Review of Unconventional Aircraft Design Concepts

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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 200- to 400-passenger-sized aircraft. The fuel crisis also provided the motivation for a concerted effort within NASA, 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 Program.[1-4] Advanced technologies such as supercritical wing, advanced composite materials, advanced turbofan and prop-fan propulsion, and laminar flow control have been identified in these programs as those that show the most significant potential benefits for conventional aircraft, and that merit acceleration toward technology readiness.[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, VA, in April 1979[9-11] and the second in Washington, DC, in May 1982.[12-14] These conferences covered a very broad range of vehicles including lighter-than-air ships, surface-effects ships, marine systems, nuclear-powered aircraft, hydrogen-fueled aircraft, and other air vehicles.[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.[15,16]

This paper presents the results of conceptual design system studies of VLA and 200- to 400-passenger-sized aircraft. Design concepts reviewed include span-distributed loading, multibody, wing-in-ground effect, flatbed, and transonic biplane. The data include a comparison of the performance and economics of each concept relative 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 1×10^6 lb, and ranges up to 5500 n.mi.

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, the tactical requirement to fly at extremely low altitude combined with the proposed power augmented ram lift system makes a comparison with a high-altitude cruise reference aircraft less meaningful. Such comparison data are available in Ref. 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 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[8,12,15,17] to synthesize aircraft for design variables such as wing loading, aspect ratio, cruise power setting, Mach number, range, payload, and field performance. GASP has also been used to define aircraft optimized to figures-of-merit such as minimum direct operating cost, gross weight, acquisition cost, and fuel usage.

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III. Results of System Studies

Very Large Aircraft

One of the significant events in the evolution of VLA 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 Fig. 1. The Lockheed configuration has a gross weight of 1.2×10^6 lb, a payload capability of 660,000 lb for a range of 3300 n.mi., and a cruise speed of $M = 0.75$. The supercritical wing is swept back 40 deg for the 20% wing thickness to provide the volume for two rows of 8×8 ft 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 structures, lift augmentation for improved airport performance, and an air-cushion landing gear. More details of the design are contained in Ref. 18. A relative size comparison of the spanloader design and the Lockheed C-5 transport is shown in Fig. 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 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.

Other problem areas of the spanloader concept as determined by NASA wind-tunnel tests include adverse effects of operation of these very large aircraft near the ground plane, including low effectiveness of landing flaps, as reported in Refs. 19 and 20.

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

Interest in the span-distributed loading concept by the NASA Langley Research Center[21] resulted in NASA/industry system studies by Boeing, Douglas, and Lockheed.[22-25] Design studies by Boeing covered payloads over 1 million pounds as shown in Figs. 4 and 5 for a span-distributed load freighter with a gross weight of 2.354×10^6 lb, payload of 1.047×10^6 lb, a range of 3600 n.mi., 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% reduction in DOC, as compared to a conventional equivalent freighter aircraft.

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.

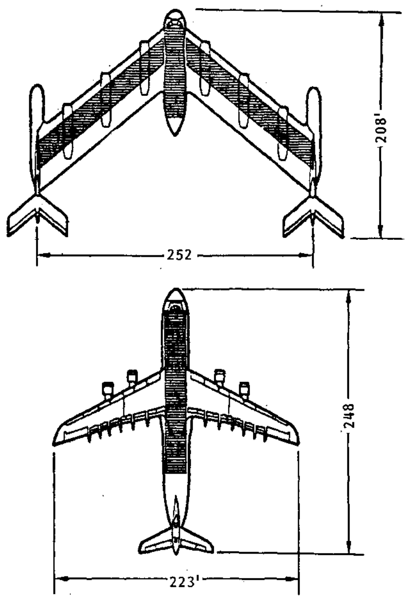


Fig. 2 Comparison of spanloader and C-5.

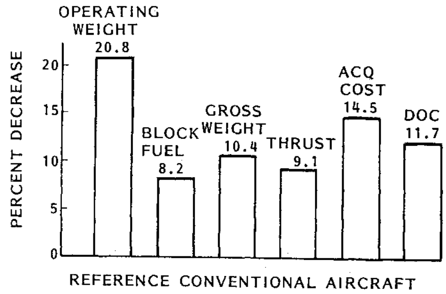


Fig. 3 Benefits of the spanloader concept.

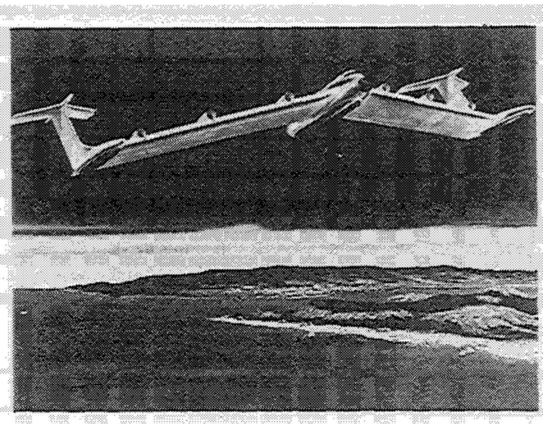


Fig. 1 Lockheed spanloader design concept.

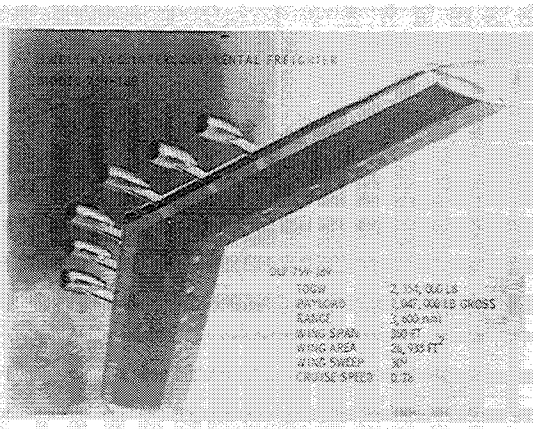


Fig. 4 Boeing distributed load freighter.

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 Fig. 7 for a two-body 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 are possible as compared to the larger fuselage required on the comparable payload conventional airplane.

Preliminary Lockheed studies were made for a 441,000 lb payload, 4000 n.mi. range, $M = 0.80$ cruise speed transport.[26] More detailed study and optimization were accomplished in a NASA-funded study of the multibody concept by Lockheed.[27,28] In the NASA study, the payload was 772,000 lb for a range of 3500 n.mi. and a cruise speed of $M = 0.80$. A general arrangement drawing of this large payload multibody configuration is given in Fig. 8. The aircraft were sized to achieve minimum 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.

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

The multibody design concept has also been analyzed for civil 150- and 250-passenger commercial transports and the results presented in Ref. 29. These studies show 26% reduction in seat miles per gallon for the 150-passenger aircraft and 38% reduction in seat miles per gallon for 250-passenger aircraft, as compared to their single-fuselage counterparts. These aircraft utilize technologies associated

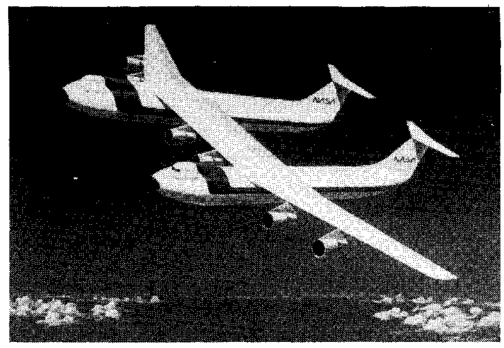
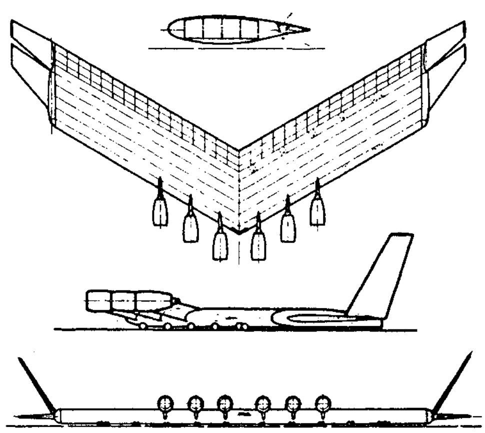
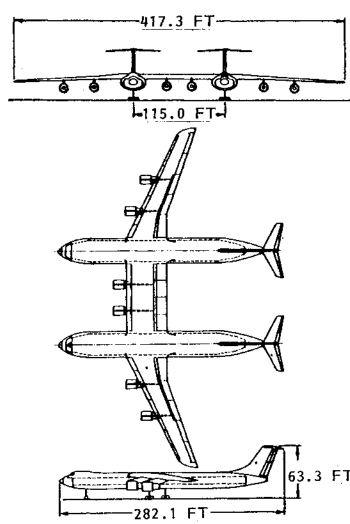


Fig. 7 Multibody cargo transport concept.



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

Fig. 5 General arrangement, Boeing distributed load freighter.



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 RATION	10.74

Fig. 8 Multibody general arrangement.

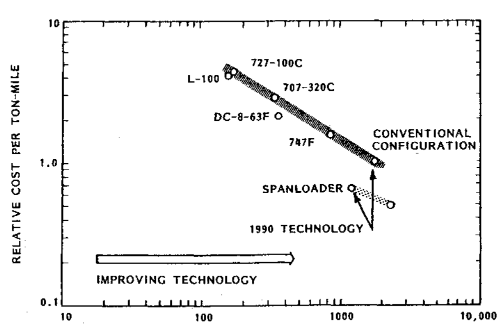


Fig. 6 Operating cost trend.

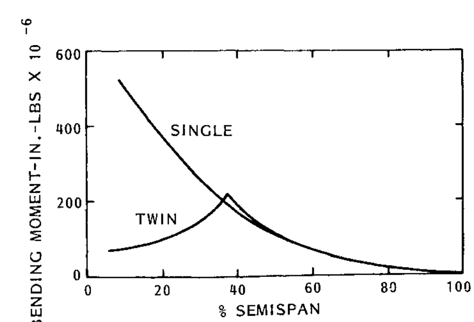


Fig. 9 Comparison of wing bending moments for single- and twin-fuselage configurations.

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.

Whereas this paper is confined to subsonic aircraft design concepts, it should be noted that the multibody concept has also been applied to transonic and supersonic aircraft. The multibody concept is one of the design options in the oblique wing concept of John.[29] Systems studies at NASA Langley have developed design concepts for multibody supersonic transports.[30]

The characteristics of multibody configurations relative to interference drag, dynamic loads, aeroelastic effects, flutter, longitudinal, and lateral stability behavior are discussed by Houbolt in Ref. 29. It appears that the aforementioned characteristics are dependent on the configuration arrangement of a multibody concept. The aeroelastic behavior analysis of the configuration shown in Fig. 8 did not reveal the existence of the flutter problem as reported in Ref. 28. Lateral stability and control behavior of multibody configurations are of concern due to the inertia effects of the separated fuselages. Simulator studies of a large multibody configuration by NASA for approach and landing flight conditions are reported in Ref. 31. The results indicate that considerable stability augmentation is required to provide acceptable low-speed handling qualities of the configuration investigated, and that the roll performance is the most critical area.

Wing-in-Ground Effect Aircraft

The transport aircraft shown in Fig. 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 take off from the sea surface, transport 441,000 lb of payload 4000 n.mi. 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 Georgia Division of Lockheed Aeronautical Systems Co., and part of the results were sponsored by the Naval Air Development Center under the Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project.[32,33]

The cruise altitude is determined as a compromise between the ideal altitude specified by the classical ground effect theory shown in Fig. 12,[34] 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 in Fig. 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

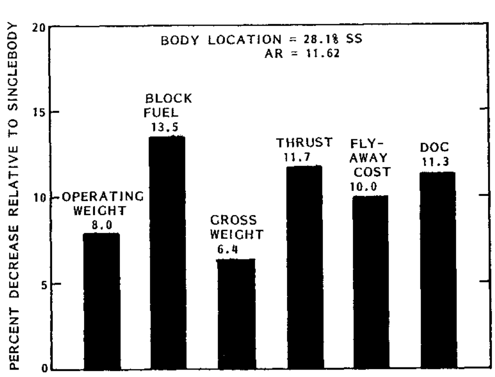


Fig. 10 Benefits of the multibody concept.

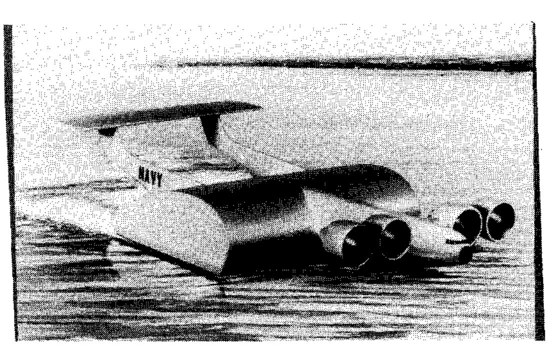


Fig. 11 Wing-in-ground effect transport.

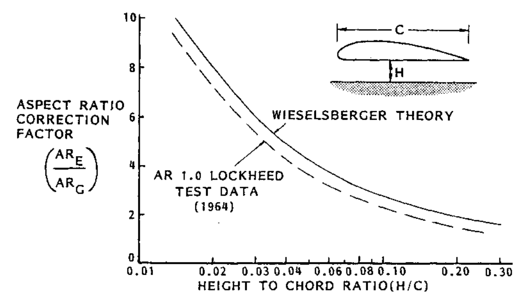


Fig. 12 Ground effect theory.

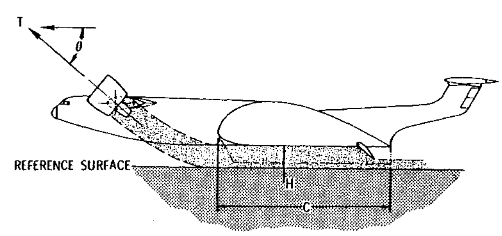
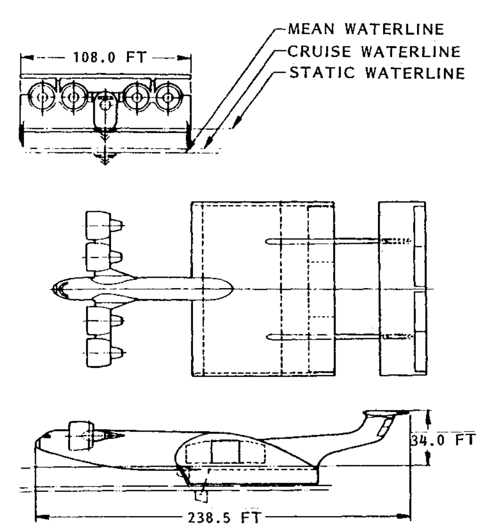


Fig. 13 PAR lift augmentation.



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

Fig. 14 PAR/WIG spanloader configuration.

wing surface, including end plates h, above the water surface divided by the wing chord c. The solid line represents Wieselsberger's theory,[34] and the dashed line is extracted from Lockheed wind-tunnel tests.

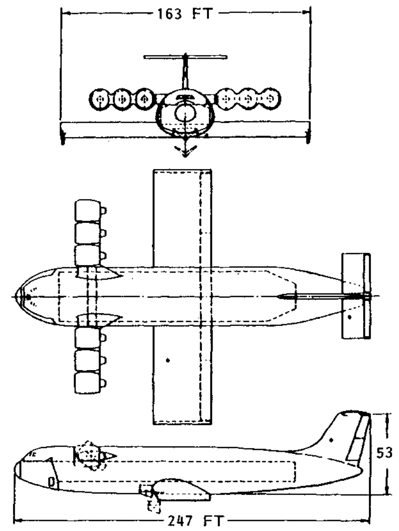
Basic to the design of the wing-in-ground effect aircraft discussed here is the application of the power-augmented ram (PAR) lift based on the pioneering investigations of the David W. Taylor Naval Ship Research and Development Center on water-based ground effect vehicles.[35-37] These investigations 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%; 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 Fig. 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% of the thrust for acceleration. A complete description of the theory and experiments on PAR is given in Ref. 35.

The general arrangement of the span-loader PAR/WIG aircraft shown in Fig. 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 ft 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 9828 ft^2, a takeoff gross weight of 1.362×10^6 lb for a payload of 441,000 lb, and four engines with sea-level static thrust of 95,600 lb 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.

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 four to six. The resulting design of the fuselage loader with a payload of 441,000 lb is shown in Fig. 15. The aircraft has an effective aspect ratio of 11.02, a takeoff gross weight of 1.1962×10^6 lb and six engines with a sea-level static thrust of 50,400 lb each. The data for the spanloader and fuselage loader design characteristics presented in Fig. 16 show that as compared to the fuselage loader the spanloader is 9% heavier in operating weight, 14% heavier in gross weight, uses 33% more fuel, and has 25% lower cruise efficiency. Part6 of this deficiency in performance of the spanloader design is attributed to the restriction of wing span to 108 ft, and the attendant effect on the reduced wing aspect ratio.

As mentioned previously in Sec. II, the WIG-type transports are special mission designs utilizing power-augmented ram lift, the limited wing span for the spanloader concept, and are required to fly in ground effect only. Because of these restrictions in the design parameters, a comparison with conventional high-altitude cruise aircraft is not as significant as with other aircraft. Nevertheless, comparison data for the WIG-type transports and conventional transports are provided in Ref. 17. For the comparison, a conventional land-based military transport was designed with the same payload, 441,000 lb, and range of 4000 n.mi., but with a cruise speed of $M = 0.85$ and cruise altitude of 36,000 ft. The data in Ref. 17 show for the conventional transport a cruise lift-to-drag ratio of 20.9, aspect ratio of 11.4, mission fuel of 355,300 lb, takeoff gross weight of 1.3688×10^6 lb, and cruise efficiency of 2.48 ton-miles per pound of fuel. As expected, the conventional transport shows greater efficiency than the span-loader WIG transport with 47% reduction in mission fuel and 32% increase in ton-miles per pound of fuel. The higher effective aspect ratio of the fuselage WIG design results in a more favorable comparison with the conventional transport. In this case the conventional transport, as compared to the fuselage WIG transport, shows an 11% reduction in mission fuel and 10% increase in ton-miles per pound of fuel.



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

Fig. 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

Fig. 16 Comparison of spanloader and fuselage loader designs.

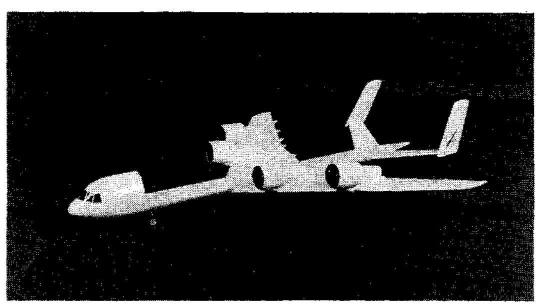


Fig. 17 Basic flatbed configuration.

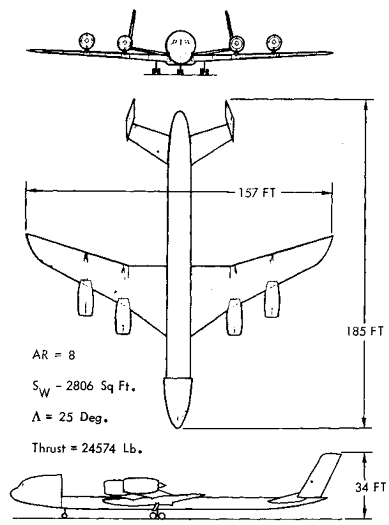


Fig. 18 Flatbed general arrangement.

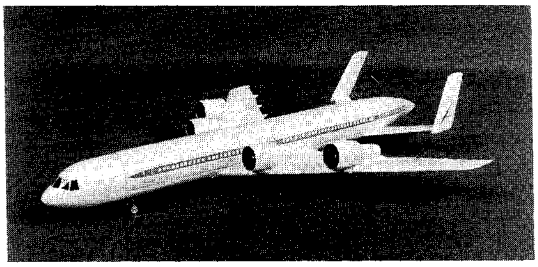


Fig. 19 Flatbed with passenger module.

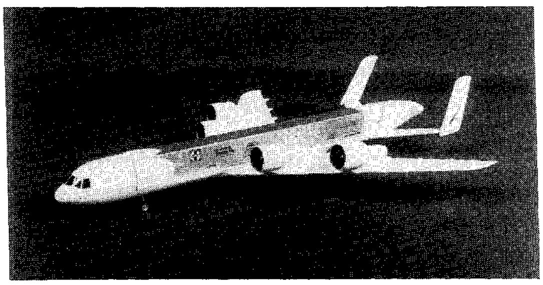


Fig. 20 Flatbed with cargo containers.

	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

Fig. 21 Flatbed performance data.

Flatbed Design Concept

Another Lockheed design concept is the flatbed, featuring versatility of payloads carried on an open fuselage floor for multirole mission capabilities with the same airframe.[38] The flatbed truck inspired the possibilities of a flying flatbed. The basic flatbed configuration is shown by the model in Fig. 17, and the general arrangement drawing in Fig. 18.

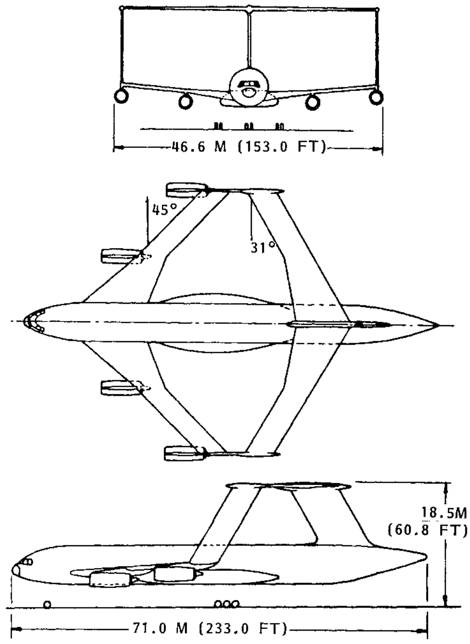


Fig. 22 Transonic biplane concept.

The design of the fuselage backbone structure of the flatbed concept for carrying the various payloads, and the loads of the empennage and landing gear, presented some formidable challenges, as described in Ref. 39. A modified elliptical cross section for the backbone fuselage emerged as the best design from the standpoint of stiffness, torsion, stress, and weights. The stiffness of the fuselage backbone of the flatbed concept is comparable to that of the C-141 aircraft.

The aircraft design shown is of C-141 size, with a payload capability of 75,000 lb, cruise Mach number of 0.82, range of 2600 n.mi., and a gross weight of 279,543 lb with the passenger module shown in Fig. 19. The fuselage floor width is 140 in. and the length is sized for five 20-ft-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 Fig. 20.

A summary of flatbed performance data for passenger and container payloads is provided in Fig. 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.[39]

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.[40] Drag reductions of as much as 50% of the monoplane induced drag are predicted in Ref. 40 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 Lockheed's Georgia Division. In the transonic biplane concept shown in Fig. 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 Ref. 41.

Whereas the biplane theory of Prandtl[40] gave no consideration of wing sweep, the stagger theory for biplanes by Munk[42] would indicate that sweep has no effect on the reduction in induced drag expected. Low-speed wind-tunnel tests at the Lockheed-California Co. in 1972 confirmed these analytical results by showing induced drag values consistent with the theory of Ref. 40 for a swept biplane similar to that shown in Fig. 22.[43] High subsonic and low supersonic speed wind-tunnel tests of a similar biplane configuration were conducted by NACA in 1953, but the vertical separation between the wing was very small, and no drag reduction was obtained.[44] 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 Fig. 23, the theory of Ref. 40 for a closed biplane system predicts a value of induced drag of 60% of that for an equivalent monoplane of the same aspect ratio at a height to span ratio of 0.30.

Parametric preliminary design system studies conducted on the transonic biplane design concept of Fig. 22 are reported in Ref. 45. 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 Fig. 24. The data in Fig. 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 beyong the scope of the investigation.

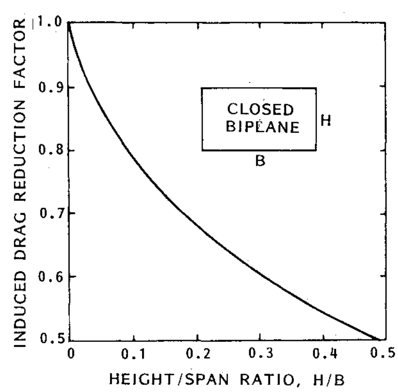


Fig. 23 Closed biplane drag reduction.

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

Fig. 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. 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% over that for the reference biplane, but also showed a large drag increase and was, therefore, eliminated from further consideration. 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.[46] 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.

The joined-wing concept represents a different class of design concept from that of the transonic biplane. The data on biplane systems contained in Ref. 47 indicate that the reduction in induced drag for the tip-jointed wing concept is considerably less than that for the closed rectangular system.[46] On the other hand, Wolkovitch predictions for the joined-wing concept include reduced structural weight as compared to a conventional aircraft. Additional advantages in reduced weight, high wing stiffness, improved transonic area distribution, and good stability and control are predicted for design concepts where the rear wing is joined inboard of the tip of the forward wing.

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 still remains when the aircraft design is optimized to a figure-of-merit such as minimum weight or direct operating costs. 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.

References

[1]Kramer, J. J., "Planning a New Era in Air Transport Efficiency," *Astronautics and Aeronautics*, Vol. 16, July-Aug. 1978, pp. 26-28.

[2]Conner, D. W., "CTOL Concepts and Technology Develop-

ment," *Astronautics and Aeronautics,* Vol. 16, July–Aug. 1978, pp. 29–37.

[3]Leonard, R. W., "Airframes and Aerodynamics," *Astronautics and Aeronautics,* July–Aug. 1978, pp. 28–46.

[4]Nored, D. D., "Propulsion," *Astronautics and Aeronautics,* Vol. 16, July–Aug. 1978, pp. 47–119.

[5]Gatzen, B. S. and Hudson, S. M., "General Characteristics of Fuel Conservation PropFan Propulsion System," Society of Automotive Engineers Paper 751087, Nov. 1975.

[6]Wagner, R. D. and Fischer, M. C., "Developments in the NASA Laminar Flow Control Program," AIAA Paper 83-0090, Jan. 1983.

[7]Lange, R. H., "A Review of Advanced Turboprop Transport Activities," AGARD Paper 1-1, AGARD Symposium on Aerodynamics and Acoustics of Propellers, AGARD Conf. Preprint 366, Oct. 1984.

[8]Lange, R. H., "Design Integration of Laminar Flow Control for Transport Aircraft," *Journal of Aircraft,* Vol. 21, Aug. 1984, pp. 612–617.

[9]Arata, W. H., "Very Large Vehicles To Be Or ...?" *Astronautics and Aeronautics,* Vol. 17, April 1979, pp. 20–25, 33.

[10]Noggle, L. W. and Jobe, C. E., "Large-Vehicle Concepts," *Astronautics and Aeronautics,* Vol. 17, April 1979, pp. 26–32.

[11]Whitehead, A. H. and Kuhlman, W. H., "Demand for Large Freighter Aircraft as Projected by the NASA Cargo Logistics Airlift System Studies," AIAA Paper 79-0842, April 1979.

[12]Lange, R. H. and Moore, J. W., "System Study of Application of Composite Materials for Future Transport Aircraft," AIAA Paper 82-0812, May 1982.

[13]Liese, H., "Toward VLA Air-Cargo Service," *Astronautics and Aeronautics,* Vol. 20, April 1982, pp. 36–41.

[14]Dornier, C., Jr., "Very Large Aircraft—A Common Response to a Rapidly Changing Global Environment," AIAA Paper 82-0799, May 1982.

[15]Lange, R. H., "Future Large Cargo Aircraft," Society of Automotive Engineers Paper 780874, Sept. 1978.

[16]Mikolowsky, W. T. and Garrett, A., "Joint Civil/Military Cargo Aircraft: Prospects and Current Projections," Society of Automotive Engineers Paper 801052, Oct. 1980.

[17]Lange, R. H. and Moore, J. W., "Large Wing-in-Ground Effect Transport Aircraft," AIAA Paper 79-0845, April 1979.

[18]Lange, R. H., "The Spanloader Advanced Transport Concept," Society of Automotive Engineers Paper 760616, May 1975.

[19]Kjelgaard, S. O. and Paulson, J. W., Jr., "Effect of Sweep and Aspect Ratio on the Longitudinal Aerodynamics of a Spanloader Wing In- and Out-Of-Ground Effect," NASA TM 80199, June 1981.

[20]Paulson, J. W., Jr., "A Theoretical and Experimental Investigation of the Longitudinal Aerodynamics of a Series of Thick Wings In- and Out-Of-Ground Effects," Ph.D. Thesis, George Washington Univ, Washington, DC, Feb. 1982.

[21]Whitehead, A. H., Jr., "Preliminary Analysis of the Span-Distributed-Load Concept for Cargo Aircraft Design," NASA TMX 3319, Dec. 1975.

[22]"Technical and Economic Assessment of Span-Loaded Cargo Aircraft Concepts," prepared by Douglas Aircraft Co., NASA CR 144962, Jan. 1976.

[23]Whitlow, D. H. and Whitner, P. C., "Technical and Economic Assessment of Span-Distributed Loading Cargo Aircraft Concepts," prepared by Boeing Commercial Airplane Co., NASA CR 144963, June 1976.

[24]Johnston, W. M. and Muehlbauer, J. C., "Technical and Economic Assessment of Span-Distributed Loading Cargo Aircraft Concepts," prepared by Lockheed-Georgia Co., NASA CR 145034, Aug. 1976.

[25]Whitener, P. C., "Distributed Load Aircraft Concepts," AIAA Paper 78-100, Jan. 1978.

[26]Lange, R. H., "Trends in Very Large Aircraft Design and Technology," AIAA Paper 80-0902, May 1980.

[27]Moore, J. W. and Maddalon, D. V., "Design Analysis and Benefit Evaluation of Multibody Aircraft," AIAA Paper 82-0810, May 1982.

[28]Moore, J. W., Craven, E. P., Farmer, B. T., Honrath, J. F., Stephens R. E., and Meyer, R. T., "Multibody Aircraft Study," NASA TP 2183, 1983.

[29]Houbolt, J. C., "Why Twin-Fuselage Aircraft?" *Astronautics and Aeronautics,* Vol. 20, April 1982, pp. 26–35.

[30]Maglieri, D. J. and Dollyhigh, S. M., "We Have Just Begun to Create Efficient Transport Aircraft," *Astronautics and Aeronautics,* Feb. 1982, p. 26.

[31]Grantham, W. D., Deal, P. L., Keyser, G. L., Jr., and Smith, P. M., "Simulator Study of Flight Characteristics of a Large Twin-Fuselage Cargo Transport Airplane During Approach and Landing," NASA TP 2183, 1983.

[32]Moore, J. W., Craven, E. P., and Stephens E. T., "Parametric and Conceptual Design Study of Aircraft Wing-in-Ground Effect (WIG) Vehicles," Lockheed-Georgia Co., Rept. 76020-30 and LG77ER0049, May 1977.

[33]Lange, R. H. and Moore, J. W., "Large Wing-in-Ground Effect Transport Aircraft," *Journal of Aircraft,* Vol. 17, April 1980, pp. 260–266.

[34]Wieselberger C., "Wing Resistance Near the Ground," NACA TM 77, April 1922.

[35]Gallington, R. W. and Chaplin, H. R., "Theory of Power Augmented Ram Lift at Zero Forward Speed," David W. Taylor Naval Ship Research and Development Center, Rept. ASED-365, Feb. 1976.

[36]Krause, F. H., "Parametric Investigation of a Power Augmented Ram Wing Over Water," David W. Taylor Naval Ship Research and Development Center, ASED TM 16-76-95, Oct. 1976.

[37]McCabe, E. F., Jr., "Parametric Investigation of a Power Augmented Ram Wing with Load Alleviation Devices Over Water Waves of Various Sea States," David W. Taylor Naval Ship Research and Development Center, Rept. ASED TM 16-76-97, 1976.

[38]Smethers, R. G., "Flatbed—A Unique and Versatile Transport Airplane," Society of Automotive Engineers Paper 801064, The Netherlands, Oct. 1980.

[39]Smethers, R. G., Caldwell, E. W., Warnock, W. E., and Wilson, J. M., "Study of an Advanced Transport Airplane Design Concept Known as FLATBED," Lockheed-Georgia Co., NASA CR 159337, 1980.

[40]von Kármán, T. and Burgers, J. M., "General Aerodynamics Theory—Perfect Fluids," *Aerodynamic Theory,* Vol. II, edited by W. F. Durand. Durand Reprinting Committee, California Inst. of Technology, Jan. 1943.

[41]Lange, R. H., Sturgeon, R. F., Moore, J. W., and Bennett, J. A., "Study of the Application of Advanced Technologies to Long-Range Transport Aircraft," Lockheed-Georgia Co., NASA CR 112088, May 1972.

[42]Munk, M. M., "The Minimum Induced Drag of Airfoils," NACA Rept. 121, 1921.

[43]Miranda, L. R., "Boxplane Configuration—Conceptual Analysis and Initial Experimental Verification," Rept. LR 25180, Lockheed-California Co., NASA CR 112088, March 1972.

[44]Cahill, J. F. and Stead, D. H., "Preliminary Investigation at Subsonic and Transonic Speeds and the Aerodynamic Characteristics of a Biplane Composed of a Sweptback and a Sweptforward Wing Joined at the Tips," NACA RM L53L24b, 1954.

[45]Lange, R. H., et al., "Feasibility Study of the Transonic Biplane Concept for Transport Aircraft Application," Lockheed-Georgia Co., NASA CR 132462, June 1974.

[46]Wolkovitch, J., "The Joined Wing: An Overview," *Journal of Aircraft,* Vol. 23, March 1986, pp. 161–178.

[47]Miranda, L. R. and Dougherty, G. L., "Transonic Wind Tunnel Testing of a Low Induced Drag Lifting System; Volume I: Test Definition and Analysis," U.S. Naval Air Systems Command Contract N00019-73-C-0499, Feb. 1974.