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Concept for a Large Multimission Amphibian Aircraft

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A very large aircraft is proposed to meet both civil cargo and military transport needs in 1995 and beyond. The concept features a wide, noncircular fuselage cross section with a low wing, thick inner wing section, fuselage-mounted engines, and an air cushion landing gear. The civil freighter operates independently of congested passenger airports, using sheltered water as a runway and a waterfront land site for parking and ground operations. The military transport can operate from a wide variety of surfaces and temporary bases. The air cushion landing gear weighs substantially less than conventional gear and permits use of extended takeoff distance resulting in improved payload/gross weight ratio.

Background

FUTURE military airlift needs during periods of national crises can be provided most economically by large, pure cargo, civil transport aircraft available under the Civil Reserve Air Fleet (CRAF). The Military Airlift Command envisions these aircraft as carrier-owned freighters capable of economically airlifting military "outsize" cargo in excess of 100,000 lb as well as commercial bulk, palletized, and containerized cargo over intercontinental range.[1]

The military definition of "outside" cargo is that which exceeds the capabilities of the C-141 aircraft (67.5 ft long, 9.75 ft wide, and 8.75 ft high) and, therefore, requires the use of the C-5A aircraft. The 747-200F is not capable of carrying outsize cargo based on this definition because of the 8 ft 2 in. height limit for the nose cargo door and the 10 ft high side door cannot accommodate the outsize length. The critical military needs for outsize must be better defined for future studies. Currently, the definition ranges from a size just slightly larger than well-established commercial needs, up to C-5A size (121 ft 1 in. long, 19 ft wide, and 13.5 ft high), which exceeds any everyday economical commercial need. The Advanced Medium STOL Transport (AMST) aircraft represent a mid-range of outsize width and height with nominal cargo capability of 47 ft long, 11.7 ft wide, and 11.2 ft high.

The concept of a dedicated civil freighter aircraft that is also well suited for military cargo goes beyond the well-established civil-military CRAF contract relationships and requires a civil-military partnership that probably involves common aircraft, spares, ground equipment, training, and personnel. There are well-recognized commonality penalties, however, that stand as barriers to efficiently combining any two of the three different requirements for large aircraft—commercial passenger, commercial cargo, and military airlift.[2] The dominant commercial passenger needs have historically prevailed over the "stepchild" commercial cargo needs. The high cargo decks and 8 ft wide containers used by commercial cargo designs have been incompatible with the larger and denser requirements of military tanks. The military need for standby capability results in low utilization and systems not always compatible with everyday, economic operations (Fig. 1). Since this concept of a future civil-military cargo airlift partnership is based upon meeting the practical commercial marketplace economic needs, this paper first focuses on the future commerical needs before proposing a candidate aircraft that meets civil needs and also would be attractive for military use.

Future Civil All-Cargo Aircraft

An in-depth study of the free world commercial airfreight business, including future market and aircraft fleet projections, has recently been completed.[3] The forecast for revenue ton-mile growth by all-cargo aircraft through year 2008 is shown in Fig. 2. The top 44 foreign airlines are shown leading the growth and increasing their share of the market from 53% in 1978 to 75% in 2008. The dominant factor causing this shift from major U.S. dominance is the projected relative catch-up growth in gross national product worldwide. The all-cargo aircraft market (shown in Fig. 2) was assumed to have increased its share of the total air cargo market (which includes belly cargo) to the following proportions by year 2000: 55%

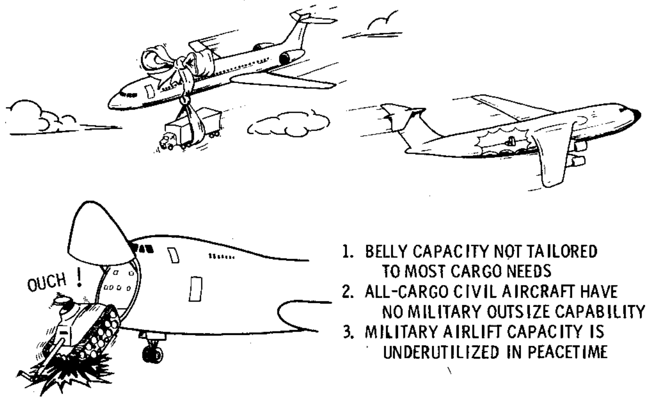

Fig. 1 Commonality penalites.

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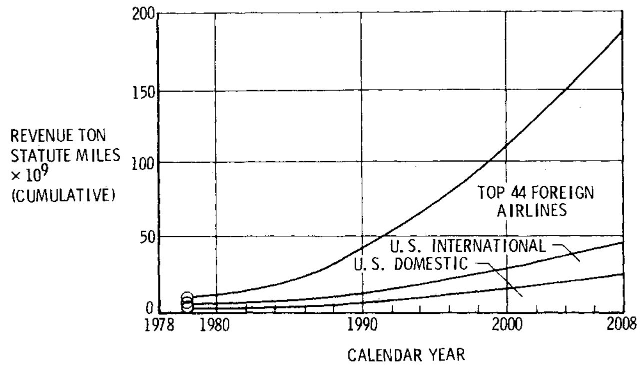


Fig. 2 Air freight market forecast for all-cargo aircraft.

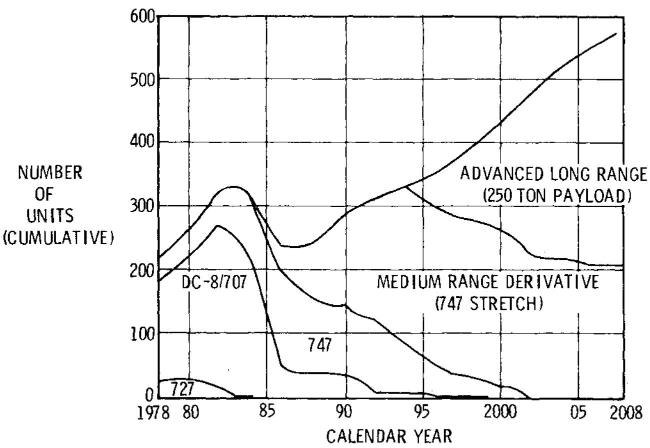


Fig. 3 1978-2008 all-cargo aircraft fleet mix.

U.S. domestic, 60% foreign airlines, and 70% U.S. international.

The optimum all-cargo aircraft fleet mix needed to meet this projected market growth is shown in Fig. 3. The fleet mix selections were determined through use of a simulation program which considered market demand, aircraft characteristics (range, payload, speed), and investment factors. Figure 3 shows that the market needs will finally catch up with the large cargo capability of current wide-body aircraft in about 1982. From 1982 to 1994, the 747 aircraft and a projected medium-range stretch derivative could gain the dominant share of the all-cargo worldwide market.

In 1994, technology advances available to an all-new design and continued market growth should be sufficient to justify the introduction of an advanced long range (ALR) cargo aircraft. The best worldwide commercial range for this new aircraft can be estimated at approximately 3800 n. miles. The best payload size, however, is very difficult to determine at this point. Payload size depends upon many technical, economic, environmental/political, and national interest factors. If the ALR payload were chosen as 250 tons, then it could capture enough of the market to result in 377 units by year 2008. The optimum ALR payload size can only be bracketed at this point between approximately 100 and 400 tons of payload.

Table 1 shows that the optimum payload size depends upon what criteria are selected. Minimum airline trip costs (i.e., cost of crew, fuel and oil, maintenance, and landing fees) are achieved with approximately a 200 ton payload based upon projected technology capabilities. For a given 200 units breakeven for the aircraft manufacturer, the maximum airline return on investment (ROI) and minimum total airline investment is achieved with a 400-500 ton payload. A dramatic decline in the optimum payload is made if it is assumed that the aircraft manufacturer should receive a 15% ROI for the units produced from 1994 to 2008. This condition requires a large production run with many more units and, hence, smaller payload to meet the demand. The optimum payload for maximum airline ROI and minimum airline investment under this condition is only 75-100 tons. Possible military purchases and/or assistance with development funds were not included in the analysis, but would have the effect of increasing the optimum payload size under this 15% manufacturer's ROI condition. Finally, when considering the physical constraints of present airports and the desire to hold aircraft departures to a presently acceptable number, the best payload size is roughly 150 tons. The stretch 747F could meet the payload size of 150 tons, but not at the desired 3800 n. mile range.

Table 1 Optimum payload size for new, civil all-cargo aircraft (1994-2008) using conventional configurations

Optimum payload, ton	Criteria
200	Minimum trip costs
400-500	Airline max ROI and min investment (at 200 breakeven units for manufacturer)
75-100	Airline max ROI and min investment (at 15% ROI for manufacturer)
150	Approximate max size for present airports

The new technology projected to be available in 1994-2008 for an ALR was found to be sufficient to allow an ALR to compete effectively with stretch derivatives of current wide-body aircraft. The study[3] did not include two current configuration drawbacks which a new ALR design could possibly overcome. Two main drawbacks of the 747F for the military are: 1) the 8 ft 2 in. nose door height eliminates "outsize" capability and leaves susbstantial volume unused aft of the crew deck, and 2) the 16 ft 1 in. main cargo deck height requires special ground loading equipment and makes loading of large military vehicles via ramps much more difficult and time consuming.

Barriers to New, Very Large Aircraft

The introduction of a new, very large aircraft requires major ground facility changes or new operating sites. One important advantage that the 747 and any of its stretch derivatives have is that as more are sold through 1994, more airport facilities will be built and sized around it. Two major airport adjustments that would be needed to accommodate a new, very large aircraft are: 1) wider, longer, stronger runways and taxiways for optimum aircraft performance, and 2) larger ramp area and terminal spacing. These are major changes that are difficult to incorporate. An analogy can be drawn to ship, truck, and rail where the maturing of the transportation mode resulted in the maximum vehicle size being determined by the ground facilities. Vehicle size barriers are the width of canals and highways, the depth of ports, the strength of pavements, and the height of bridges. Nevertheless, new passenger airport sites will eventually be needed due to saturation,[4] and off-shore or waterfront sites have to be considered.[5]

Cargo airports could be established independent of passenger airports, since they primarily need only a good highway interface for truck spokes going out 350 miles. It appears, however, that growth of the civil all-cargo aircraft market through 2008 is insufficient by itself to justify building new ground facilities to handle aircraft much larger than the 747. Further, the military does not want the basing inflexibility brought on by very large aircraft that must use only a few special airports.

Another barrier to introducing new, very large aircraft is the FAR Part 36 noise regulations. Noise is allowed to in-

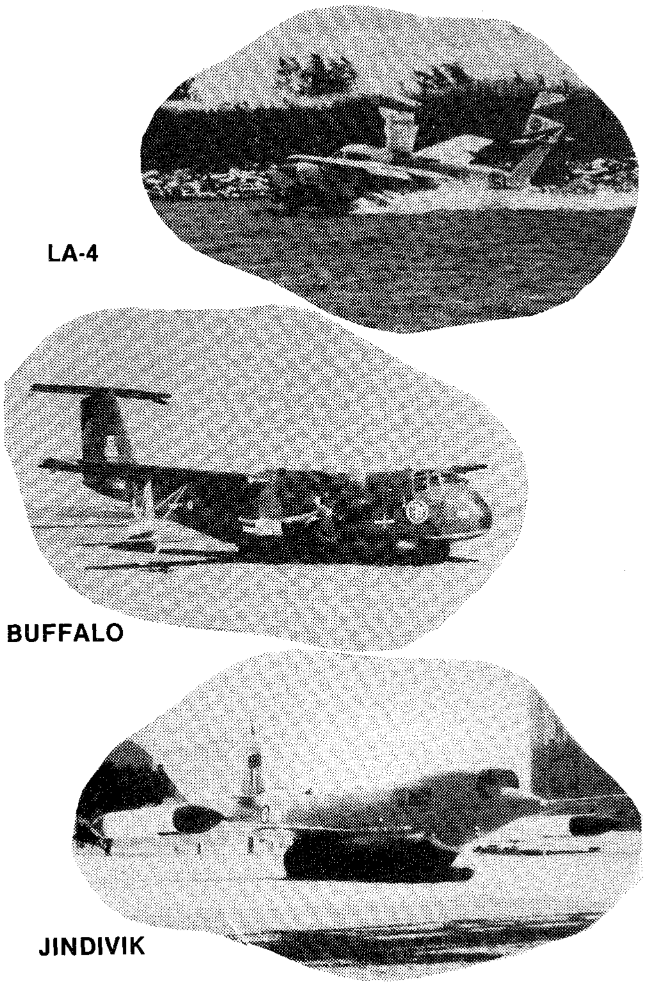


Fig. 4 Air cushion development aircraft.

crease with aircraft gross weight only up to 850,000 lb. Therefore, unless aircraft design thrust/gross weight is lowered, or the regulations are eased for more isolated sites, this noise limit will be another major factor in limiting size.

There are three possible ways of breaking this "747 size barrier." First, the sheer size of the future passenger market could require larger aircraft and ground facilities. Second, new configurations could be developed that increase the optimum payload size, such as a distributed load configuration with either twin bodies or a constant chord, payload-carrying wing.[6] Third, a system could be developed using air cushion landing gear (ACLG) aircraft to operate from waterfront bases and eliminate the need to build wider, longer, and stronger runways and taxiways. This basing flexibility has obvious military appeal. The very large air cushion aircraft can be designed with a lower thrust/weight ratio and operated from less congested sites. This should help alleviate noise problems.

ACLG Description

Air cushion landing gear was first fitted to the 2500 lb Lake LA-4 light amphibian. The first air cushion takeoff and landing were made on Aug. 4, 1964, by Bell Aerospace Textron.

Subsequently, a considerable effort was sponsored by the U.S. Air Force and the Canadian government—the similar retrofit of a medium cargo transport, the 41,000 lb deHavilland Buffalo. Fifty-seven air cushion takeoffs or landings were made in this now completed program. Concurrently, in a smaller effort, the USAF developed an air cushion takeoff and landing recovery system for drones, which was fitted to the 3200 lb Australian Jindivik, and ground tested. These aircraft are seen riding their respective air cushions in Fig. 4.

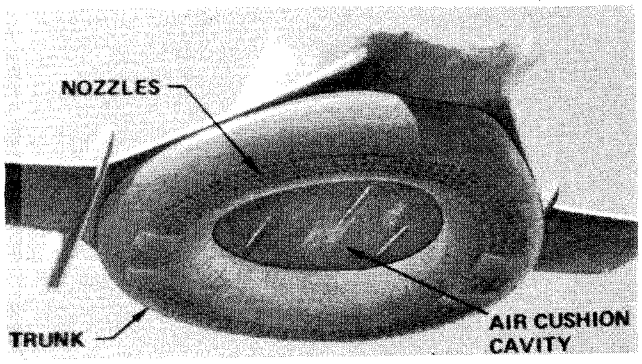


Fig. 5 ACLG inflated—bottom view.

The function of the air cushion gear is to replace wheel gear, amphibian hulls, floats, and skis (or their combinations) with a single, lightweight, powered, retractable air cushion gear. The air cushion is a large pocket of air beneath the aircraft, contained by a flexible material "trunk" and kept at the slight pressure needed to support the aircraft by a continuous airflow escaping at the bottom near the ground.

The flexible trunk, when inflated, is like half of a distorted inner tube or doughnut, sliced across its axis and fastened to the bottom of the aircraft (see Fig. 5). Inflation for takeoff or landing is accomplished by engine fan bleed or a separate onboard fan. The fan pressure keeps the trunk inflated and also maintains an airflow through nozzles at the bottom near the ground. No other feed is needed to pressurize the air cushion and keep the trunk just off the ground, supporting the aircraft nearly friction free. Residual ground friction depends upon the amount of airflow, the surface roughness, and the longitudinal trim.

When not in use, either in flight or on the ground, the trunk is retracted. Retraction can be accomplished by making the trunk elastic, using a fabric-reinforced rubber. The trunk then simply shrinks to fit snugly on the surface when the airflow is stopped, like pneumatic deicing boots on a wing or tail leading edge.

When the aircraft rotates for takeoff and the front of the trunk rises, making a vent, full cushion pressure cannot be retained. If wing lift is not enough to carry the remaining aircraft weight, some of it will be supported by the trunk. The air from the nozzles forms a lubricating film, so that there is still very low ground friction in takeoff rotation and in landing touchdown. In landing, the vertical impact energy is absorbed by the increased pressure in the cushion cavity as the trunk is compressed. This occurs in water landing also, providing load alleviation. Expulsion of air from the cushion and trunk throughout the stroke provides vertical damping.

Braking can be accomplished by transferring a portion of the aircraft weight from the nearly frictionless air cushion pressure support to brake pads at the bottom of the trunk. The air cushion pressure can be vented by distorting the trunk with internal actuators, thus increasing the air gap. The brake pads are on each side for differential braking action. The pads are wear resistant and replaceable.

The ACLG permits takeoff and landing on hard runway, water, snow, and soft ground as seen in the LA-4 photographs of Fig. 6. This triphibious gear capability is achieved without the weight or drag penalties of conventional landing gear combinations.

Large Multimission Amphibian (LMA)

ACLG Configuration

In the recent NASA study of Ref. 7, the application of ACLG as an integrated concept was studied, whereby the

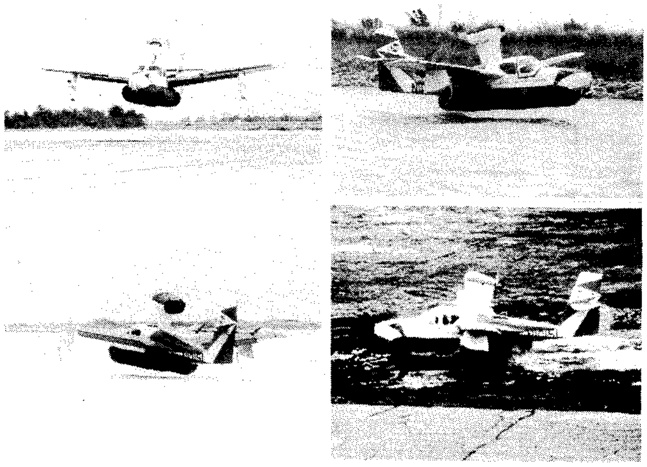


Fig. 6 LA-4 operating from hard runway, water, snow, and soft ground.

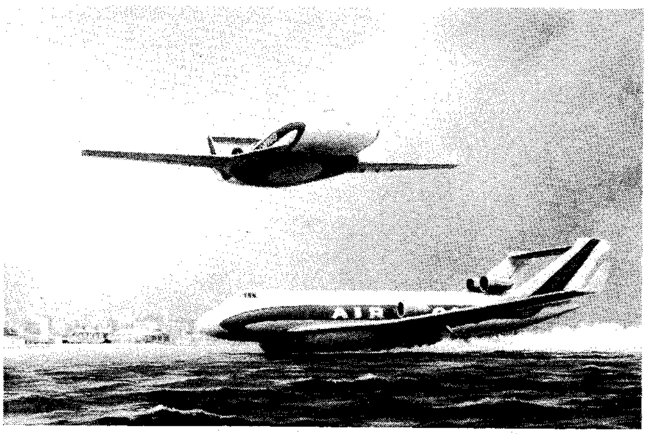


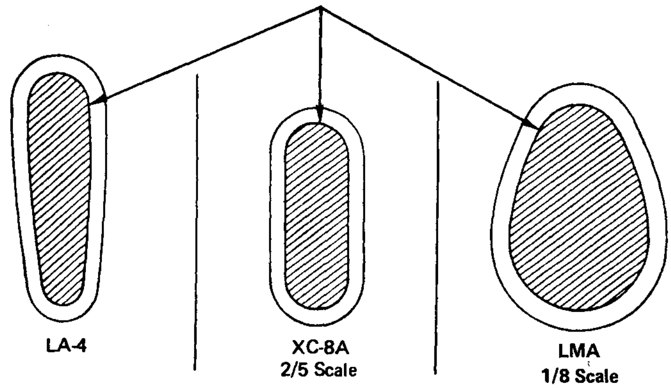
Fig. 7 Large multimission amphibian (LMA).

ACLG would be designed in from the start rather than retrofitted. This made possible a new, lower cost, lower weight approach which should overcome a number of problems which hampered the XC-8A retrofit development program.

This new air cushion configuration is used for the large multimission amphibian (LMA) projected in this paper and shown in Fig. 7. The LMA is characterized by a low wing design with a highly swept, thick-section inner wing having a wide oval air cushion flush mounted beneath it on a curved undersurface plus high mounted engines.

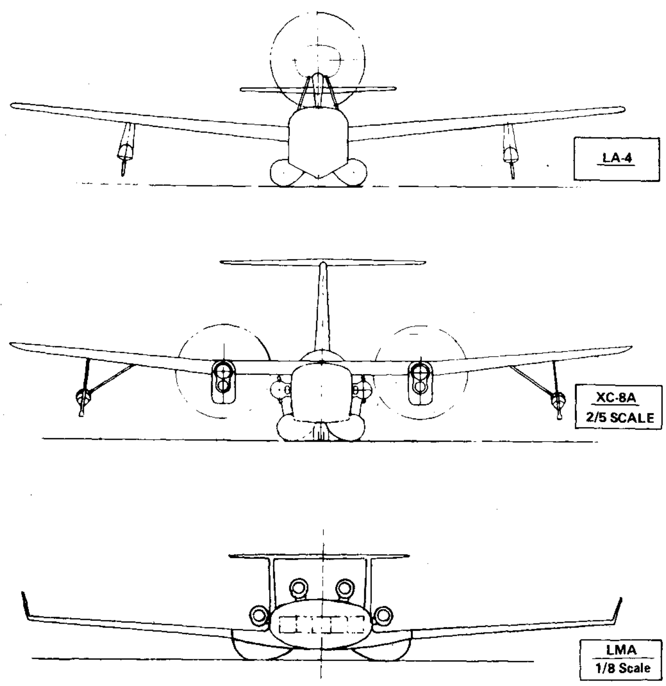
The problems encountered in the Buffalo XC-8A ACLG development program are tabulated in Table 2. Comments in the table indicate why the new configuration will hopefully eliminate these problems. In addition to their avoidance, this integrated concept provides a greater planform area, which reduces the cushion power requirements. Planforms are compared in the diagram of Fig. 8. Figure 9 compares the frontal views. In both figures, the XC-8A is shown at 2/5 scale and the LMA at 1/8 scale, while the LA-4 is represented at full scale.

Figure 10 shows the reduced trunk material stretch needed for the LMA versus the XC-8A, even when designed for the same 10 ft/s landing sink rate. This lower stretch will increase trunk life and results from mounting the trunk under the wing and body rather than wrapping it around the fuselage. Additionally, the diagram beneath illustrates the effect of superimposing the peripheral strain, which is also reduced in the improved design.



	LA-4	XC-8A		LMA	
scale	full	2/5	full	1/8	full
cushion area, ft^2	44	38	240	77	4928
perimeter, ft	32	26	65	35	280
pressure, Psf	57	68	171	31	245

Fig. 8 Air cushion planform comparison.



	LA-4	XC-8A		LMA	
scale	full	2/5	full	1/8	full
wing span, ft	38	38.4	96	36.8	294
maximum track, ft	3.66	3.78	9.45	8.1	65
max trunk radius, in	11	10	25	15	120
min. ground clearance, in	8	13.6	34	15.8	126

Fig. 9 Frontal view comparison.

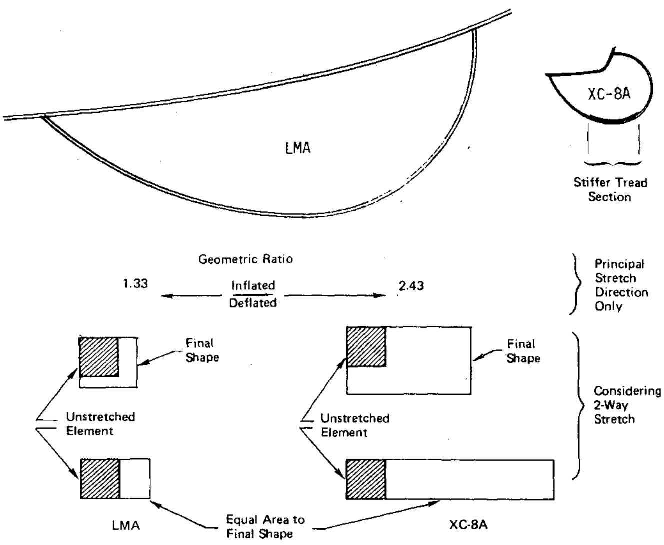


Fig. 10 Trunk cross section and stretch comparison.

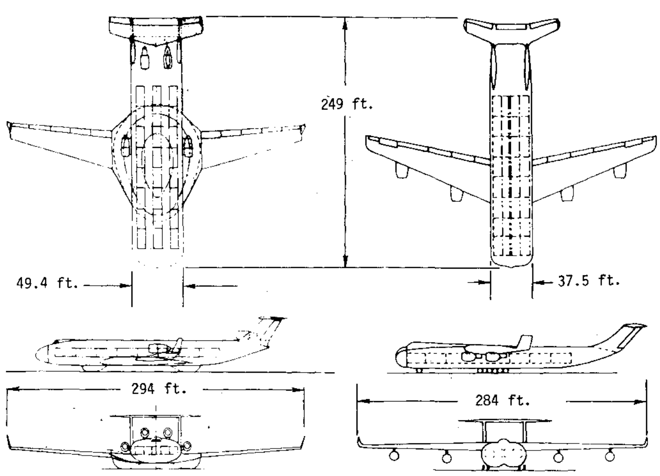


Fig. 11 LMA/759-182A three-view comparison.

LMA Description

The large multimission air cushion amphibian illustrated in Fig. 7 is projected as a very large commercial/military freighter. It was derived from a Boeing preliminary design called the 759-182A with a conventional wheeled gear, which was a comparator in the study of span-distributed load freighters (DLF) of Ref. 6.

An air cushion aircraft this size, with a 7-8 ft deep air cushion trunk should have no difficulty on 3-4 ft waves. Generally, the ACLG aircraft will be able to use rougher water than the same sized flying boat hull. Peak wave drag occurs at approximately 12 knots and is equal to 45% of takeoff thrust, decaying rapidly above this speed.

The approach taken was to modify the given 759-182A design minimally for the ACLG installation. The inner wing shaped for the air cushion invited a wider body. This suggested that containers be carried athwartships, permitting side door loading which is lighter in weight than nose door loading. Alternately, if compatibility with ground rail nose door loading is necessary, containers could be carried five abreast in a three-lobe structure. Alternative loads to freight containers have not been considered in detail but military payloads or passengers could evidenty be accommodated. The highly swept, thick-section inner wing and the fuselage lift contribution should have favorable effects on the structure weight. The conventional concentration of payload in the center, producing wing root bending, becomes a difficult

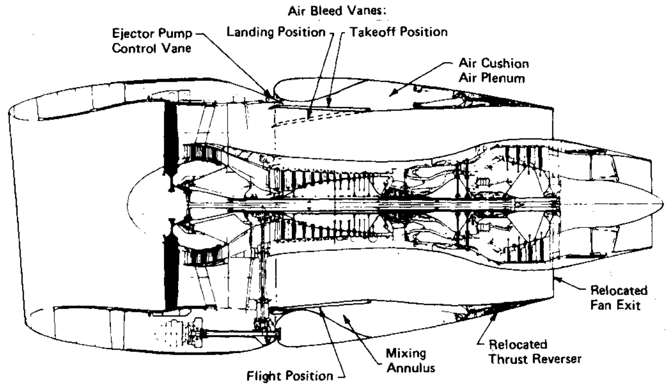


Fig. 12 CF6-50 engine showing proposed modification for ACLG fan bleed.

problem at very large size and is one reason for the DLF approach.

Three views of the 759-182A and the LMA design are compared in Fig. 11. Both aircraft are powered by CF6-50 engines of approximately 52,500 lb sea level static (SLS) thrust each. Because the LMA is designed to be amphibious, two engines are located above the fuselage and two mounted off the fuselage side above the air cushion trunk. The latter are also used to power the air cushion. For this purpose, a modification to the engine package to permit fan bleed for air cushion power could be used as shown in Fig. 12.

ACLG Air Supply System

This fan bleed provides a low weight air cushion power system. All power reverts to propulsion thrust immediately after liftoff and is available for climbout and cruise. The air cushion elastic trunk requires essentially the same pressure and flow in both takeoff and landing. This requirement is met in takeoff by using the high pressure available from the propulsion engine fan at takeoff power to drive an augmentor and pump additional flow from outside, minimizing fan flow bleed and thrust drain. Calculations indicate that the cushion power requirement would reduce the takeoff thrust by ap-

Table 2 Problems encountered in De Havilland-Buffalo program

Problem	Comment
Engine ingestion of grass and snow	Did not occur on LA-4 amphibian. Engine location typical of amphibian is needed.
Cushionborne trunk vibration.	Should not occur with stiffer trunk geometry, without straight sides or cushion flow trim ports.
Cushionborne pitch/heave ground resonance ("porpoising")	Analysis shows a stiffer trunk geometry than XC-8A may be required. This is provided by underwing mounting.
Roll wallow	Outer wing support is adequate. Wide cushion track is better.
In-flight flagellation	Can be avoided by curved undersurface and tauter retracted trunk.
Trunk fatigue	Excessive strain resulted in short life. Overall strain will be halved by underwing mounting.
Trunk structural failure	Rigorous analysis programs are now available. This is not a continuing problem.
Excessive system weight	Major penalties were due to the external duplicated auxiliary power system and the constraints of retrofit.
Excessive trunk replacement time	New design will allow for rapid changeover.

Table 3 Comparison of landing energy parameters

Parameter	LA-4	XC-8A	LMA
Landing weight, lb	2500	39,100	1,000,000
Landing wing loading, lb/ft^2	14	40	110
Stalling speed, knots	45	68	116
Stopping energy/aircraft weight, ft-lb/lb	90	205	596
Total stopping heat, Btu $\times 10^{-3}$	0.29	10.3	766
Cushion area, ft^2	44	240	4,960
½ total heat/cushion area, Btu/ft^2	3.3	21.5	77.3

proximately 8% assuming 70% of the thrust comes from the cold flow. This would result in a similar 8% longer takeoff ground roll than would be the case without the air cushion power requirement.

In landing, with the engines near flight idle, fan pressure is insufficient to drive the augmentor. Therefore, a greater proportion of the fan flow from two engines, approximately half, would be bled directly into the air cushion trunk to maintain inflation.

ACLG Trunk

An externally retracted, elastic trunk was assumed for the design, based essentially upon the technology developed in the XC-8A program but with many detail design differences to provide for low cost fabrication and improved performance, and assuming further technology effort is applied. The size of the trunk sheet does not require extrapolation of material thickness and strength beyond that already tested in the laboratory.

The flexible trunk is the key component of the air cushion system. Elastic trunk material technology is especially important, since it appears that only by means of this development can system weight, performance, and reliability advantages be justified for a fully retractable system. Through the LA-4 and XC-8A Buffalo programs an entirely new, reinforced rubber, high stretch material system was fabricated, having comparable strength/weight ratio to the best available inelastic materials. No fundamental technical barrier to its further development and use has been identified.

Braking

In larger and faster aircraft, braking energy absorption requirements become more demanding. The problem is common to any braking device including wheel brakes and is due to the fact that airplane kinetic energy at touchdown tends to vary as the fourth power of scale (weight varying as the cube and speed as the square root), whereas available contact area tends to vary as the square of scale. This problem appears as a technical barrier to high energy land landings but would not impact a primarily water landing large aircraft such as the LMA discussed in this paper. The relative energy absorption parameters of the LA-4, XC-8A, and LMA are compared in Table 3.

An XC-8A type of braking system provides three functions: 1) venting cushion pressure to insure a ground contact load, 2) providing a skid at the ground interface, and 3) allowing differential braking. The skid brake function differs fundamentally from wheel braking because the energy (heat) is absorbed at the ground interface rather than in a brake drum. This has the advantage of dissipating probably more than half of the heat into the ground while the remainder (absorbed into the skid) is not confined and is rapidly cooled after operation. However, the use of an elastrometric skid material will limit the maximum interface temperature to a much lower value than is currently achievable in conventional wheel brakes. Further, in the XC-8A brake scheme, the contact pressure is well above trunk pressure, which results in concentrating the energy into small skid areas with resulting higher interface temperature.

Table 4 LMA/759-182A weight comparison, lb

	759-182A	LMA
Structure total	293,700	307,928
(landing gear)	(56,880)	(41,278)
Propulsion	39,320	39,320
Fixed equipment	47,700	53,595
Paint and options	5,280	5,550
Empty weight	386,000	406,393
Gross payload	429,400	536,750
Zero fuel weight	815,400	943,143
Maximum gross weight	1,035,330	1,215,000

Table 5 ACLG weight breakdown, lb

Summary for LMA		
Elastic trunk	22,100	
Cushion brake system	6,700	
Parking skids	6,075	
Trunk attachment	4,253	
CF6-50 modification	2,150	
	41,278	
Comparative data	LMA	XC-8A
Trunk outer radius, in.	120	25
Trunk pressure, lb/ft^2	490	342
Cushion pressure, lb/ft^2	245	170
Trunk material tension, lb/in.	408	61
Air cushion perimeter, ft	249	65
Wave drag/gross weight ratio	0.071	0.218
Displacement, ft	3.9	2.7
Cushion length, ft	132.5	28

An XC-8A type of brake system could be used for braking the LMA from moderate speed, since the LMA is regarded as principally using water for takeoff and landing but always loading and unloading on shore as shown in Fig. 7. The Btu/sq. ft figure for the LMA from Table 3 would be reduced to the same value as that for the XC-8A if braking were restricted to 58 knots or less.

ACLG Weights

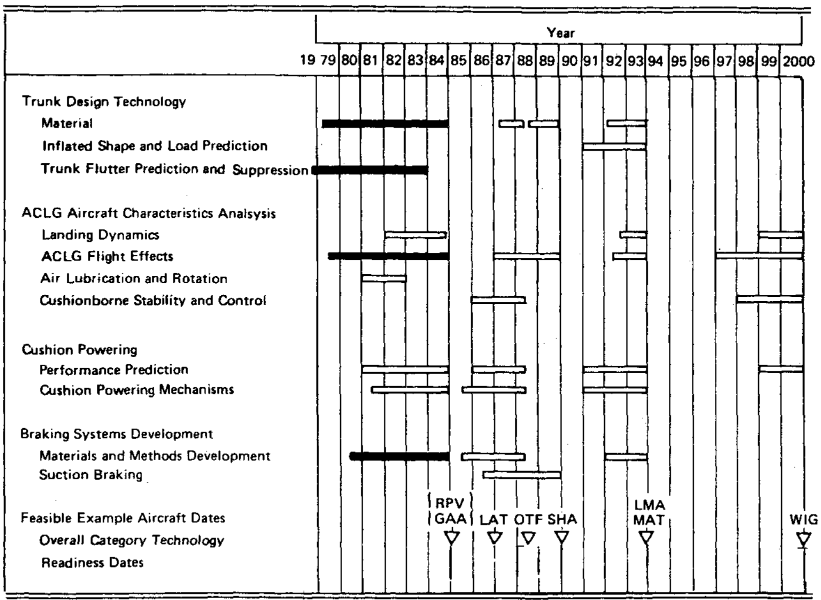
The air cushion distributes the landing load into the structure in satisfactory fashion and at the scale of the LMA, is expected to save about 6% of the structure weight compared with wheel gear. Estimated weights are compared in Table 4. The LMA total structure weight was scaled from the high wing 759-182A weight, and may be too high based on recent, more in-depth comparisons of high wing versus low wing freighter aircraft.[8] Substantial weight and drag savings are projected for low wing configurations, for example, a 37,540 lb saving in gross weight is estimated for a 340,000 lb payload when using a low wing instead of a high wing design.

The ACLG weight is further broken down in Table 5. It is based on XC-8A experience, factoring to the large scale by means of the comparative data also shown. The low cushion pressure of the LMA results in substantial air supply power savings. The LMA is approximately a 3:1 scale up from the XC-8A Buffalo, based upon significant dimensions,

Table 6 LMA performance comparison

	747-200F	759-182A	LMA
Gross weight, lb	820,000	1,035,300	1,215,000
SLS thrust, lb	210,000	209,200	210,000
Thrust/weight	0.256	0.202	0.173
TOFL, ft	10,250	11,900	15,600
Wing loading, lb/ft^2	149	122	133
Gross payload, lb	260,000	429,400	536,000
Payload/gross weight	0.32	0.41	0.44
Cruise L/D	18.2	21.58	20.4
Range, n. miles	3,200	3,600	3,600

Table 7 ACLG Technology Development Timetable



RPV = remotely piloted vehicle (3,200 lb TOGW)
GAA = general aviation amphibian (3,600 lb)
LAT = light amphibious transport (12,500 lb)
OTF = off-runway tactical fighter (14,000 lb)
SHA = short haul amphibian (105,000 lb)
MAT = medium amphibious transport (350,000 lb)
LMA = large multimission amphibian (1,215,000 lb)
WIG = wing in ground-effect (60,000 lb)

therefore, a cushion pressure three times greater would be expected. But, due to the large area cushion of the LMA, the factor is only 1.44 and the resulting displacement (in static overwater hover) is only one-third of the maximum trunk depth. Additionally, the peak overwater drag is only 7% of the gross weight. The trunk pressure is similarly low, compatible with CF6-50 fan bleed and the resulting material tension is well within current technology; numerous elastic material samples of varying strength up to at least six times this value were made by Bell in support of the XC-8A program and provides the basis for the trunk weight estimate.

LMA Analysis

The 759-182A design already capitalizes on the economic advantages of long takeoff using a field length of nearly 12,000 ft for a very high 41% payload fraction at a range of 3600 n. miles. It has a static thrust/weight ratio of only 0.202 and the very low power system weight fraction of only about 3.3%. The long takeoff advantage is evident from the values on Table 6, comparing the 759-182A with the LMA and also with the 747-200F. Part of the advantage in payload/gross weight fraction is due to the reduced static thrust to weight ratio as well as the increased field length. This will result in a lower initial cruise altitude capability, but is not significant as far as cruise efficiency is concerned.

The increased takeoff field length (TOFL) of the LMA will be most readily obtainable over water; thus, the LMA operation is conceived as principally using a stretch of sheltered water for takeoff and landing, but transitioning to shore for loading/unloading. The increased TOFL resulting from reduced thrust/weight permits a 17.5% increase of gross weight compared with the 759-182A and results in a payload fraction of 44%, accommodating 40 instead of 32 of the 13,400 lb, 8×8×20 ft containers. Structure weight and drag adjustments were made for the increased fuselage capacity and for the substitution of air cushion gear for wheelgear.

The effect of the increased payload fraction on economy and productivity is to increase the ROI potential from 12% for this version of Boeing's advanced dedicated freighter to 17% for the ACLG-LMA. LMA operating costs have been determined in parallel fashion for comparison with those presented for the 759-182A. The direct operating cost comparison is shown in Fig. 13.

Indirect costs must be added in any future, more detailed comparison study. This may alter the comparison greatly, since it is possible that considerable new facilities may have to be charged against these large airplanes, which indeed may have to carry their whole burden. Such facilities may be greatly different and possibly much lower in cost for the LMA operating over water than for the comparable land plane

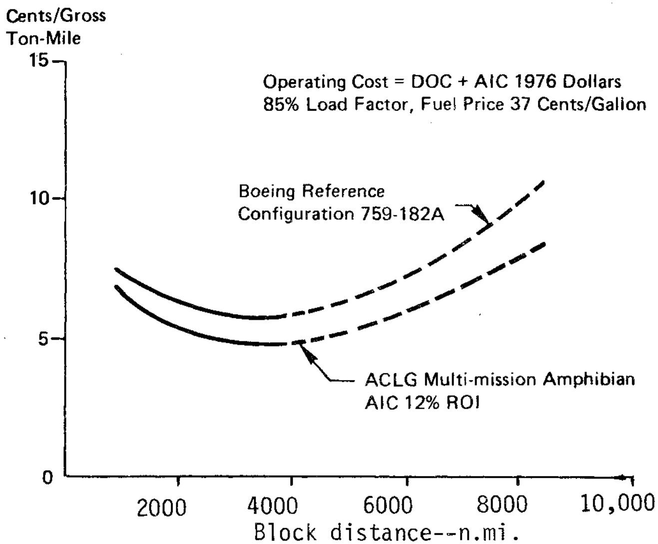


Fig. 13 Operating cost comparison.

whether of conventional design (i.e., the 759-182A) or flying wing distributed load freighters.

Conclusion

The air cushion landing gear is perhaps the most viable option available to break the 747 size barrier and create a civil-military cargo partnership with a new, very large, long range aircraft. The ACLG allows the flexible basing required by the military. Also, the ACLG offers the commercial operators the structural and aerodynamic efficiencies of a low wing, and a reasonable cargo floor height for the military. The ACLG operating flexibility also offers unique opportunities for alternate missions such as basing and dispersal of missile-carrying aircraft, naval and marine waterfront logistics, and civil disaster emergency airlift.

Interest in waterfront and similar off-runway operations with amphibious aircraft is more intense today in the USSR, Japan, Germany, United Kingdom, France, and Canada than it is in the U.S. ACLG will find its initial use in foreign countries rather than in the U.S. The number of ACLG equipped aircraft of all types that could be sold to foreign free-world operators may exceed U.S. sales by an order of magnitude. Nevertheless, a U.S. lead role in the development and manufacture of ACLG aircraft is considered easily achievable at this time and also to be in the best national interest.

Table 7 shows the relatively straightforward technology development steps needed for ACLG before it is ready for application to very large aircraft. Initial work must be done on materials, and in small sizes such as for general aviation aircraft. ACLG development takes a commitment that has yet to be made.

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