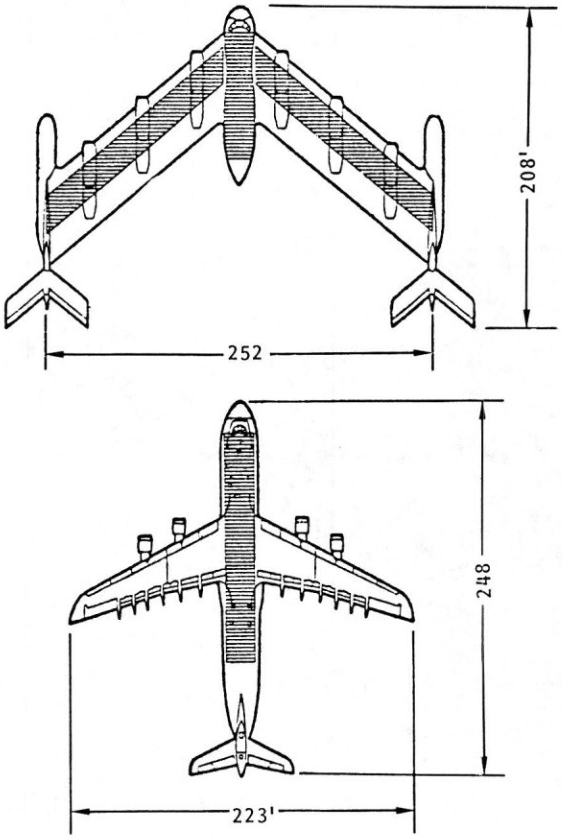


Figure 2. Comparison of Spanloader and C-5

The Lockheed configuration has a gross weight of 1,200,000 pounds, a payload capability of 660,000 pounds for a range of 3,300 nautical miles and a cruise speed of M = 0.75. The supercritical wing is swept back 40° for the 20 percent wing thickness to provide the volume for two rows of 8x8 foot cargo containers and also achieve the M = 0.75 design cruise speed. The effective aspect ratio of the wing is 6 including end plate effects. Advanced technologies utilized include graphite epoxy composite materials in primary and secondary structure, lift augmentation for improved airport performance, and an air cushion landing gear. More details of the design are contained in Reference 18. A relative size comparison of the spanloader design and the Lockheed C-5 transport is shown in Figure 2 and illustrates a disadvantage of the spanloader concept. The disadvantage results from the need to support the payload throughout the wing span to the tips. This aircraft, therefore, requires very wide runways and taxiways which are not available at current airports. To alleviate this disadvantage and to provide airfield flexibility, the Lockheed concept has air cushion landing systems located at each wing tip and at the centerbody.

Benefits due to the Lockheed spanloader design concept as compared to that for a conventional design aircraft are summarized in Figure 3 and show: 12 percent lower direct operating costs, 8 percent lower fuel consumption, and 10 percent lower gross weight.

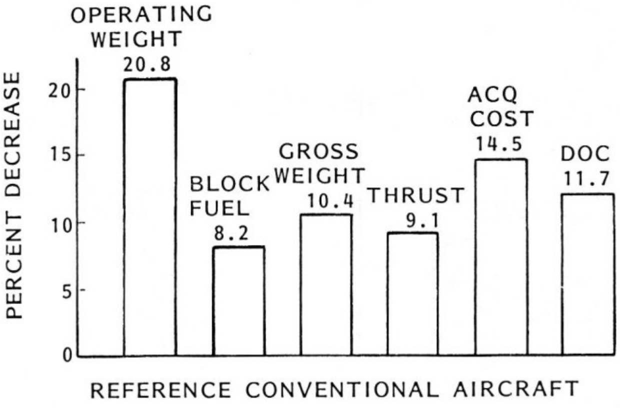


Figure 3. Benefits of The Spanloader Concept

Interest in the span distributed loading concept by the NASA Langley Research Center (Reference 19) resulted in NASA/industry system studies by Boeing, Douglas, and Lockheed reported in References 20 - 23. Design studies by Boeing covered payloads over 1 million pounds as shown in Figures 4 and 5 for a span-distributed load freighter with a gross weight of 2,354,000 pounds, payload of 1,047,000 pounds, a range of 3,600 nautical miles, and a cruise Mach number of 0.78. The effective aspect ratio of the wing is 7.73 including the end plate effects of the tip fins. This configuration resulted in a 50 percent reduction in direct operating costs, DOC, as compared to a conventional equivalent freighter aircraft.

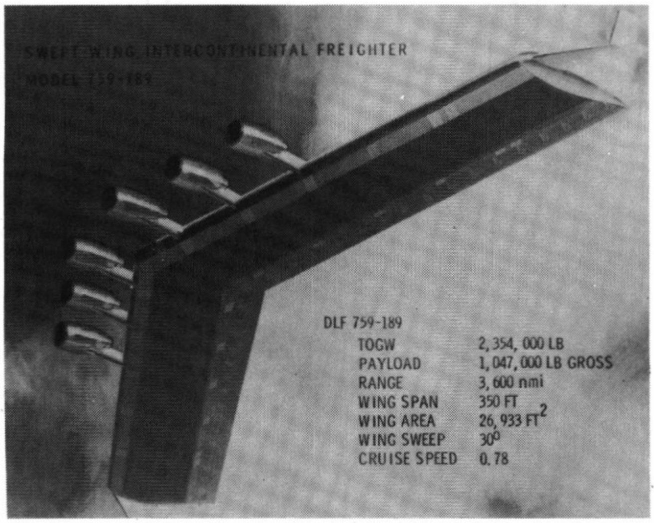
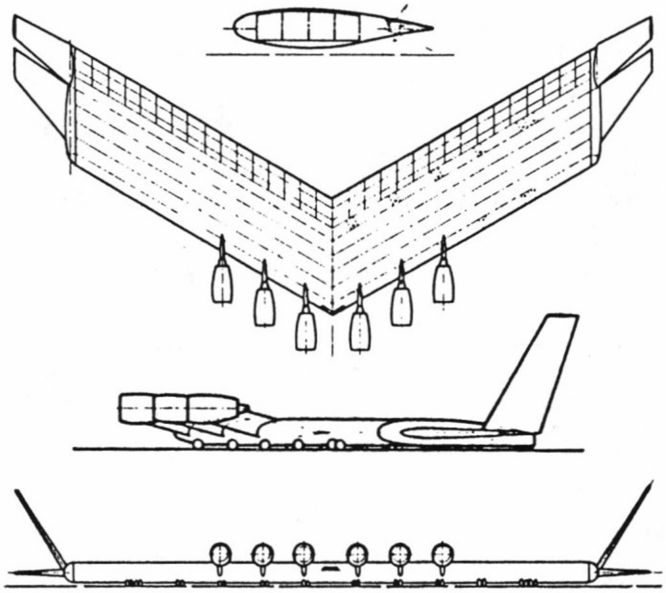


Figure 4. Boeing Distributed Load Freighter



TOGW		2,354,000 LB
OEW		687,936 LB
WING AREA		26,933 FT^2
ASPECT RATIO (EFF)		7.73
SWEEP		30°
t/c		0.19
CRUISE MACH		0.78
ENGINES	BPR	9.5
	SLST	93,000 LB

Figure 5. General Arrangement, Boeing Distributed Load Freighter

Figure 6 shows relative direct operating costs as a function of aircraft gross weight for several existing freighter aircraft and projected future aircraft. The shaded line depicts the large reduction in operating cost per ton-mile as aircraft size increases from the L-100/727 through the 707/DC-8 to the 747. The slope of the line is also a result of the improvement in technology which has occurred simultaneously with the progressive increases in size. Also shown on this line is a projected conventional aircraft with 1990 technology representing a further significant increase in aircraft size. The points below the shaded line represent the unconventional spanloader aircraft concept that shows potential for highly-efficient cargo operations with even greater reductions in DOC.

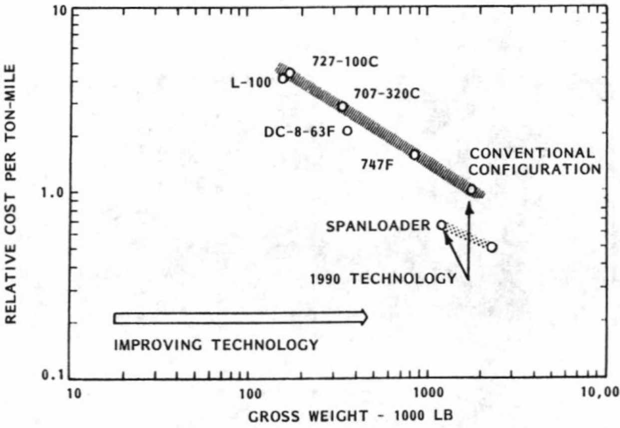


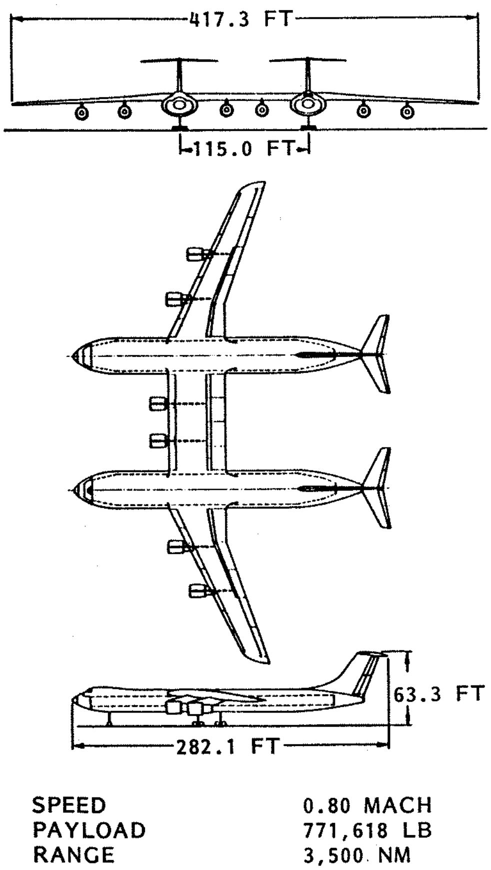
Figure 6. Operating Cost Trend

An interesting alternative to the spanloader design concept is the multibody concept wherein the payload is carried in separate bodies located on the wing as illustrated in Figure 7 for a two-body

Figure 7. Multibody Cargo Transport Concept

arrangement. The basic advantage of the multibody concept is the reduction in wing root bending moments and the synergistic effects of the resulting reduction in wing weight on the performance of the aircraft. It is also expected that faster loading and unloading of the two fuselages is possible as compared to the larger fuselage required of the comparable payload conventional airplane.

Preliminary Lockheed studies were made for a 441,000-pound payload, 4,000-nautical-mile range, M = 0.80 cruise speed transport (Reference 24). More detailed study and optimization were accomplished in a NASA-funded study of the multibody concept by Lockheed as reported in References 25 - 26. In the NASA study the payload was 772,000 pounds for a range of 3,500 nautical miles and a cruise speed of M = 0.80. A general arrangement drawing of this large payload multibody configuration is given in Figure 8. The aircraft were sized to achieve minimum direct operating cost, DOC, for the mission requirements. Advanced technologies employed include supercritical aerodynamics, relaxed static stability, and advanced structural materials. Graphite epoxy composite materials are used for all secondary structure and empennage primary structures. Wing and fuselage structures are selectively reinforced with boron epoxy composite materials.



SPEED	0.80 MACH
PAYLOAD	771,618 LB
RANGE	3,500 NM
OPERATING WT	763,000 LB
GROSS WT	1,980,100 LB
BLOCK FUEL	372,200 LB
ASPECT RATIO	10.74

Figure 8. Multibody General Arrangement

As discussed previously, the basic advantage of the multibody concept is the reduction in wing-root bending moments as compared with a singlebody configuration. The variation of wing bending moments from root to tip given in Figure 9 show a reduction in wing-root bending moment of 51 percent for the multibody at the cruise flight condition. The synergistic effects of the reduction in multibody aircraft weight as compared to the singlebody aircraft given in Figure 10 show reductions of 8 percent in operating weight, 13.5 percent in block fuel, 11.7 percent in engine thrust, 10 percent in aircraft unit cost, and 11 percent in DOC.

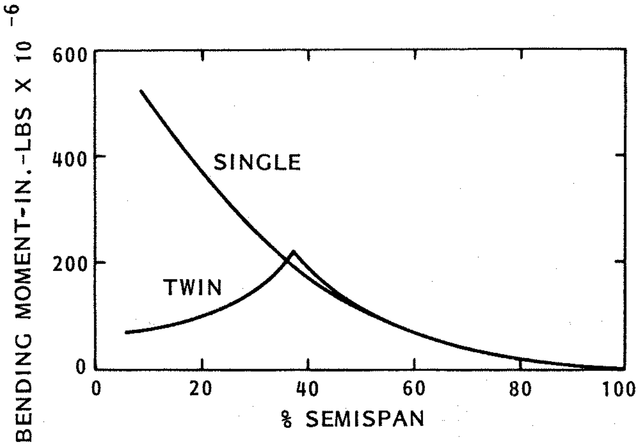


Figure 9. Comparison of Wing Bending Moments for Single and Twin Fuselage Configurations

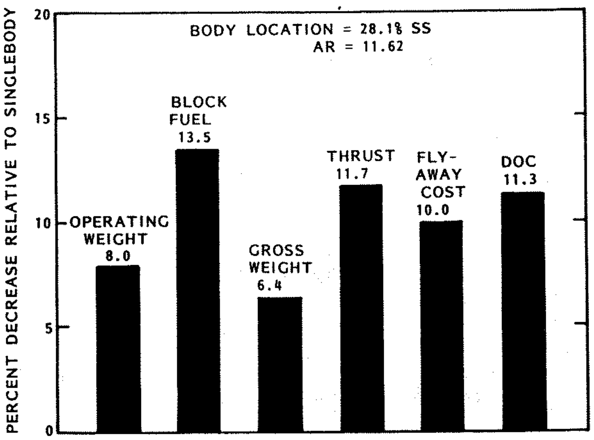


Figure 10. Benefits of the Multibody Concept

The multibody design concept has also been analyzed for civil 150 and 250 passenger commercial transports and the results presented in Reference 27. These studies show 26 percent reduction in seat miles per gallon for the 150 passenger aircraft and 38 percent reduction in seat miles per gallon for 250 passenger aircraft as compared to their single fuselage counterparts. These aircraft utilize technologies associated with current in-service commercial passenger transports. In effect the study represents a way of achieving improvements in performance and economics without relying on new technology advances.

Wing-in-Ground Effect Aircraft

The transport aircraft shown by the artist's sketch in Figure 11 utilizes a power augmented ram system for lift augmentation during takeoff and landing and cruises in close proximity to the ocean surface where drag is reduced in accordance with wing-in-ground effect theory. The logistics mission requires the aircraft to takeoff from the sea surface, transport 441,000 pounds of payload, 4,000 nautical miles, over sea state 3 conditions at a cruise speed of 0.40 Mach and then land on the sea surface. Part of the study results were generated under continuing preliminary design and system studies by the Lockheed-Georgia Company and part of the results were sponsored by the Naval Air Development Center under the Advanced Naval Vehicles Concepts Evaluation Project (References 28 and 29).

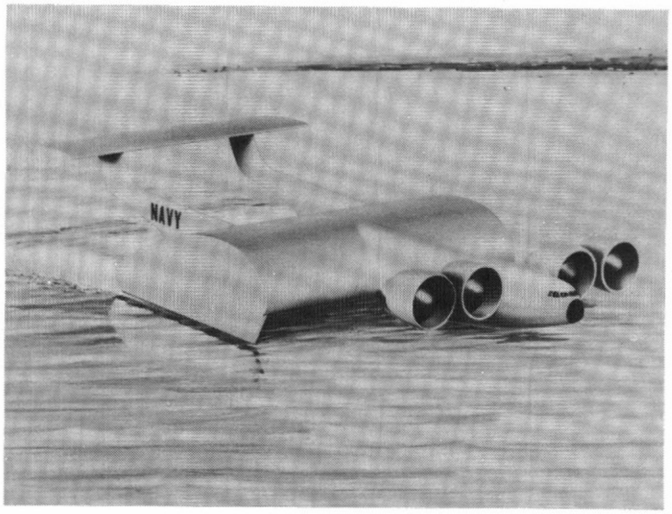


Figure 11. Wing-in-Ground Effect Transport

The cruise altitude is determined as a compromise between the ideal altitude specified by the classical ground effect theory shown in Figure 12 (Reference 30) and the operational requirement for sea state 3 with a structural design limit for sea state 4. Flight in ground effect inhibits the downwash induced by the wing lift, thus suppressing the induced drag. This reduction can be expressed as an increase in effective wing aspect ratio. This relationship is shown on Figure 12, where the ratio of effective aspect ratio (A_E) to geometric aspect ratio (A_{GEOM}) is given as a function of the height of the lowest extension of the wing surface, including endplates (h), above the water surface divided by the wing chord (c). The solid line represents Wieselsberger's theory and the dashed line is extracted from Lockheed wind tunnel tests.

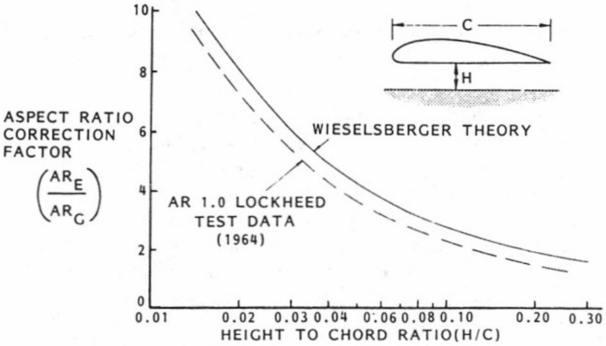


Figure 12. Ground Effect Theory

Basic to the design of the wing-in-ground effect aircraft discussed here is the application of power-augmented ram (PAR) lift based upon the pioneering investigations of the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) on water based ground effect vehicles (References 31 - 33). These investigations showed that the PAR system can be used to provide lift enhancement during takeoff and landing so that the wing loading of the WIG can then be optimized for cruise performance conditions. Furthermore, by means of PAR lift during takeoff and landing the contact speed between the water and primary structure is reduced by about 60 percent; hence, there is no need for a hulled surface and the structural weight of the aircraft is reduced.

PAR lift augmentation during takeoff and landing is illustrated in Figure 13 for the spanloader PAR/WIG configuration. The engines are rotated so that the primary propulsion efflux is directed toward the cavity under the wing formed by the wing lower surface, wing end plates, wing trailing-edge flaps, and the water surface. In this manner lift up to six times the installed thrust can be obtained while still recovering 70 percent of the thrust for acceleration. A complete description of the theory and experiments on PAR is given in Reference 31.

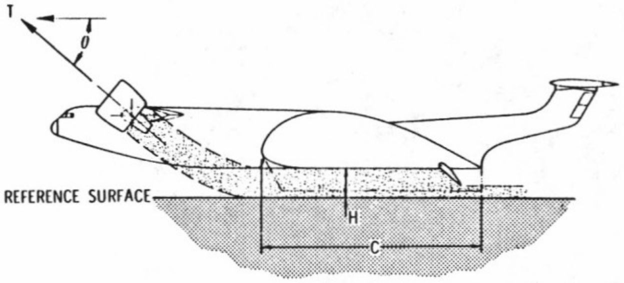
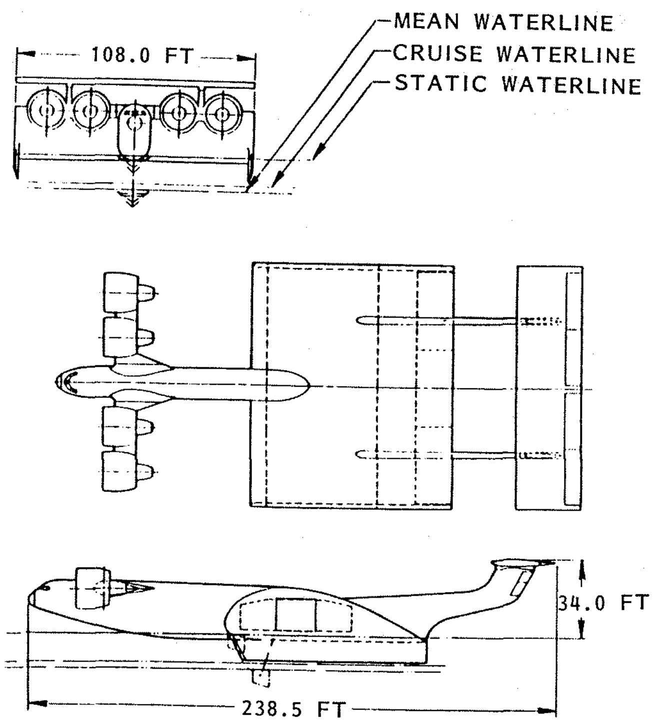


Figure 13. PAR Lift Augmentation

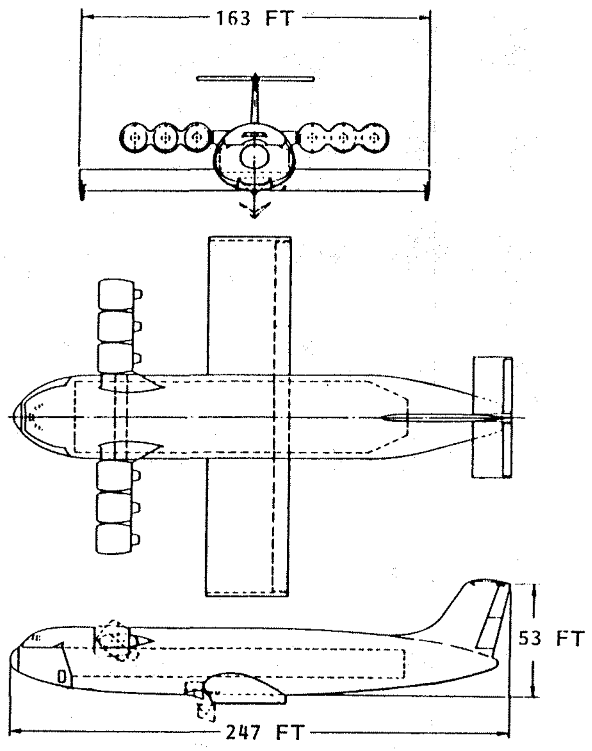
The general arrangement of the spanloader PAR/WIG aircraft shown in Figure 14 is the result of the unusual characteristics of the system. These characteristics include PAR lift augmentation for takeoff and landing, cruise flight only in ground effect, payload contained in the wing, and all operations accomplished on or above the ocean surface. An additional constraint imposed in the ANVCE study was the span limitation of 108 feet to allow use of facilities sized for the majority of contemporary naval vessels. The resulting transport configuration has a very low aspect ratio wing, rotatable engines mounted forward on the fuselage, a wing area of 9,828 square feet, a takeoff gross weight of 1,362,000 pounds for a payload of 441,000 pounds, and four engines with sea level static thrust of 95,600 pounds each. Twin vertical tails and an all movable horizontal tail provide aerodynamic control. This aircraft has a relatively low operating weight empty as compared with its takeoff gross weight.



OPERATING WEIGHT	357,900 LB
FUEL	563,100 LB
GROSS WEIGHT	1,362,000 LB
WING AREA	9,828 SQ. FT.
ASPECT RATIO (G)	1.19
ASPECT RATIO (E)	5.70
WING LOADING	139 LB/SQ. FT.
THRUST/WEIGHT	0.2808
THRUST/ENGINE	95,600 LB

Figure 14. PAR/WIG Spanloader Configuration

The alternate fuselage-loader PAR/WIG design development includes differences from the spanloader design in that the payload is contained in the fuselage, the restriction on wing span is removed, and the number of engines is increased from 4 to 6. The resulting design of the fuselage loader with a payload of 441,000 pounds is shown in Figure 15. The aircraft has an effective aspect ratio of 11.02, a takeoff gross weight of 1,196,200 pounds, and 6 engines with a sea level static thrust of 50,400 pounds each. The data for the spanloader and fuselage loader design characteristics presented in Figure 16 show that as compared to the fuselage loader the spanloader is 9 percent heavier in operating weight, 14 percent heavier in gross weight, uses 33 percent more fuel, and has 25 percent lower cruise efficiency. Part of this deficiency in performance of the spanloader design is attributed to the restriction of wing span to 108 feet and the attendant effect on the reduced wing aspect ratio.



OPERATING WEIGHT	329,800 LB
FUEL	425,400 LB
GROSS WEIGHT	1,196,200 LB
WING AREA	6,743
ASPECT RATIO (G)	3.94
ASPECT RATIO (E)	11.02
WING LOADING	177 LB/SQ. FT.
THRUST/WEIGHT	0.2526
THRUST/ENGINE	50,000 LB

Figure 15. PAR/WIG Fuselage Configuration

PAYLOAD = 441,000 LB. RANGE = 4000 NM SPEED = 0.4 CRUISE ALT = SL			
	SPANLOADER	FUSELAGE LOADER	Δ%
GEOMETRIC ASPECT RATIO	1.19	3.94	-70
EFFECTIVE ASPECT RATIO	5.70	11.02	-48
CRUISE L/D	15.59	19.79	-21
NUMBER ENGINES	4	6	-33
THRUST/WEIGHT RATIO	0.2808	0.2526	+11
CRUISE POWER SETTING	0.65	0.57	+14
OPERATING WEIGHT - LB	357,900	329,800	+9
BLOCK FUEL - LB	524,600	394,700	+33
GROSS WEIGHT - LB	1,361,900	1,196,200	+14
PAYLOAD/GROSS WT.	0.324	0.369	-12
TON-MILE/LB. FUEL	1.68	2.23	-25

Figure 16. Comparison of Spanloader and Fuselage Loader Designs

The Flatbed Design Concept

Another Lockheed design concept is the Flatbed featuring versatility of payloads carried on an open fuselage floor in order to accomplish multirole mission capabilities with the same airframe (Reference 34). The flatbed truck inspired the possibilities of a flying flatbed. The basic Flatbed configuration is shown by the model in Figure 17 and the general arrangement drawing in Figure 18. The aircraft design shown is of C-141 size with a payload capability of 75,000 pounds, cruise Mach number of 0.82, range of 2,600 nautical miles, and a gross weight of 279,543 pounds with the passenger module shown in Figure 19. The fuselage floor width is 140 inches and the length is sized

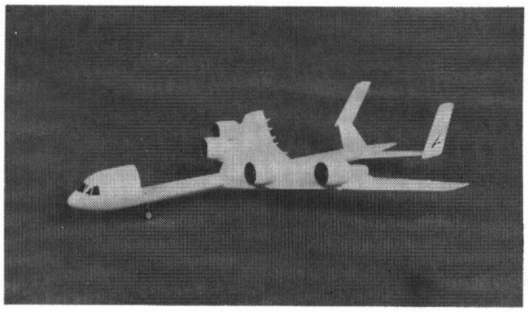


Figure 17. Basic Flatbed Configuration

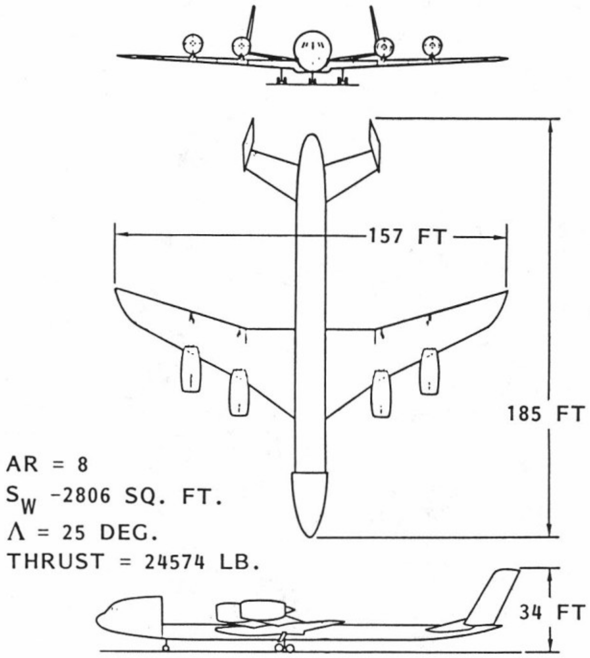


Figure 18. Flatbed General Arrangement

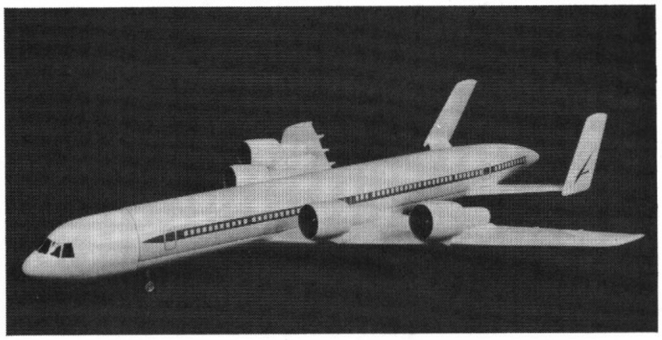


Figure 19. Flatbed with Passenger Module

for five 20 foot long cargo containers. The fuselage is sufficiently low to the ground to permit easy loading at loading docks and roll-on, roll-off of vehicles. The cockpit section is hinged to swing aside to provide for loading from the front. For the passenger module, a quick disconnect fixture to the engine bleed system provides for pressurization and environmental requirements. Cargo containers can be loaded unchanged and special fairings are installed fore and aft to reduce drag as shown in Figure 20.

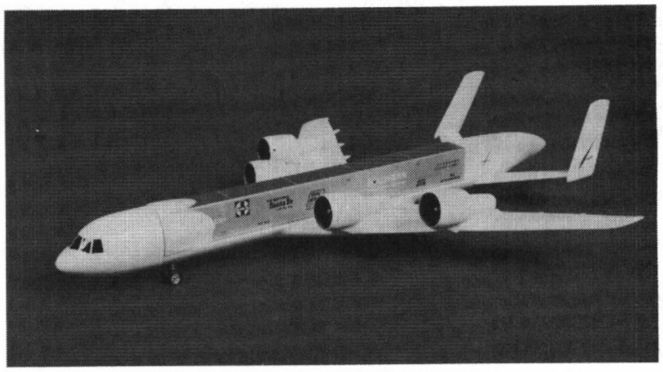


Figure 20. Flatbed with Cargo Containers

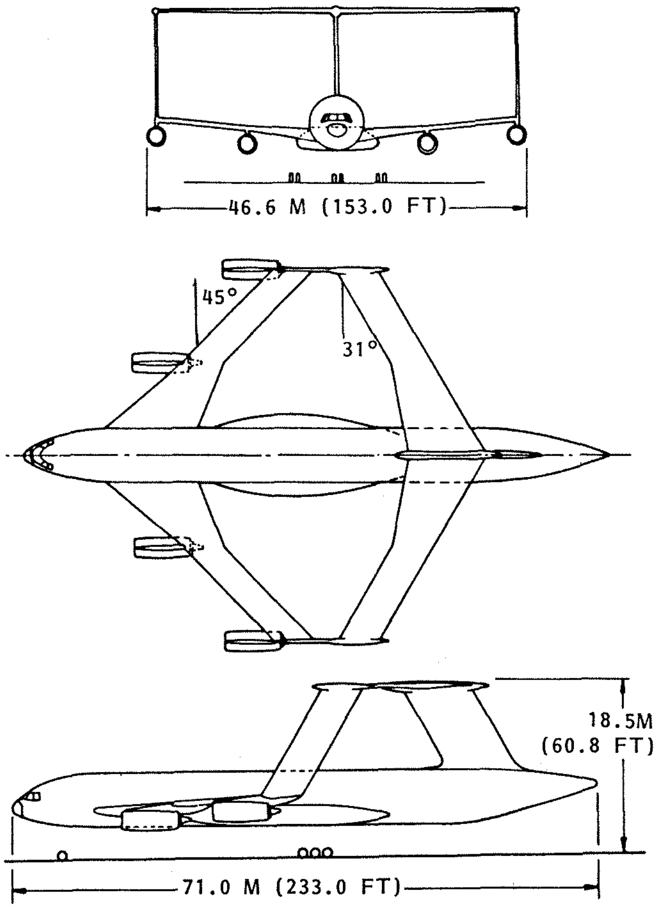
A summary of Flatbed performance data for passenger and container payloads is provided in Figure 21. Lockheed and NASA funded studies for the Flatbed concept indicate reduced turnaround time, improved quick change operations, easy convertibility to civil and military use, and reduced operating costs (Reference 35).

	PASSENGER		CONTAINER CARGO	
	REF A/C	FLATBED	REF A/C	FLATBED
CRUISE MACH NO.	0.82	0.82	0.82	0.82
RANGE - NM	2,600	2,600	2,600	2,600
CRUISE ALTITUDE - FT	35,000	35,000	35,000	35,000
GROSS PAYLOAD - LB	50,760	81,300	75,000	76,100
BLOCK FUEL - LB	57,204	63,551	68,988	89,281
TOGW - LB	258,995	279,543	290,092	303,011
T.O. DIST - FT	5,657	5,388	5,500	4,218
RATED THRUST - LB	19,132	20,535	22,519	20,535

Figure 21. Flatbed Performance Data

Transonic Biplane Concept

Another method of improving aircraft performance and efficiency is by use of a biplane design. The aerodynamic foundation was established as early as 1934 when it was shown that a closed rectangular lifting system (a biplane with fins connecting the wing tips) would produce the smallest possible induced drag for a given span and height (Reference 36). Drag reductions of as much as 50 percent of the monoplane induced drag are predicted in Reference 36 for a vertical separation between the wings equal to the semispan. Accordingly, as an extension of the NASA/Industry Advanced Transport Technology, ATT, program completed in 1972, reconsideration was given to the concept of a transonic biplane as proposed by the Lockheed-Georgia Company. In the transonic biplane concept shown in Figure 22 the two primary lifting surfaces are a swept-back wing attached to the lower part of the forward fuselage and a swept-forward wing attached to the top of the vertical tail at the rear of the fuselage. The cruise Mach number, payload and range are the same as that for the NASA/Lockheed ATT 400 passenger monoplane transport described in Reference 37.



SPEED	0.95
PAYLOAD	84,800 LB
RANGE	5500 NM
OPERATING WT	281,392 LB
GROSS WT	664,896 LB

Figure 22. Transonic Biplane Concept

Whereas the biplane theory of Prandtl in Reference 36 gave no consideration of wing sweep, the stagger theory for biplanes by Munk in Reference 38 would indicate that sweep has no effect on the reduction in induced drag expected. Low speed wing tunnel tests at the Lockheed-California Company in 1972 confirmed these analytical results by showing induced drag values consistent with the theory of Reference 36 for a swept biplane similar to that shown in Figure 22 (Reference 39). High subsonic and low supersonic speed wind tunnel test of a similar biplane configuration were conducted by NACA in 1953, but the vertical separation between the wing was very small, and as expected, no drag reduction was obtained (Reference 40). For the subject transonic biplane concept the vertical separation between the wings selected corresponds to a height to span ratio of 0.30. As shown in Figure 23 the theory of Reference 36 for a closed biplane system predicts a value of induced drag of 60 percent of that for an equivalent monoplane of the same aspect ratio at a height to span ratio of 0.30.

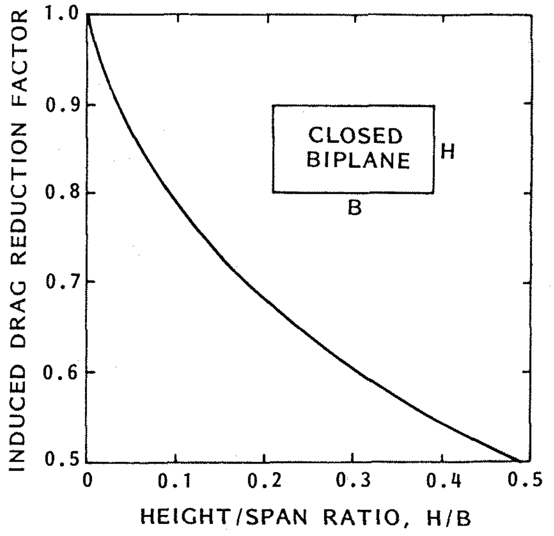


Figure 23. Closed Biplane Drag Reduction

Parametric preliminary design system studies conducted on the transonic biplane design concept of Figure 22 are reported in Reference 41. In the parametric design study, the configuration variables evaluated were aspect ratio, cruise lift coefficient (or wing loading) and small variations in wing sweep. The principal results of the study are shown in the weight summary comparison of Figure 24. The data in Figure 24 show that the weight and fuel required for the biplane concept are approximately the same as those for the monoplane design of the NASA/Lockheed ATT study for the same mission requirements. Furthermore, the biplane concept incurred flutter instabilities at speeds well below those required for transport aircraft cruising at M = 0.95. The flutter motions are extremely complex and no single feature of the configuration was isolated as the source of the instabilities. The low frequencies shown by the flutter results would make the biplane amenable to flutter suppression by means of active control systems, but this was beyond the scope of the investigation.

ITEM	BIPLANE LB	MONOPLANE LB
FORWARD WING	13,060	48,284
AFT WING	13,570	-
TIP FINS	9,033	-
HORIZONTAL TAIL	-	4,105
VERTICAL TAIL	14,079	3,212
FUSELAGE	58,970	54,125
OPERATING WEIGHT	281,392	282,377
PASSENGER PAYLOAD	84,800	84,800
MISSION FUEL	298,704	299,248
RAMP GROSS WEIGHT	664,896	666,425

Figure 24. Weight Summary Comparison

A brief investigation of the alternate configurations to provide for passive flutter elimination did not provide a satisfactory resolution of the problem. The alternate configurations included reduced wing tip spacing and a rear wing with a gull-like inboard section. Whereas the biplane configuration results in substantial reductions in drag due to lift, the parametric studies show that minimum airplane gross weights occur at aspect ratios lower than those for an equivalent monoplane. The cruise lift-to-drag ratios for the optimum biplane (at aspect ratio of 4.4) are approximately the same as those for the monoplane.

A recent AIAA survey paper on the joined wing concept contains information on related configurations such as the subject biplane concept (Reference 42). The joined wing is defined as a design concept that incorporates tandem wings arranged in such a manner as to form diamond shapes in both the plan view and the front view. It should be noted that such a configuration with joined wing tips in the front view corresponds to a height to span ratio of zero, and thus, as shown in Figure 23 there is no reduction in induced drag over that for a monoplane configuration. As noted previously one of the alternate configurations considered for the subject biplane had wing tip spacing reduced to one half that of the reference biplane design. The reduced wing tip spacing showed a flutter speed increase of 25 percent over that for the reference biplane but also showed a large drag increase and was, therefore, eliminated from further consideration.

IV. Concluding Remarks

Unconventional design concepts based upon the potential benefits to be derived from the singular effect of an aerodynamic or structural principle must be subjected to the preliminary design system study process that incorporates aerodynamic, structural, propulsion and other system elements. In this manner it can be determined if the potential benefit still remains when the aircraft design is optimized to a figure of merit such as minimum weight or direct operating costs, DOC. Whereas the best available methods are used to determine the weight and performance of these unconventional design concepts, generally there is a lack of statistical and experimental data to validate the performance estimates. As shown by the results in the present paper some of the unconventional concepts such as span-distributed loading, multibody, and wing-in-ground effect show potential for significant benefits in performance as compared with conventional designs. The expected benefits for the transonic biplane concept are not borne out in the results of the design system study. This result, even though a negative one, is still of value to the aircraft design community by enhancing the data base for unconventional aircraft concepts.

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