NASA Contractor Report CR 159002

(NASA-CR-159002) AIR CUSHION LANDING GEAR APPLICATIONS STUDY Report, Jan. - Mar. 1979 (Textron Bell Aerospace Co., Buffalo, N. Y.) 83 p HC A05/MF A01 CSCL 01C
N79-26045
Unclas
G3/05 26027

AIR CUSHION LANDING GEAR APPLICATIONS STUDY

T.D. EARL

BELL AEROSPACE TEXTRON
BUFFALO, NY 14240

REPORT NO. D7605-927002
APRIL 1979

CONTRACT NAS 1-15202

National Aeronautics and
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FOREWORD

This document presents the results of the Bell Aerospace Textron studies of Air Cushion Landing Gear Applications. These studies were performed for the National Aeronautics and Space Administration Langley Research Center under Contract NAS 15202. LTC J.C. Vaughan III was the NASA Technical Representative. The report was written by Mr. T.D. Earl and assisting in the technical work were: Messrs J. Daley (design), C.E. Satterlee (aircraft performance), C.E. Tilyou (weights), and J.D. Witsil (aircraft costing); Mr. H.K. Owens assisted with the survey.

ACKNOWLEDGEMENT

For the performance of the study,opinions were sought from key organizations such as airframe manufacturers, civil operators and governmental agencies, both in verbal discussion and from comments on a preliminary brief that was prepared and circulated. Many valuable comments and criticisms were received, contributing greatly to the report, and are gratefully acknowledged.

The author wishes particularly to thank all those individuals who provided engineering comments, including representatives of the Boeing Airplane Company, McDonnel Douglas Aircraft Company, Lockheed Georgia Company, Rockwell International (Columbus), Northrop Corporation, Beech Aircraft Corporation, Cessna Aircraft Company, Piper Aircraft Corporation, Hustler Gulfstream (Savannah), U.S. Navy (NASC, NADC, NSRDC), U.S. Air Force (Flight Dynamics Laboratory), National Aeronautics and Space Administration (O.A.S.T., Ames and Lewis Research Centers) and the University of Kansas (Department of Aerospace Engineering).

SUMMARY

In this study, a series of aircraft air cushion landing gear applications were considered in order to determine the most attractive, and to analyze potential benefit.

The method followed consisted of assembling a long list from which preliminary selections were made. Selected concept designs were prepared and used in a survey to obtain informed opinion which then modified the preliminary selections. The resulting final selections were then analyzed and a preliminary brief circulated to about 60 organizations for comments. The analyses were modified in accordance with comments on the brief and the results are presented in this report.

In the report, a short background of ACLG development test experience is first given, followed by an explanation of the ACLG embodiment considered. The advantages of ACLG are briefly stated under the headings: Tolerance of Conditions (which includes crosswind), Triphibious Weight/Drag Savings, Safety and Comfort, Increased Payload, Basing Flexibility, Ground Level Parking and Load Distribution.

Eight final selections were made consisting of a general aviation amphibian (GAA), light amphibious transport (LAT), short haul amphibian (SHA), medium amphibious transport (MAT), large multi-mission amphibian (LMA), off-runway tactical fighter (OTF), remotely piloted vehicle (RPV) and wing in ground effect with ACLG (WIG).

The first five are transports and are a family of designs employing a new integrated ACLG aircraft configuration. This is possible because in this work ACLG has been considered as incorporated into the design from the start and not as a retrofit. This has permitted a lower weight and cost approach to the ACLG, and should overcome a number of problems which hampered the XC-8A development program.

The advantages of this configuration partly arise from increased cushion area and wider track, which are compared with previous designs and first displayed in the GAA design. Weight and cost of the ACLG are analyzed.

Benefit is identified with effects on economy and safety. Operating cost comparisons were made for the GAA, LAT, MAT and LMA, and safety is discussed relative to the GAA and SHA. Significant economy can result from provision of efficient triphibious capability (without weight drag penalty). Also an important contribution of ACLG to economy is to facilitate longer takeoff, particularly overwater – leading to increased aircraft payload/gross weight. The principal contributions of ACLG to safety would be improved crosswind landing and the ground accident tolerance resulting from its off-runway capability.

A summary of the ACLG technology status is given. Eleven items are discussed and four of them are identified as near-term development priorities. These four are trunk material life development, cushion braking development, trunk flutter suppression (currently under study) and flight effects. Two scenario timetables of possible system development are suggested embracing the eleven items discussed and related to the kinds of aircraft postulated.

It is concluded that the dominant feature of ACLG is the provision of a superior amphibious/triphibious capability. Other desirable features such as crosswind landing, soft ground performance or improved ground-accident tolerance are unlikely to lead to its adoption. Thus the most attractive near-term use is as replacement for existing amphibians. This leads to the conclusion that the largest

market may be outside the United States. The ACLG could introduce a new economical water/land basing option. This opportunity can be seen through the spectrum of designs presented and is particularly attractive for general aviation and also for very large aircraft.

It is also concluded that whatever class of aircraft is the most attractive end objective, initial technology advancement will be most cost-effective at the smallest meaningful size. Hence, small size trunk development is recommended, with parallel model tests and operational studies of large aircraft.

LIST OF ACRONYMS/ABBREVIATIONS

A/C	Aircraft
ACL	Air Cushion Landing
ACLG	Air Cushion Landing Gear
ACV	Air Cushion Vehicle
AIC	Acquisition Investment Cost
ALF-502	Lycoming Engine Designation
AMST	Advanced Medium STOL Transport
ASNAP	Axisymmetric Seal Non-Linear Analysis Program
ASW	Anti-Submarine Warfare
ATA	Air Transport Association
AV-8B	USMC Airplane Designation
BHP	Brake Horse Power
CF-6-50 GE CF-6-50	General Electric Engine Designations
CLASS	Cargo Logistics Airlift System Study
CTOL	Conventional Take-Off and Landing
DLF	Distributed Load Freighter
FAA	Federal Aviation Administration
FAR	Federal Airworthiness Requirements
FEBA	Forward Edge of Battle Area
FLAP	Flutter Lateral Analysis Program
FRG	Federal Republic of Germany
GAA	General Aviation Amphibian
GE	General Electric
GW	Gross Weight
ICAC	Initial Cruise Altitude Capability
IO, T-IO	Lycoming Engine Designations
L/D	Lift/Drag
LA-4	Lake Aircraft Designation
LMA	Large Multi-Mission Amphibian
LAT	Light Amphibious Transport
MAC	Military Airlift Command
MARS	Mid Air Retrieval System
MAT	Medium Amphibian Transport
NASA	National Aeronautics & Space Administration
OTF	Off-Runway Tactical Fighter

PT-6	Pratt & Whitney Canada Engine Designation
ROI	Return on Investment
RPV	Remotely Piloted Vehicle
SES	Surface Effect Ship
SHA	Short Haul Amphibian
SLS	Sea Level Static
SR-N5	British Hovercraft ACV Designation
STOL	Short Take-Off and Landing
TF-34, T-34	General Electric Engine Designations
TOFL	Take-Off Field Length
USAF	United States Air Force
UK	United Kingdom
USSR	Union of Soviet Socialist Republics
VTOL	Vertical Take-Off and Landing
V/STOL	Vertical/Short Take-Off and Landing
WIG	Wing In Ground Effect
XC-8A	Designation for de Havilland Buffalo with ACLG
YC-14	USAF Airplane Designation

INTRODUCTION

General

This document presents results of a study of Air Cushion Landing Gear (ACLG) application to selected aircraft types.

The study concentrates on a particular integrated ACLG design approach, maximizing potential benefit. A family of designs is presented, ranging from a small, single piston-engined general aviation aircraft up to a very large freighter and including a lightweight fighter concept as well as others.

ACLG Background

Air Cushion Landing Gear was first fitted to an 1134 kg (2500 lb) Lake LA-4 light amphibian. The first air cushion takeoff and landing were made on August 4, 1967, by Bell Aerospace Textron.

Subsequently, a considerable effort was sponsored by the USAF and Canadian Government - the similar retrofit of a medium cargo transport - the 18,597 kg (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 1452 kg (3,200 lb) Australian Jindivik, and ground tested.

These aircraft are seen riding their respective air cushions in Figure 1.

Operating Principles

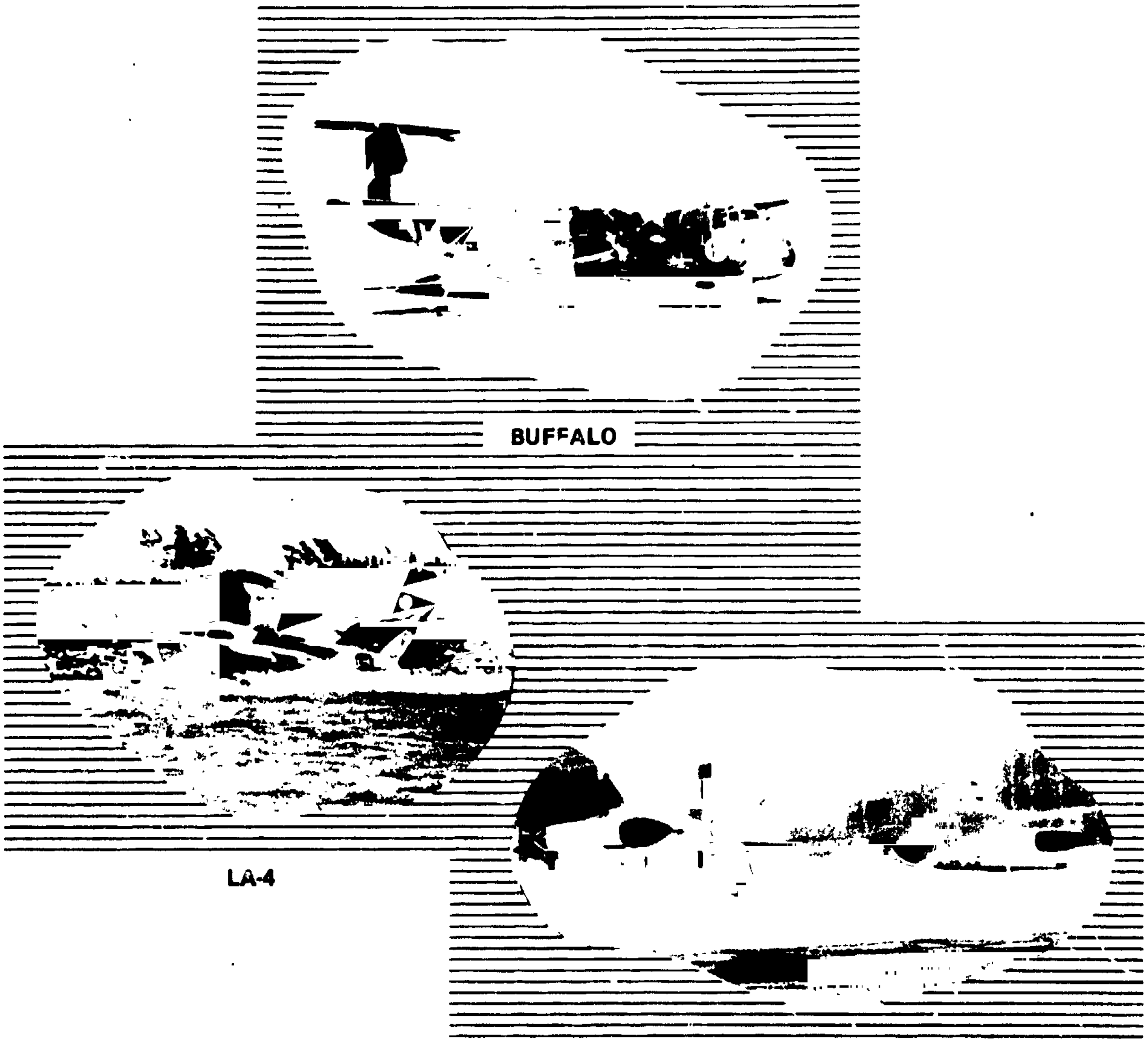
The function of the air cushion gear is to replace wheel gear, hull, floats and skis - or their combinations - with a single, lightweight, powered, retractable air cushion gear.

The air cushion is a large pocket of air beneath the aircraft, contained by a flexible material cushion "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. Inflation for takeoff or landing is accomplished by engine fan bleed or a separate on-board 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 on 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. In the primary version it is elastic, being made of a fabric reinforced rubber material, and simply shrinks to fit snugly on the surface when the airflow is stopped, like pneumatic de-icing boots on a wing or tail leading edge.

When the aircraft reaches a takeoff or landing attitude 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 air-



BUFFALO

LA-4

JINDIVIK

Figure 1. The deHavilland-Buffalo, LA-4 and Jindivik on Air Cushion

craft weight, some of it will be supported by the trunk, which will flatten against the ground, forming a rear footprint at the pressure inside the trunk, about twice the normal cushion pressure, but still very low. Because the nozzles are at the bottom, air escapes into the footprint forming a lubricating film, so that there is still very low ground friction in takeoff rotation and landing touchdown. In landing, vertical impact energy is absorbed by increased pressure in the cushion cavity as the trunk is squashed and by the trunk footprint spreading. This occurs in water landing also, providing load alleviation. The available stroke is the hard structure clearance. Expulsion of air from the cushion and trunk throughout the stroke provides vertical damping.

The lubrication effect can be, by design, partly eliminated by omitting the nozzles locally, to create braking, and fitting wear resistant (replaceable) pads at these places. If cushion pressure and air gap are maintained, there will be no braking. To brake in the primary version, the bottom of the trunk is distorted at the pads by internal actuators, to deliberately vent the cushion and cause pad contact and ground friction. The pads are at each side, for differential action, and far enough forward not to interfere with the rear footprint.

These operating principles of the air cushion and brakes are illustrated in Figure 2.

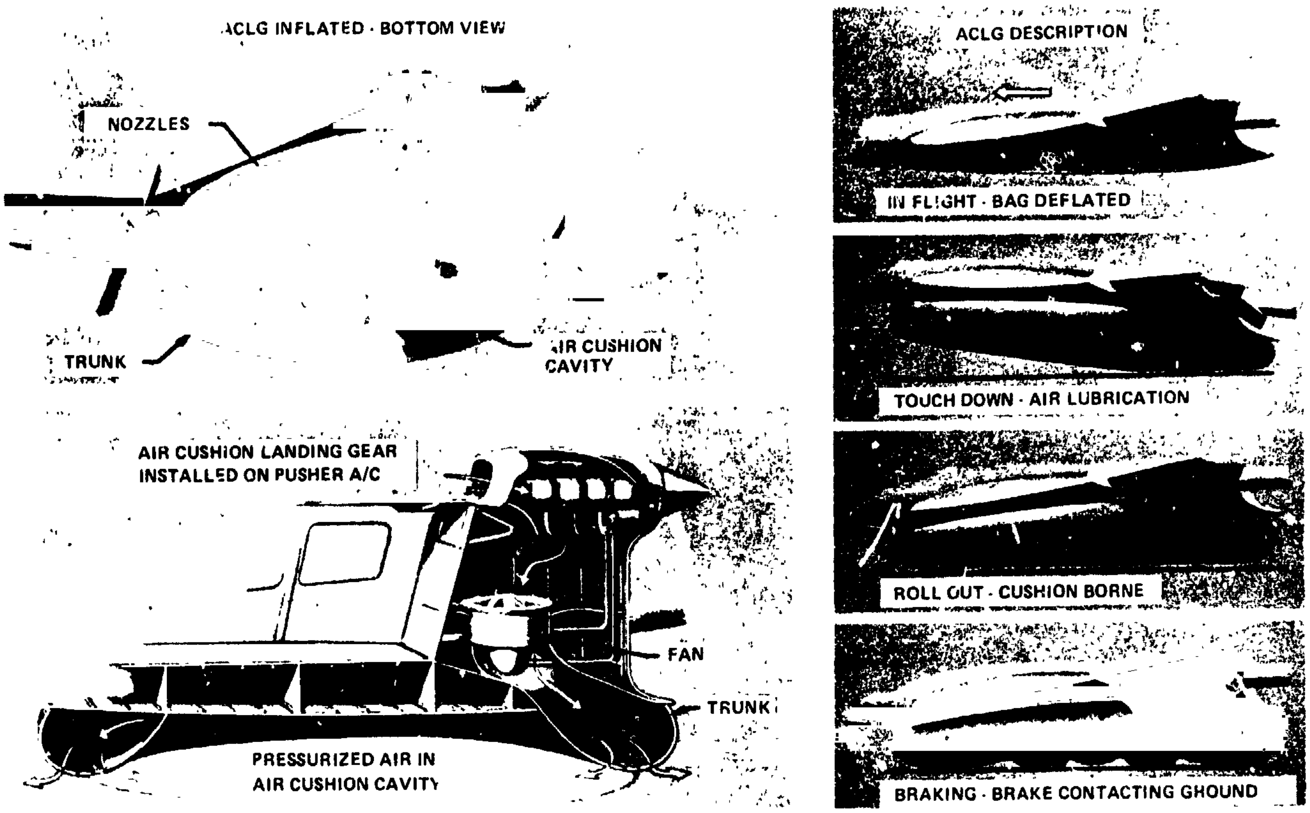


Figure 2. ACLG Operating Principles

Advantages

In summary, the advantages claimed for the air cushion landing gear are as follows:

Tolerance of Conditions – It makes for an easier takeoff and landing maneuver (i.e., is forgiving) and relaxes the airfield requirement - any surface softness is acceptable. It also accepts crabbed ground-roll in takeoff and landing - thus crosswind tolerance is unlimited.

Triphibious Weight/Drag Savings – It permits triphibious takeoff and landing (land, water, snow, as seen in the LA-4 photographs, Figure 3), without the weight/drag penalties of conventional landing gear combinations.

Safety and Comfort – It provides a higher takeoff and landing accident tolerance and has low vulnerability to damage, leading to improved safety compared with wheelgear. The element of danger in incidents such as landing short, veering-off or overrunning the paved runway may be largely avoided Emergency landing in fields or water ditching is possible without damage. The conventional seaplane hazard of flotsam damage to floats or hulls, is avoided.

ACLG also introduces a new soft touch-down (and takeoff) which is comfortable and should be highly acceptable to passengers.

Figure 3. LA-4 Operating Over Land, Water and Snow

Increased Payload – The relaxed surface requirement (especially water) allows the ACLG airplane to be designed for longer takeoff and landing, resulting in improved payload/gross-weight and economy.

Basing Flexibility – The multi-surface capability increases operational versatility, allowing (for one example) taking off from snow or runway for a destination landing on water or (for another, commonly a characteristic of amphibians) taxi from a water landing to a ground parking ramp. This permits a basing flexibility for both commercial and military operations worldwide (Figure 4). Snow covered or bomb damaged runways become less of an obstacle in military operations.

Ground Level Parking – Because of the inherent kneeling characteristic of the air cushion, the aircraft can be designed to settle onto shallow parking skids when shut down. This will usually permit easier loading, for example, permitting the cargo deck of a large freighter to be at truck bed height as in Figure 5.

Load Distribution – The ACLG can diffuse ground loads into the aircraft structure Particularly for very large aircraft (two or more times the 747); this will save weight and avoid a requirement for special runways. Extended high-speed taxi and takeoff maneuvers can be tolerated in an equilibrium condition in contrast to the limited transient loadings required on conventional tires.

Objectives and Study Scope

NASA's objectives were to pick the most attractive applications, quantitatively show their advantages, and identify technical barriers to their development in order to guide future technology support. The urgency and timing of needs were important so that the direction and pace of research and technology could be better defined.

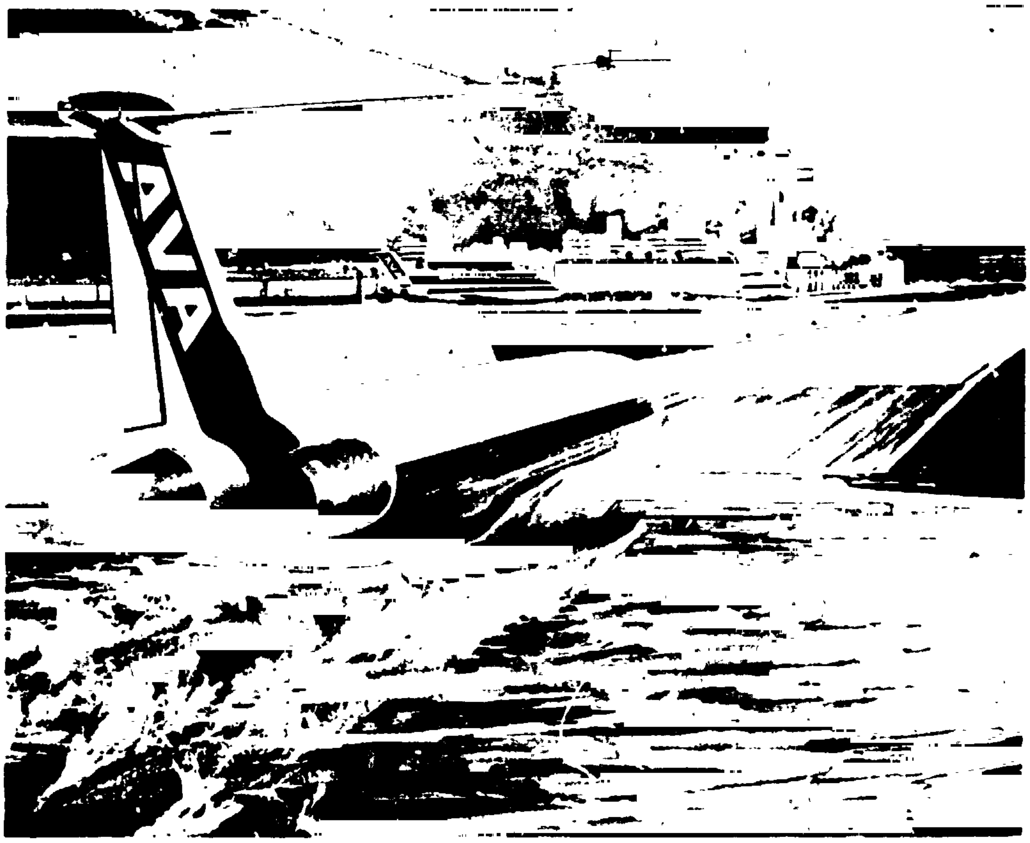


Figure 4. Part Water, Part Land Ground Roll Feature of an Aircraft with ACLG

Figure 5. Inherent Kneeling Feature of Aircraft with ACLG

The study methodology started with identifying 19 possible aerospace applications for ACLG. A preliminary selection of 7 more promising applications was then made and a briefing prepared. Visits were then made to 16 organizations (10 government, 5 aircraft manufacturers, and one airline) where this initial briefing was given, followed by in-depth discussion and some follow-on conversations. Based on these visits, 6 of the initial selections were better defined, one was substantially modified, and one was added. The final 8 selections then underwent a preliminary concept analysis. A preliminary findings brief was then prepared and mailed to 60 key organizations (5 Army, 6 Navy, 10 Air Force, 2 DoD, 4 NASA, 5 DOT, 4 universities, 7 large airframe manufacturers, 5 fighter aircraft manufacturers, 3 drone manufacturers, and 6 other aerospace companies). Comments were received from 24 of these organizations and further study was conducted in response to the comments.

The final eight applications are new designs considering ACLG from the start, not as a retrofit. This has permitted an integrated configuration which is a low-weight, low-cost approach and should also overcome a number of problems which hampered the XC-8A development program.

New ACLG Configuration

This new typical configuration is shown by the general aviation design illustrated in Figure 6. It is characterized by a low wing with a highly tapered inboard section having a wide oval cushion flush-mounted beneath it, on a curved under-surface, plus a high-mounted engine.

Figure 6. General Aviation Design

The general aviation design was the first of the eight applications studied. It is a utility type aircraft with provision for eight seats including pilot, to be powered by a piston engine driving a pusher prop, with rudder in the slipstream for cushionborne yaw control.

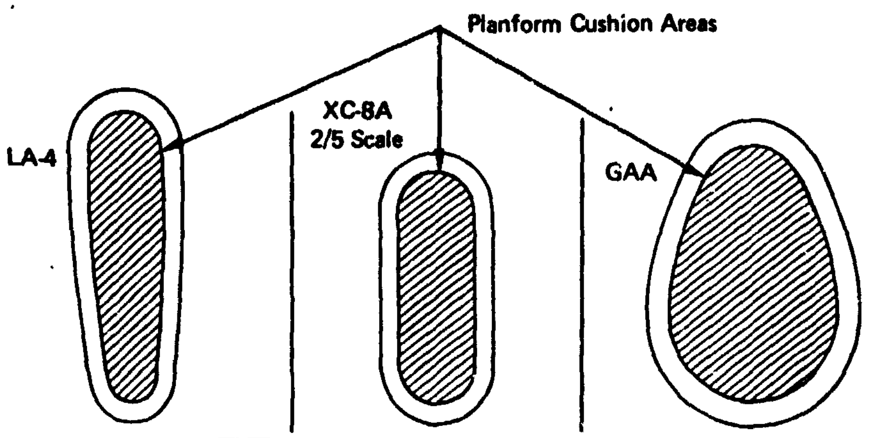
From this basic configuration, a family of ACLG aircraft designs has been evolved. Each is subsequently discussed.

The problems encountered in the Buffalo program are tabulated in Table I. Comments in the table indicate why the integrated configuration will hopefully eliminate these problems. In addition to their avoidance, this integrated concept provides a greater planform area, which improves cushion performance. Air gap and cushion performance equal to the LA-4 is predicted for the general aviation aircraft, using less horsepower, despite a 50% greater gross weight. Planforms are compared in the diagram of Figure 7. Figure 8(a) is a large scale detail specifically to show the change in strain resulting from underwing mounting. The XC-8A and GAA relative radial strain is illustrated by the cross section. Additionally the diagram beneath illustrated the effect of superimposing peripheral strain which is also reduced in the improved design.

Figure 8(b) makes the comparison showing a frontal view. In Figure 7 and 8(b), the XC-8A is shown at 2/5 scale which most closely approximates the relative airplane dimensions and weight.

TABLE I
PROBLEMS ENCOUNTERED IN THE 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.



	LA-4	XC-8A Buffalo		GAA
		2/5 Scale	Full Scale	
Cushion Area m^2 (ft^2)	4.09 (44)	3.53 (38)	22.3 (240)	7.15 (77)
Perimeter m (ft)	9.75 (32)	7.92 (26)	19.81 (65)	10.67 (35)
Pressure Pa (lb/ft^2)	2729 (57)	3256 (68)	8187 (171)	2250 (47)

Figure 7. Air Cushion Planform Comparison

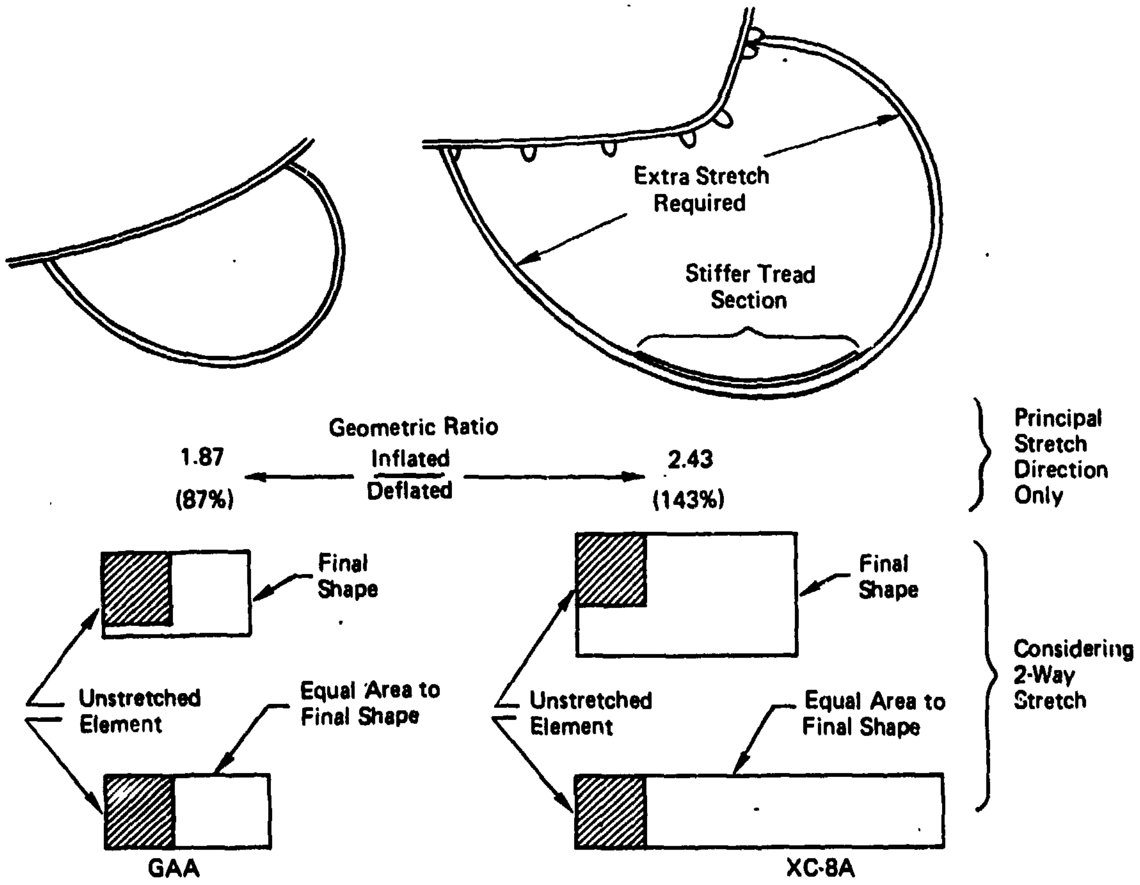
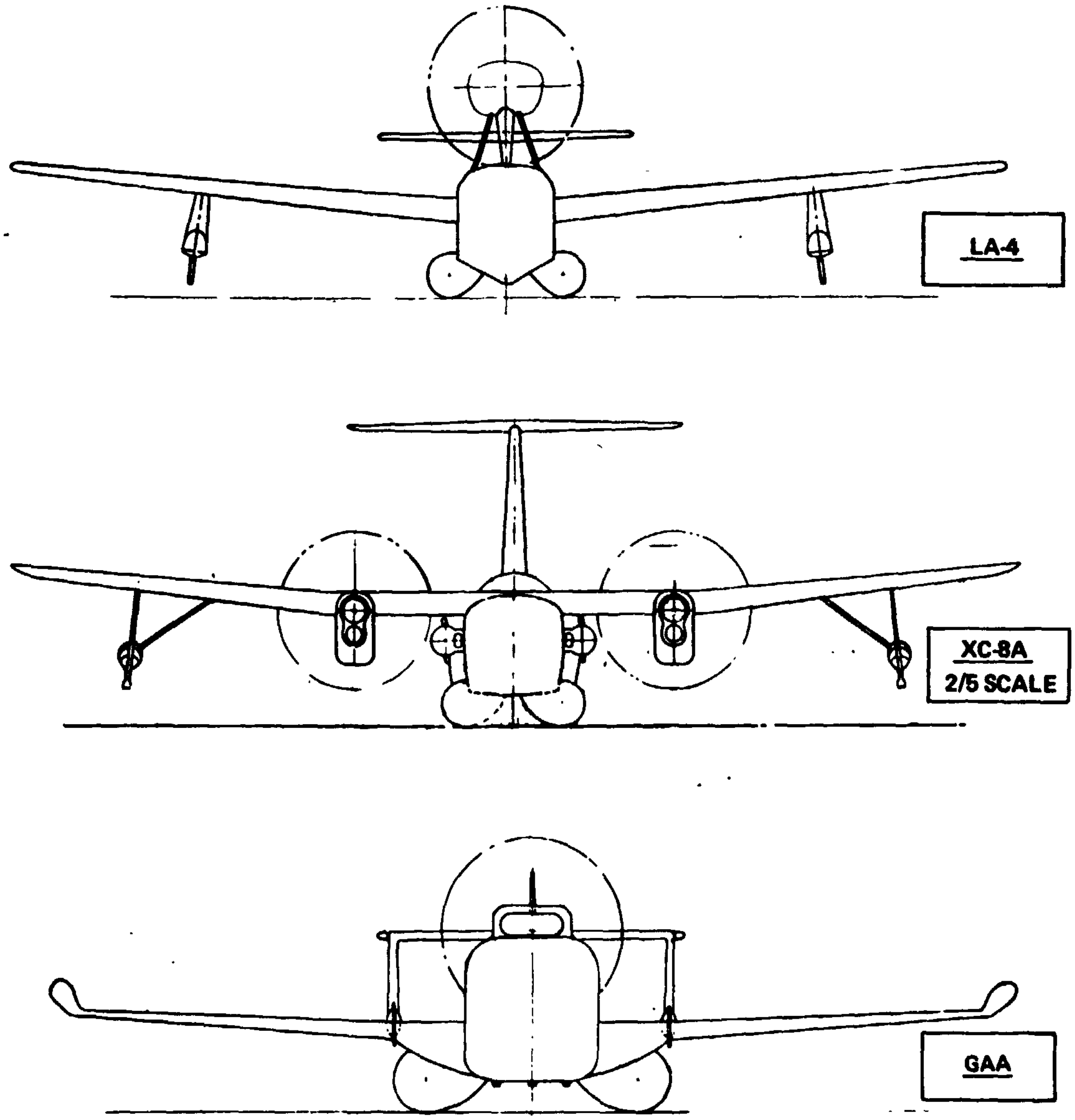


Figure 8(a). Cross Section Comparison and Stretch Diagram



	LA-4		XC-8A 2/5 Scale		Buffalo Full Scale		GAA	
Span. m (ft)	11.6	(38)	11.7	(38.4)	29.3	(96)	11.0	(36.2)
Max Track m (ft)	1.12	(3.66)	1.15	(3.78)	2.88	(9.45)	2.47	(8.1)
Max Trunk Radius cm (in.)	27.9	(11)	25.4	(10)	63.5	(25)	38.1	(15)
Minimum Ground Clearance cm (in.)	20.3	(8)	34.5	(13.6)	86.4	(34)	35.6	(14)

Figure 8(b). Frontal View Comparison

SELECTED APPLICATIONS

Five of the eight applications studied are transports. Each was selected to be comparable to an existing or currently projected conventional landing gear aircraft of the same class, whether amphibious or not, and to be sufficiently representative of other aircraft in its category to show the ACLG advantages. The transport applications considered, including the five promising ones selected for study, are listed in Table II. Preliminary design concept 3-view drawings, illustrations, and weight, drag, performance and cost estimates were made for each of the five chosen. The design weight and other differences between the comparable aircraft and the ACLG aircraft were analyzed for the economic and other effects resulting from the use of ACLG. The five are shown, all at the same scale in Figure 9.

The other applications considered, including the three chosen are listed in Table III.

Preliminary design drawings and estimates of the three selected are also shown. The same configuration-drivers for integrating the air cushion produce a fighter design resembling the transports. A similar RPV was considered, however, the existing Jindivik design adequately displays the principal advantages of this application, therefore no new design was developed. The wing in ground effect (WIG) amphibian is an ACLG version of a new concept.

Each design is presented separately in the following pages, with a preliminary analysis of benefits and comments on market potential.

TABLE II
TRANSPORT APPLICATIONS

Selected Promising ACLG Applications	Projected Gross Weight kg (lb)	Less Promising Applications Considered
1. General Aviation Amphibian (GAA)	1633 (3,600)	1. Land-Based General Aviation 2. Agricultural Aircraft
2. Light Amphibious Transport (LAT)	5700 (12,500)	3. Executive Transport 4. Land-Based Commuter
3. Short-Haul Amphibian (SHA)	47,628 (105,000)	5. Land only passenger short-haul, for low density areas
4. Medium Amphibious Transport (MAT)	158,759 (350,000)	6. Medium Range Passenger Transport 7. STOL Transport
5. Multi-Mission Amphibian (LMA)	551,120 (1,215,000)	8. Tanker Aircraft 9. Long Haul Passenger Transport 10. Supersonic Transport

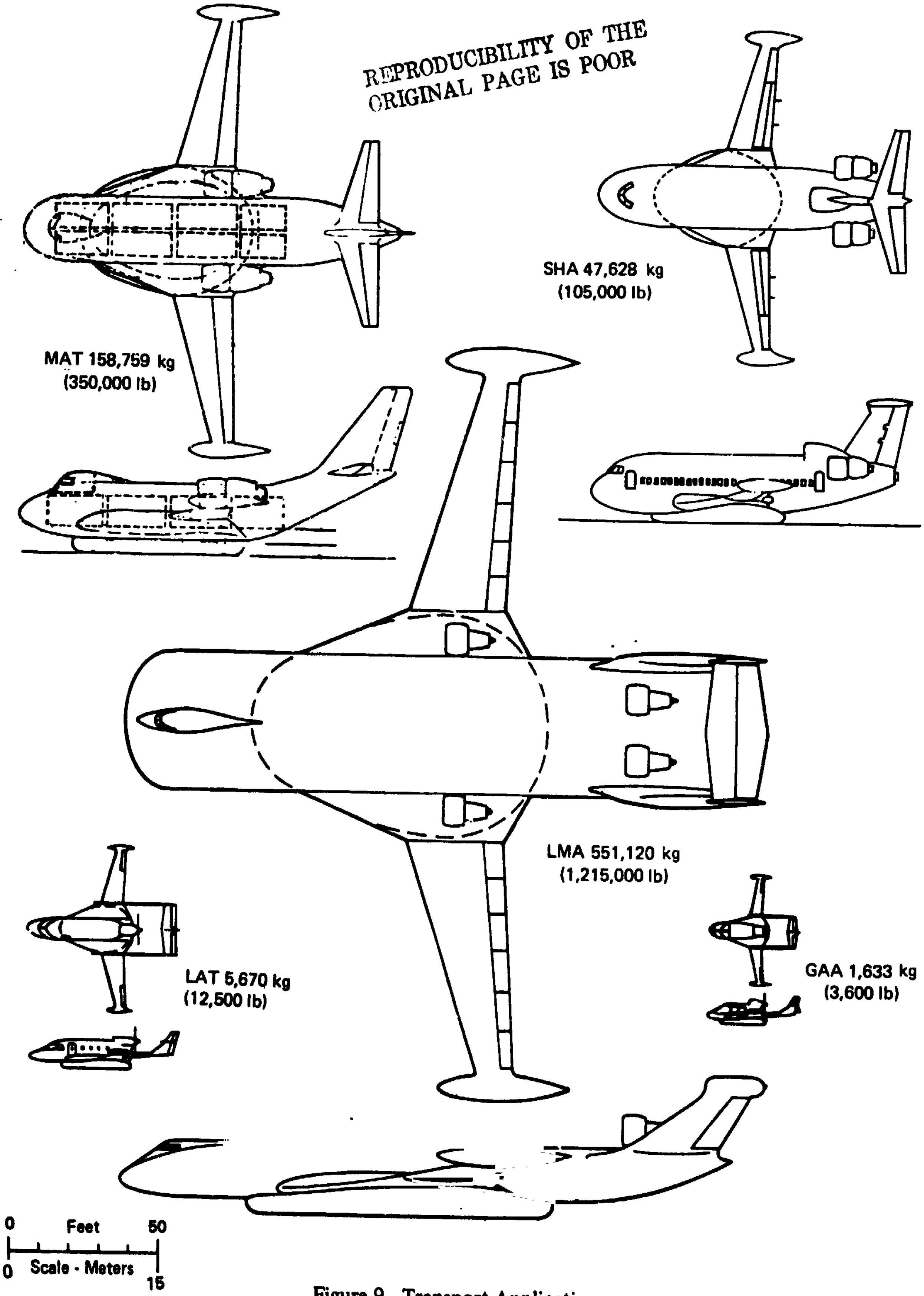


Figure 9. Transport Applications

TABLE III
FIGHTER, RPV AND WIG APPLICATIONS

Selected Promising ACLG Applications	Projected Gross Weight kg (lb)	Less Promising Applications Considered
6. Small, Off-Runway Tactical Fighter (OTF)	6,350 (14,000)	11. Fighter Bomber 12. Fighter Interceptor 13. VTOL Aircraft 14. Carrier Based Aircraft
7. Remotely Piloted Vehicle (RPV)	1,452 (3,200)	15. Small RPV 16. Supersonic RPV
8. Wing in Ground Effect (WIG)	27,216 (60,000)	17. Lighter Than Air 18. Helicopter 19. Space Shuttle

APPLICATION DESCRIPTIONS AND ANALYSIS OF BENEFITS

Though of generally similar configuration, the family of transport designs have different features and advantages.

General Aviation Amphibian (GAA)

The GAA is attractive particularly because of its efficient triphibious performance, tolerance of crosswind and safety aspects.

Description – The twin-boom pusher is chosen for cushionborne control (slipstream rudder), engine location (protection from water damage to engine or propeller), and because it provides a safe propeller location in ground handling.

The unsupercharged 298 kw (400 hp) IO 720 Lycoming engine provides 56 kw (75 hp) to the air cushion for operation on the ground with all power reverting to propulsion for a high crusing speed at altitude.

The air cushion fan is powered by a hydraulic transmission from the propulsion engine which allows constant speed fan operation from ground idle to full power. After takeoff the fan is switched off and the extra power to the propeller provides a high climb rate (579 m/min, 1900 ft/min). The fan air is taken from the engine compartment and the air cushion fan also doubles as engine cooling fan, avoiding a typical difficulty of cylinder head temperature control in taxi, common in pusher installations. The resulting warming of trunk air is beneficial in cold weather.

The elastic trunk retracts onto the lower fuselage and inner wing immediately after the fan is stopped. On land, the aircraft parks on runners beneath the keel beams. These also accept emergency dead stick landings. This is thought to be acceptable for this class of aircraft. Emergency means for temporary re-inflation could also be considered. Over water, when shut down, the aircraft floats. The inner wing and fuselage are built as a water-tight buoyancy unit, shaped for stable floatation when moored. Cushion braking is accomplished by mechanical actuators which distort the trunk and vent the air cushion. Hard wearing rubber elements are provided.

The illustrations Figures 10, 11 and 12, respectively, show the air cushion inflated with ground pads visible, floating in the water configured as an ambulance, and resting on snow configured as a

Figure 10. General Aviation Design Landing Configuration

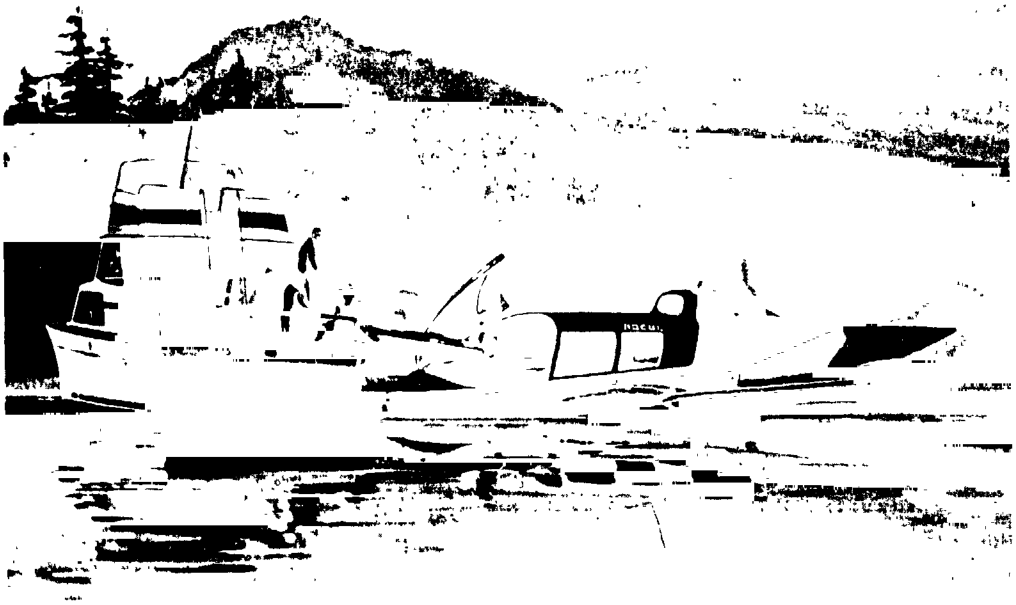


Figure 11. General Aviation Design Configured as an Ambulance

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Figure 12. General Aviation Design as Light Freighter, Parked on Snow

light freighter. Figure 13 is a 3-view showing ground/water lines cushionborne, parked and floating. Figure 14 is an inboard profile showing engine and fan positions. The fan feeds the trunk through a single entry duct and the air is distributed by the inflated trunk which is, in effect, itself a large duct.

Analysis – The estimated GAA characteristics are compared with other aircraft in Table IV. One of the aircraft is the Cessna 185 Skywagon which is offered by Cessna in an amphibious version as well as a land plane. Comparison of the Skywagon land plane figures with the Skywagon amphibian shows the penalties in performance and load-carrying typical of the amphibious floatplane. The empty weight difference is 254 kg (560 lb). The ACLG weight breakdown is given in Table V. For comparison purposes, the ACLG weight should be increased by 11.4 kg (25 lb) for the increment in engine weight needed for a new hydraulic power takeoff pad (included in the engine weight) and the fuel for air cushion taxi, takeoff and landing (estimated at 4.5 kg, 10 lb). Then, to compare with the above 254 kg (560 lb) figure, the appropriate wheelgear weight of 69.9 kg (154 lb) is subtracted from the resulting ACLG total of 99 kg (219 lb), giving a difference of 29.5 kg (65 lb). Since all of the engine power is used in climb and cruise, the weight increment associated with the air cushion power can not strictly be charged to the air cushion. But, it can be argued that a 242 kw (325 hp) supercharged engine could be used in a wheeled version of the same aircraft, giving the same power as the 298 kw (400 hp) unsupercharged engine at 6000 ft and therefore similar takeoff and cruise performance (but not climb). Such an engine (Lycoming TIO-540) would weigh 20 kg (46 lb) less, making the triphibious ACLG increment 50.3 kg (111 lb) in comparison with the 254 kg (560 lb) of the conventional amphibious float plane.

Referring again to Table IV for the land plane/amphibian comparison, full-range payload is halved and maximum speed cut by over 32 km/hr (20 mph). The ACLG airplane top speed is greater than the Skywagon landplane and climb rate is nearly double. The performance penalties of

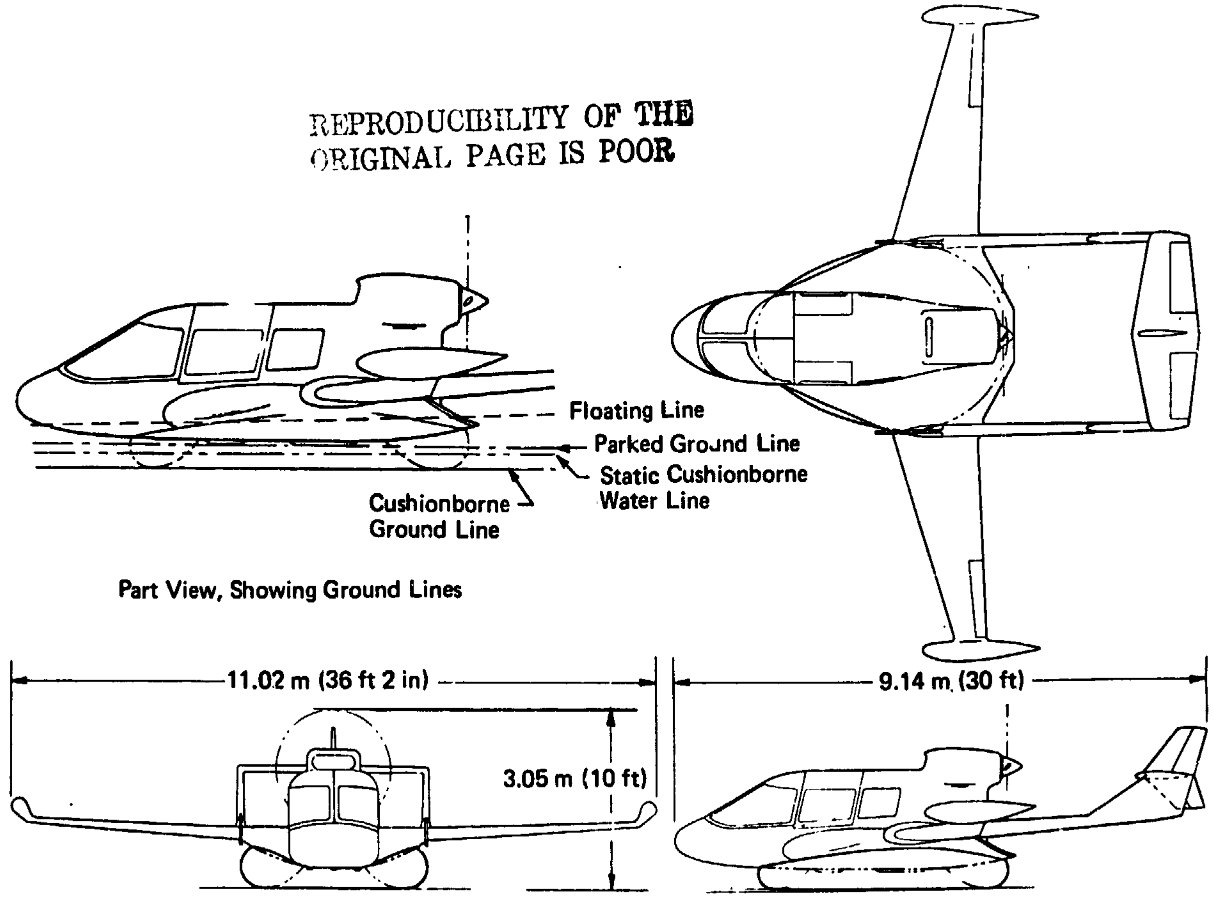

Figure 13. GAA 3-View

the hullborne conventional amphibian are reflected by the figures for the other aircraft shown, and are similar to the floatplane.

The ACLG aircraft cost is estimated to be less than the amphibious float plane but more than the fixed gear land plane. The estimated ACLG cost breakdown is given in Table VI, based on 1977 dollars, and a production of 3000 for nonrecurring costs. The air cushion components are based on detail synthetic estimates, using known techniques. Notably the trunk sheet, which is a flat rubber-nylon laminate is not a dominant element. However its replacement (also the brake elements) at regular intervals must be expected, similarly to tires.

The need for a wide base for the air cushion, the utility missions especially, and the payload capability suggested a wide body (152 cm, 60 in.) accommodating three abreast in three rows, the space being similar to a regular automobile station wagon with a seat pitch of 96.5 cm (38 in.) . A cabin comparison is shown in Figure 15. Compared with a float plane amphibian, the ACLG airplane is a clean design, with good cruising efficiency, which leads to lower per-mile costs as well as greater payload. Costs per aircraft mile and per ton mile are compared in graphs, Figure 16. The calculations show low cost per aircraft mile due to high block speed. In calculating cost per ton-mile, payload was determined from available useful load, without regard to seat capacity. The GAA design provides for eight seats including pilot, compared to seven for the Cessna 185. Because they were considered primarily as utility aircraft, the empty weights for these aircraft include only the pilot's seat. The estimated incremental weight for the GAA as a passenger aircraft is 49 kg (110 lb).

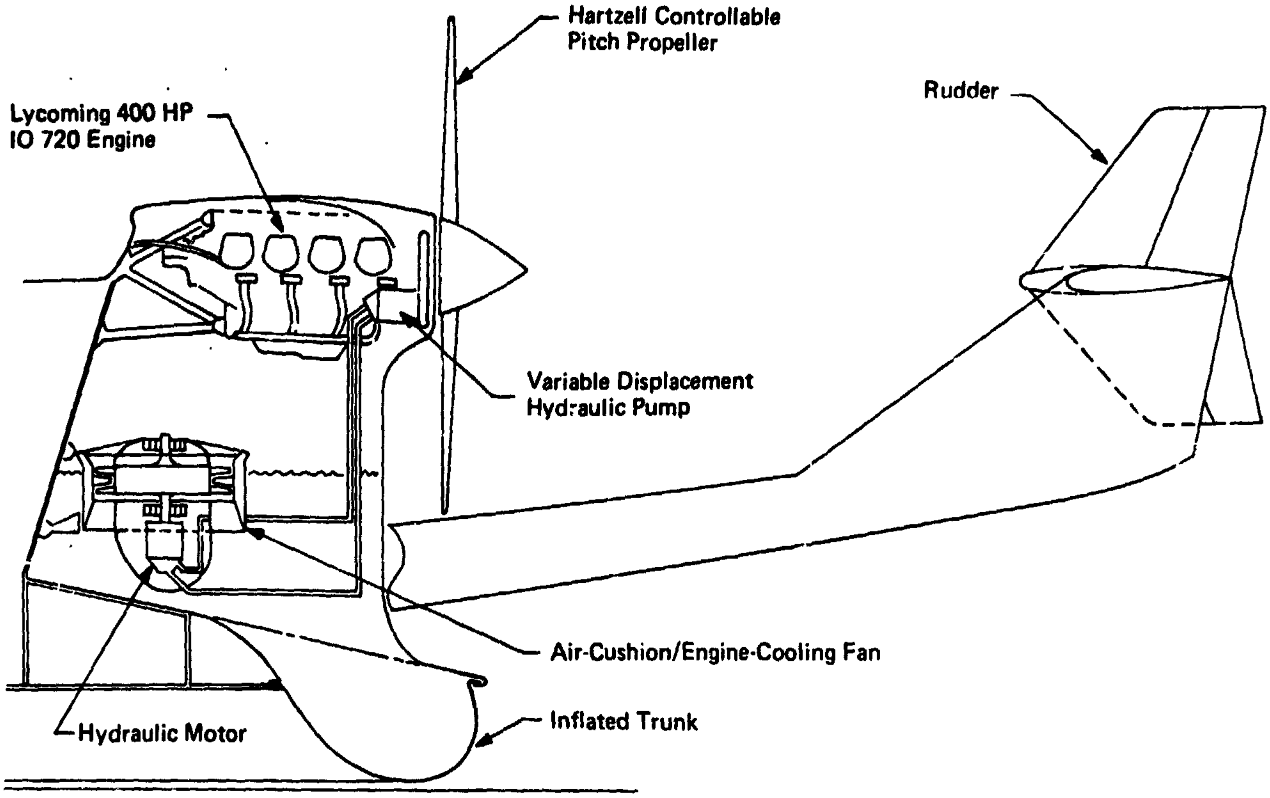

Figure 14. GAA Inboard Profile

The crosswind tolerance of ACLG is an important benefit for general aviation where pilot proficiency is less and the hazards therefore more severe. The ACLG aircraft lands crabbed so that wing-low landing or last-second heading correction is not necessary. This will greatly ease landing maneuver difficulty.

Airstrip preparation for the GAA will be significantly easier than for normally-tired light aircraft, because of the soft footprint. Soft or wet spots on a grass strip present no problem. Year-round landing on the tundra can be accomplished without surface damage - this has been established for ACVs in tests conducted by the U.S. Army Cold Regions Research and Engineering Laboratory (Ref. 1) - which are equally applicable to the GAA.

In addition, the air cushion landing on uneven grass strips is more comfortable than wheeled landing, since the trunk will not transmit small shocks comparable to successive wheel impacts. The soft landing characteristic is equally pleasant in water landings where water slapping impacts are correspondingly insulated from the aircraft itself by the air cushion. Based on ACV experience, thick bottom plating should not be necessary, avoiding the associated weight increment. This is in addition to the alleviation of impact acceleration loads by the deflection of the trunk. Quite small hovercraft (SR-N5) have been operated in full gale conditions in the English Channel in correspondingly rough sea, and they have thin, 1.0 mm (0.04 in.) aluminum bottom skins.

The ACLG is at its worst on a rock strewn or sharp-gravel surface. It is probable that large soft wheels will perform equally well and last longer in these circumstances, though incurring a weight and drag penalty.

TABLE IV
ESTIMATED GAA CHARACTERISTICS

Customary Units

			Cessna 185		Hull Amphibians	
		GAA	Land-Plane	Amphibian	Lake Buccaneer	Trident Trigull
Gross Weight	(lb)	3,600	3,350	3,265	2,600	3,800
Empty Weight	(lb)	2,004	1,575	2,135	1,555	2,500
Useful Load	(lb)	1,596	1,775	1,130	1,045	1,300
Installed BHP	(hp)	400	300	300	200	320
Top Speed at Sea Level	(mph)	220	178	156	146	168
Sea Level Rate of Climb	(ft/min)	1,900	1,010	970	1,200	1,260
Takeoff Distance to 50 feet						
Land	(ft)	1,550	1,365	1,275	1,142	1,050
Water	(ft)	1,650	-	1,430	1,780	1,400
Snow	(ft)	1,550	-	-	-	-
Landing Distance From 50 feet						
Land	(ft)	1,500	1,400	1,240	775*	1,300
Water	(ft)	1,270	-	1,460	970*	1,200
Snow	(ft)	1,950	-	-	-	-
Max Range	(miles)	930	1,075	910	825	976
With Payload	(lb)	1,050	1,289	644	715	660
Duration	(hr)	5.7	8.3	9.0	( )	( )
Price	1977 $	65,000	38,650	80,000	45,000	100,000

S.I. Units

			Cessna 185		Hull Amphibians	
		GAA	Land-Plane	Amphibian	Lake Buccaneer	Trident Trigull
Gross Weight	(kg)	1,633	1,520	1,481	1,179	1,724
Empty Weight	(kg)	909	714	968	705	1,134
Useful Load	(kg)	724	805	513	474	590
Installed Power	(kw)	298	224	224	149	239
Top Speed at Sea Level	(km/hr)	354	286	251	235	270
Sea Level Rate of Climb	(m/min)	579	308	296	366	384
Takeoff Distance to 15m						
Land	(m)	472	416	389	348	320
Water	(m)	503	-	436	543	427
Snow	(m)	472	-	-	-	-
Landing Distance from 15m						
Land	(m)	457	427	378	236	396
Water	(m)	387	-	451	296	366
Snow	(m)	594	-	-	-	-
Max Range	(km)	1,496	1,730	1,464	1,327	1,570
With Payload	(kg)	476	585	292	324	299
Duration	(hr)	5.7	8.3	9.0	( )	( )
Price	1977 $	65,000	38,650	80,000	45,000	100,000

TABLE V
GAA WEIGHT BREAKDOWN

	kg	(lb)	kg	(lb)
Power Plant			376.1	(832)
Engine	282	(624)		
Propeller	39.4	(87)		
Mounting, etc.	54.7.	(121)		
Structure			347.6	(768)
Wing	159	(351)		
Fuselage	122	(270)		
Booms	27.2	(60)		
Horizontal Tail	22.2	(49		
Vertical Tail	17.2	(38)		
Landing Gear			83.2	(184)
Trunk	14.7	(32.5)		
Brake Skids - Actuators	9.1	(20.0)		
Fan	14.5	(32.0)		
Hydr Motor	9.5	(21.0)		
Hydr Pump	12.0	(26.5)		
Hydr System	7.7	(17.0)		
Hydr Fluid	5.2	(11.5)		
Instruments	2.3	(5.0)		
Ducting	2.3	(5.0)		
Controls	1.4	(3.0)		
Trunk Attachment	4.5	(10.0)		
Equipment			99.5	(220)
Control System	28.1	(62)		
Fuel System	23.5	(52)		
Hydraulics	1.4	(3)		
Electrics	26.2	(58)		
Heating and Ventilation	13.1	(29)		
One Seat	7.2	(16)		
Empty Weight			907	(2004)
Useful Load			723	(1596)
Gross Weight			1630	(3600)

The ACLG aircraft will be easier to control in overwater taxi than the typical float plane because of the low-speed of the large wave-drag peak which is characteristic of the cushion. This allows enough thrust to be used without accelerating to enable adequate steering from the rudder in the propwash. Model test results comparing hull drag with an air cushion drag over water are shown in Figure 17, illustrating the point. Note that the peak air cushion drag is less than that of the hull.

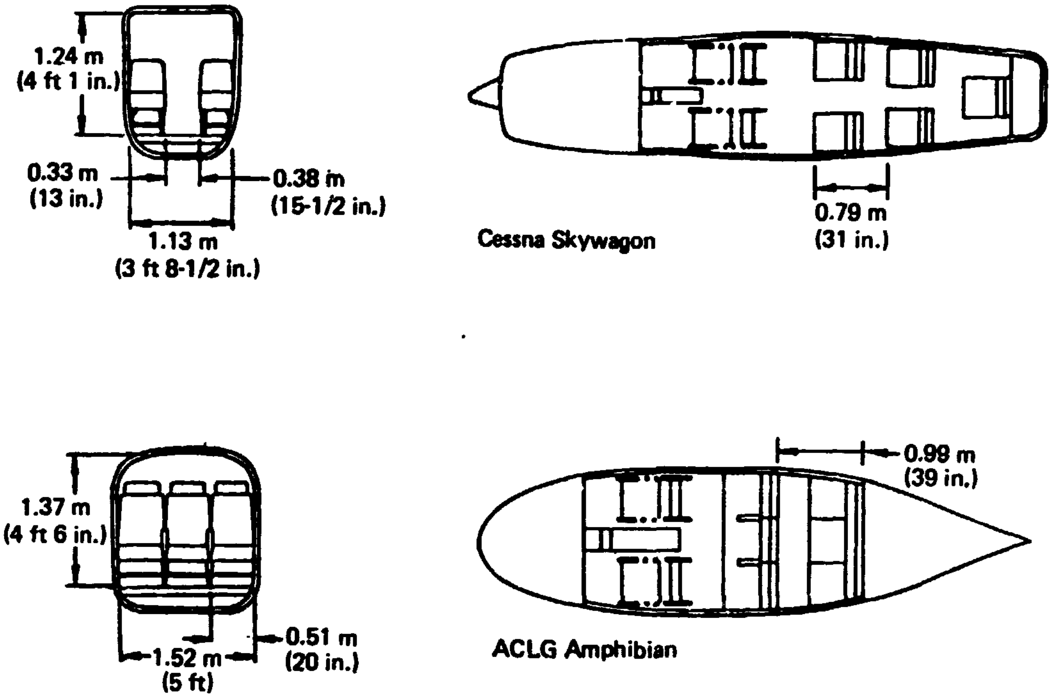

Figure 15. Comparative Accommodation

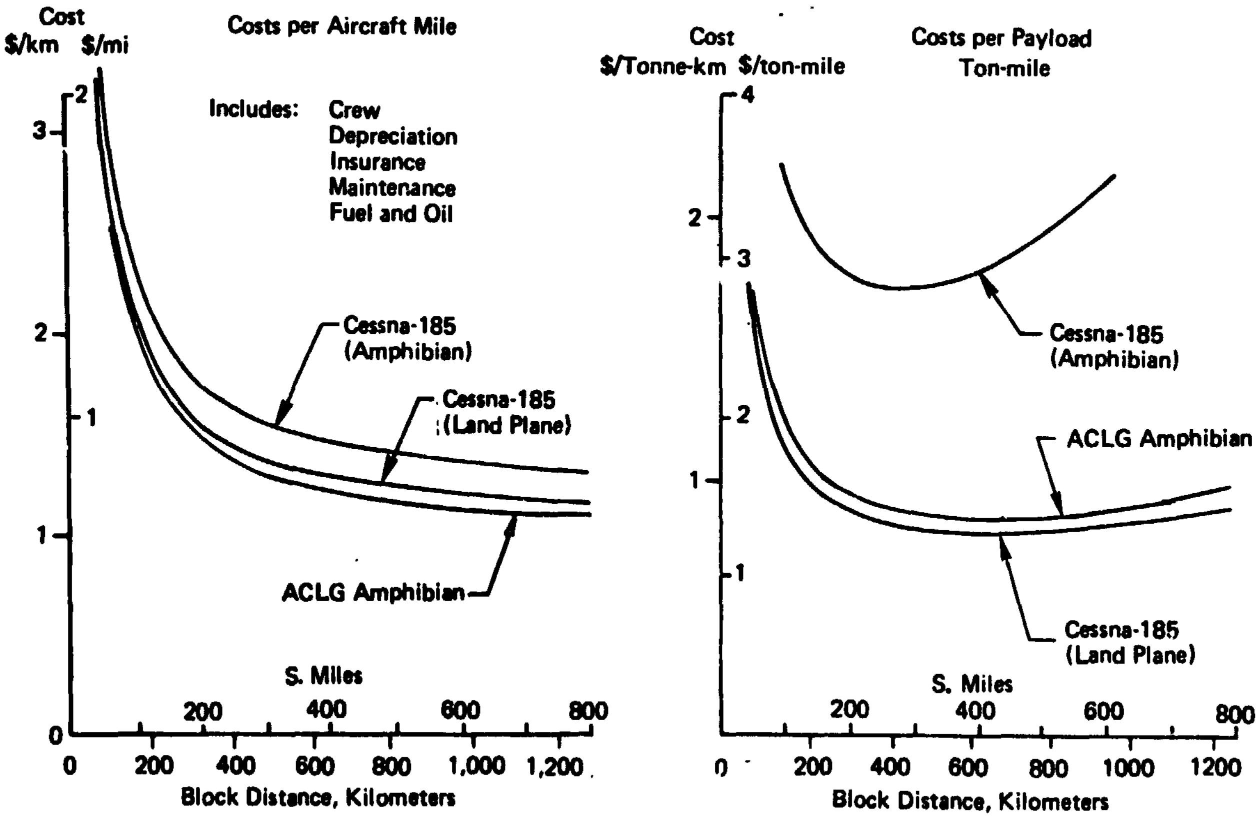

Figure 16. Operating Cost Comparisons

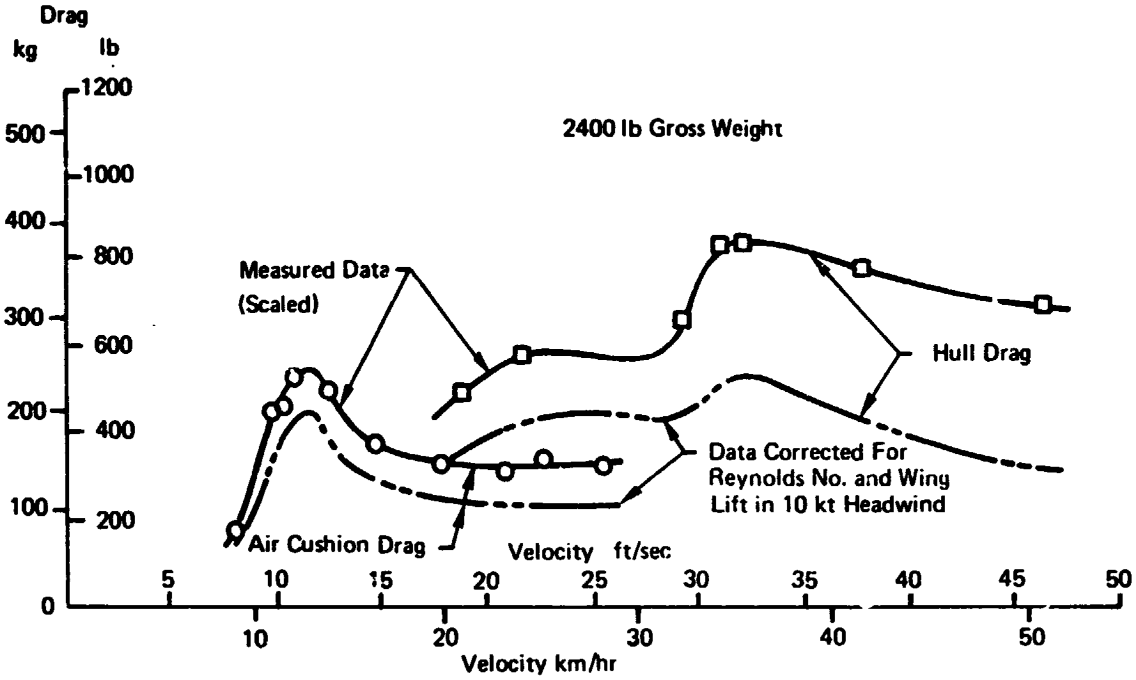

Figure 17. 1/4 Scale LA-4 Model Overwater Drag Data (Full Scale Values)

Cushionborne control over land is similar to over water. In crosswind taxi, considering steady unaccelerated motion, the aircraft is headed into the relative wind, requiring a crab angle. Tendency to drift off the intended track downwind is corrected by change of heading in the upwind direction and vice-versa. The situation is illustrated by the diagram of Figure 18. In these circumstances, with little or no sideslip, there is little or no tendency for the aircraft to roll. In early tests, precise tracking was accomplished by a skilled pilot even in strong crosswinds. In takeoff, where a large margin of thrust over drag exists, the tendency of the accelerating force to push the aircraft upwind off the intended track is compensated by heading out of wind more nearly along the track, as thrust is increased. In downwind taxi, use of brake may be necessary. Cornering is accomplished by yawing in the desired direction and driving around in a slipping turn.

Though clearly cushionborne operation is different to wheelborne, this does not seem to detract from the favorable effects on landing safety, believed to be a substantial benefit of the general aviation ACLG application. Many accidents are caused simply by unskillful landing in difficult circumstances. Though a more tolerant landing gear will do nothing to reduce the hazard of mid-air collision, which is so dramatic a problem today, nevertheless the high fatality rate in the private sector (cited on one basis as 400 times that of the commercial - see U.S. News and World Report for Oct. 9, 1978) must be principally due to other causes than mid-air collision.

The GAA aircraft is projected for a variety of uses worldwide, including traditional "bush", air taxi, private-owner recreational and business, utility freight for farm and industrial use, etc.

The market potential for the GAA can be assessed from the existing population and production rates of comparative light aircraft. Numbers for the United States and Canada only are given in the following table - Table VII. Notably, the introduction of a new 9-passenger amphibian (Grumman 711) is in the conceptual design phase, and the 6-place Trigull is entering production. (Aviation Week Dec. 4, 1978.)

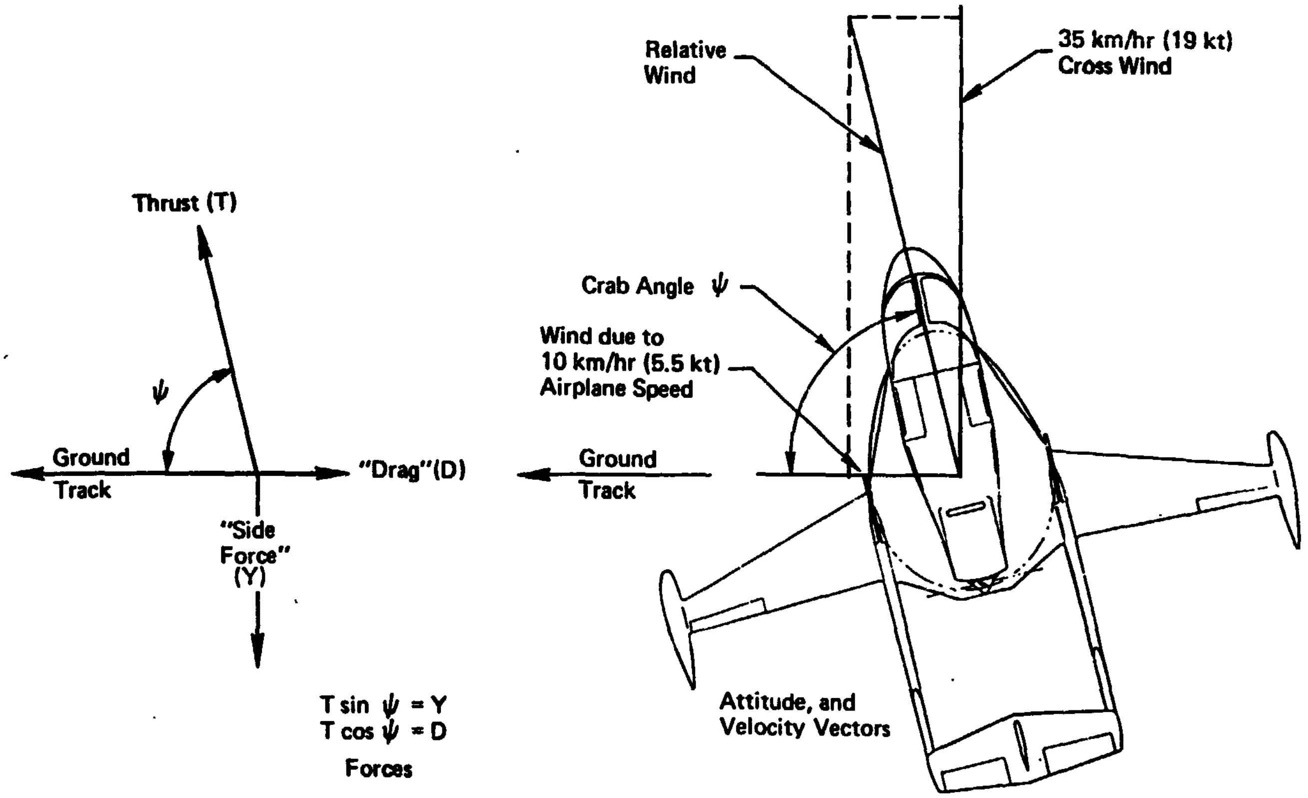

Figure 18. Equilibrium Low-Speed Taxi Conditions in Strong Cross Wind

TABLE VI
GAA AIR CUSHION GEAR COST

Trunk Sheet	1,200
Attachments and plugs	1,260
Brakes	750
Fan and Mounting	2,700
Power Drive	5,500
Increased Engine Cost	1,500
	$12,910

TABLE VII
GAA MARKET POTENTIAL

Aircraft	Total Sales through 1975	1976 Annual Rate
Cessna Skywagon (All Types	12,072	1,417
Lake LA-4	723	90

	1977 Registration		
	Float Planes Ski Planes	Amphibians	Single Piston Engine Land Places
Canada	3,232	356	N/A
U.S.	2,000	430	163,353
Totals	5,232	786	

Footnote:
(Data from Jane's "All the World's Aircraft" and the ATA "Aviation Fact and Figures")

Light Amphibious Transport (LAT)

Description – The example design is in the Twin Otter/Beech 99/Swearingen Metro Class of aircraft restricted to 5670 kg (12,500 lb), and a maximum of 19 seats to remain in the FAA small-aircraft, no-cabin-crew categories. It meets the requirements for a commuter airplane outlined by Allegheny Airlines in Reference 2. A 1342 kw (1800 hp) Twin-Pack PT6 turboprop driving a single 3.05 m (10 ft) propeller is used in a similar configuration to the GAA except that a geared drive to the fan would be used. Twin-engine reliability is provided by the Twin-Pack engine; the engine is in wide use in the Bell-Augusta Helicopter. This approach to twin-engine reliability is also being adopted in the new Lear Avia 2100. In the ACLG example, it overcomes the difficulty of mounting two, engine-driven propellers and retains the rudder-in-prop-wash concept for cushionborne control. The design is a 1.5:1 scale-up of the GAA except that the cabin is slightly widened (2.54 m (100 in.)). The floor to ceiling height is 1.9 m (6 ft 3 in.). Access by a forward door displaces two seats but with four abreast and five rows plus a center seat in the back row, 18 seats could be provided, at a seat pitch of 0.91 m (36 in.). A narrow aisle is satisfactory, since there are only three rows to cross. The design is illustrated in Figure 19. A cabin comparison is shown in Figure 20 and Figure 21 is a 3-view.

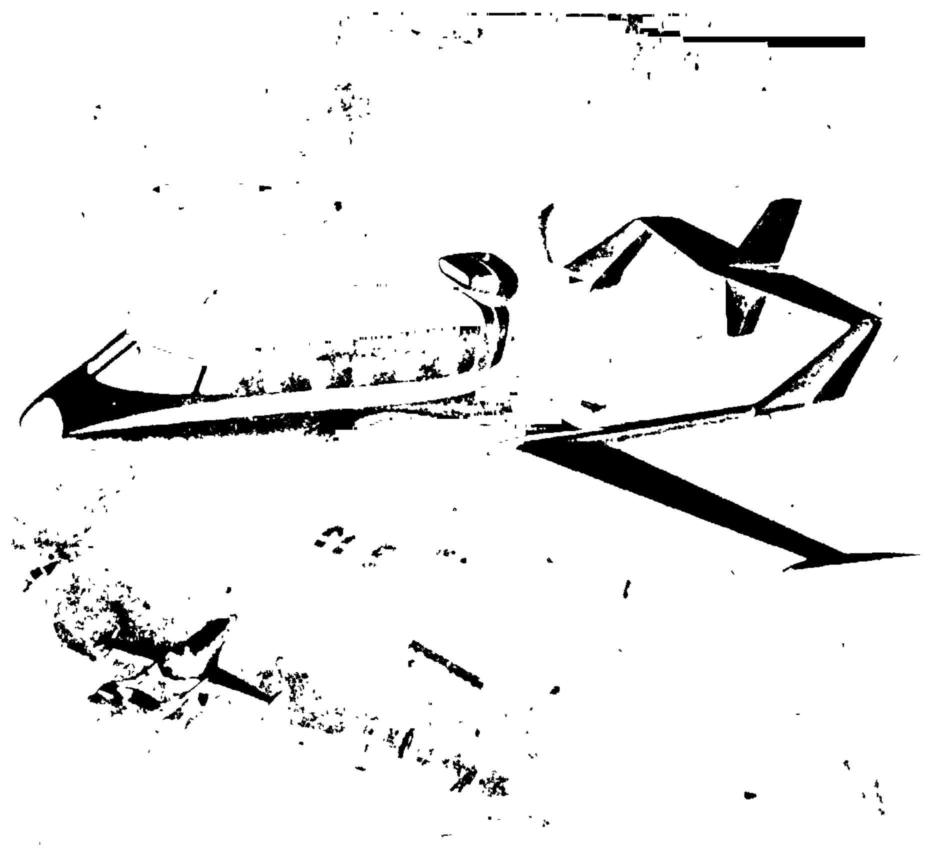

Figure 19. LAT Design

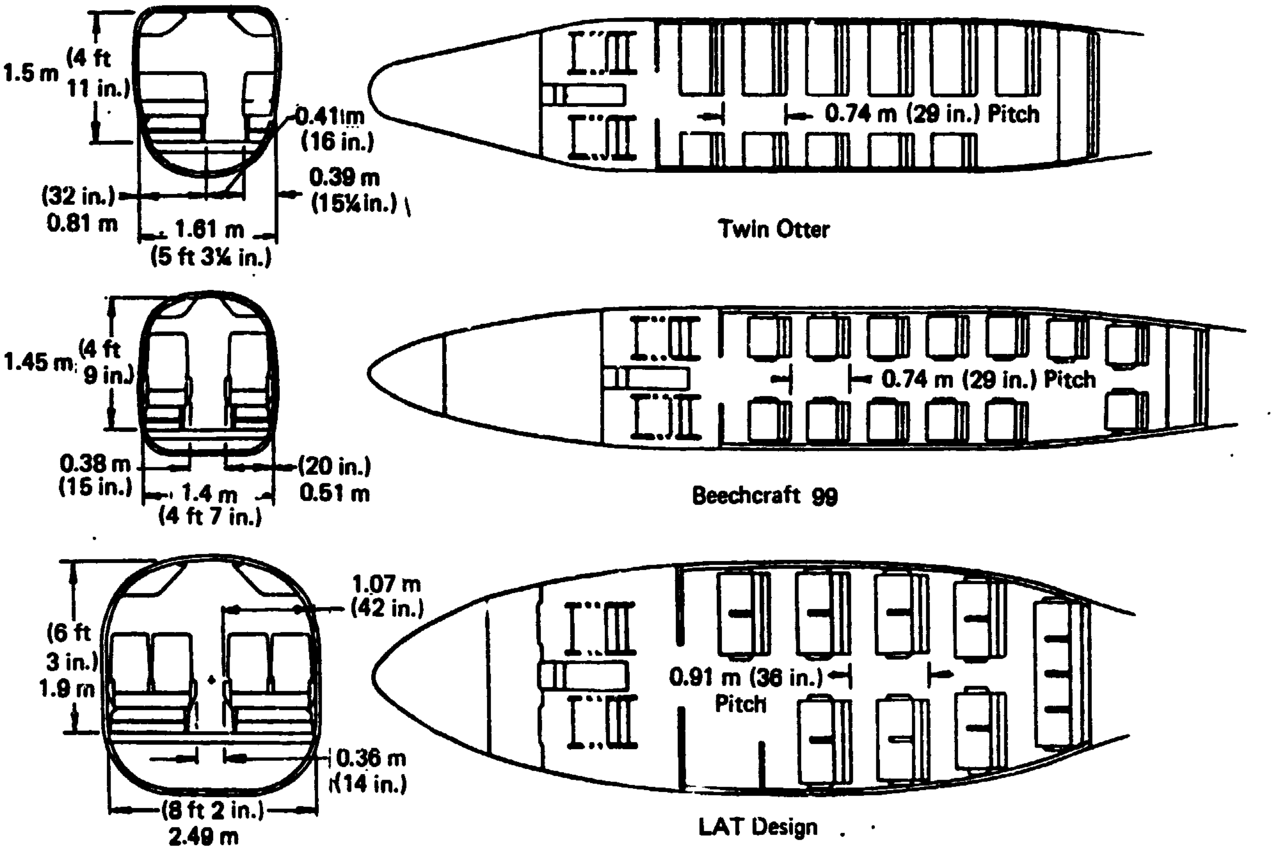

Figure 20. Comparative Accommodations

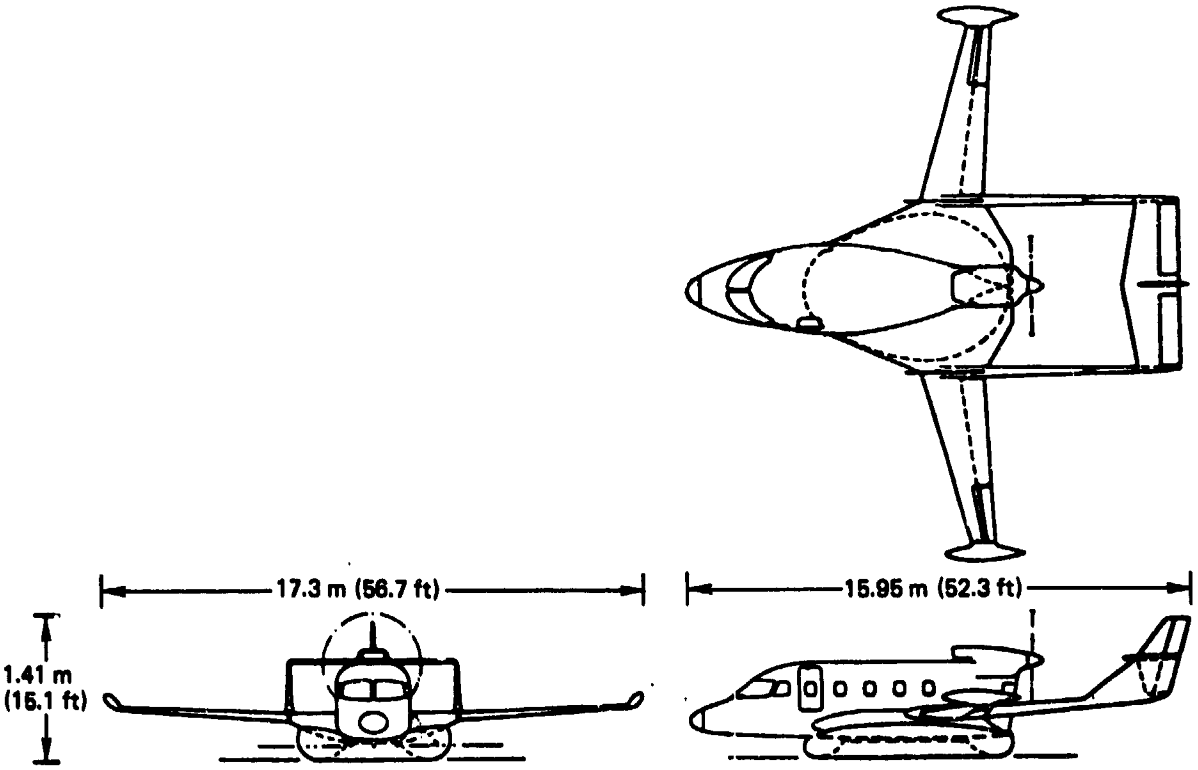

Figure 21. Light Amphibious Transport 3-View

TABLE VIII
COMPARISON OF CHARACTERISTICS

(Customary Units)

	LAT	Twin Otter	Beech 99	Swearingen Metro
Gross Weight (lb)	12,500	12,500	10,900	12,500
No. of Passengers	18	18/19	15	19/20
Wing Span (ft)	53	65	45.9	46.25
Overall Length (ft)	52.33	51.7	44.6	59.4
Wing Loading (lb/sq ft)	36	31	39	45.0
Max. Cruise Speed (mph)	277	210(185)*	280	294
Max. Rate-of-Climb (ft/min) at Sea Level	2,500	1,600(1,250)*	2,090	2,400
Takeoff Ground Run (ft)	1,500	860	1,660	≃2,100
Installed BHP (hp)	1,800	1,304	1,360	1,880
Cost and Production				
Approx. 1977 Price	≃$1,000,000	$748,000	$846,000	$942,000
Number Produced	–	555	164	33
1977 Production	–	48		20

(SI Units)

	LAT	Twin Otter	Beech 99	Swearingen Metro
Gross Weight (kg)	5,700	5,700	4,944	5,700
Wing Span (m)	16,2	19,8	14,0	14,1
Overall Length (m)	16,0	15,8	13,6	18,1
Wing Loading (kg/m^2)	176	151	120	220
Max. Cruise Speed (km/hr)	446	338(298)*	451	473
Max. Rate-of-Climb (m/min) at Sea Level	762	487(381)*	637	732
Takeoff Ground Run (m)	457	262	506	≃ 640
Installed Power (kw)	1,342	973	1,015	1,401

*Float Plane Version

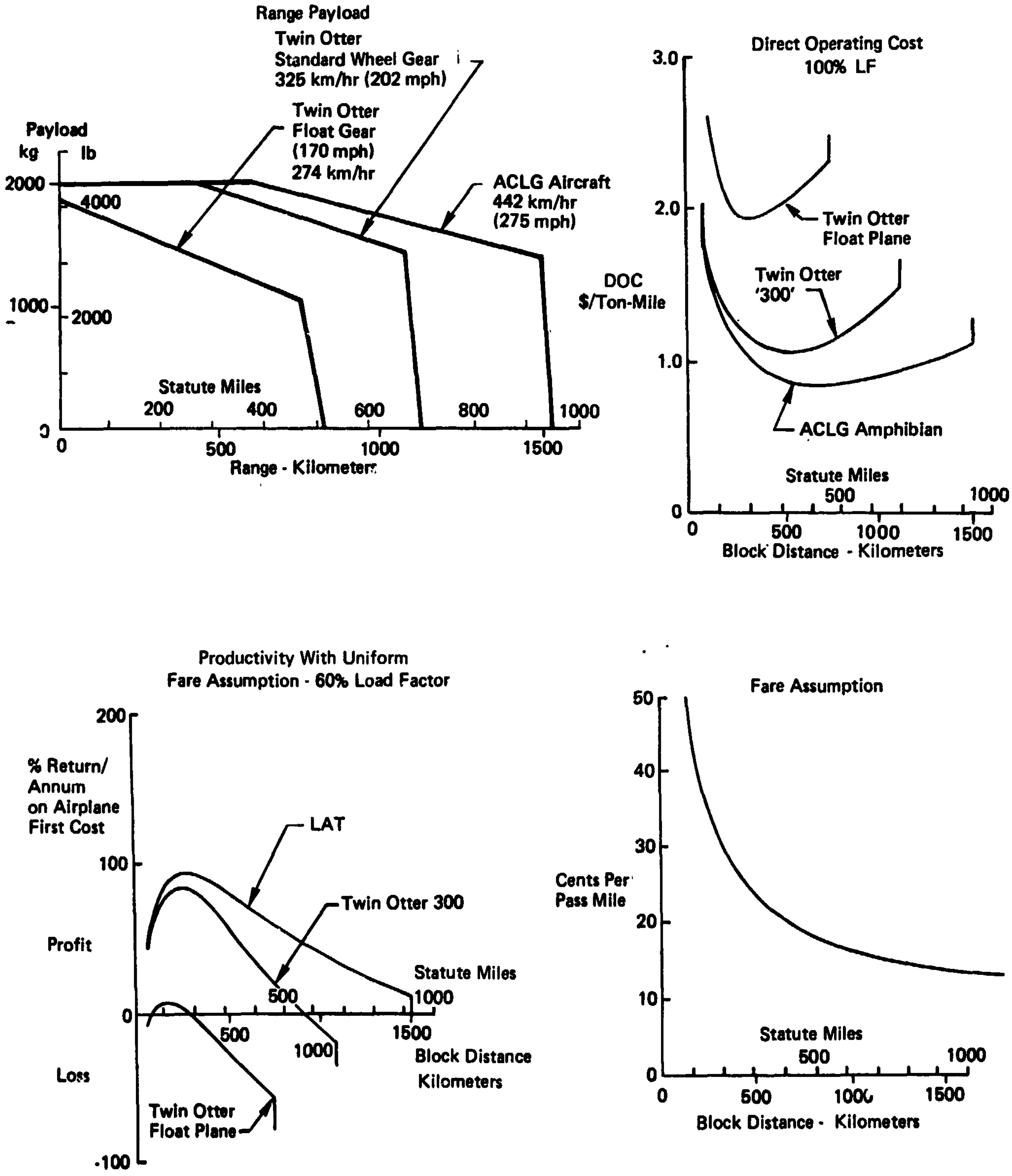

Figure 22. LAT Economic Comparisons

Analysis – Principal characteristics of the LAT are compared in Table VIII with the Twin Otter, Beech 99 and Swearingen Metro. At a power loading of 3.17 kg (7 lb)/per hp, LAT cruising speed of 442 km/hr (275 mph) is forecast. Range-payload, direct operating cost by the ATA method, with coefficients adjusted to 1978 dollar values, and productivity are graphically compared in Figure 22, also assuming the fare structure shown and using an indirect cost equal to 1.6 times direct operating cost. Again a comparison between amphibian and land plane is available, since the Twin Otter is sold in both versions. As with the Cessna 185, the land plane is a fixed gear design. The LAT (trunk retracted) is predicted to have lower, clean flight drag, contributing to the higher top speed and better air miles per pound of fuel.

The quantitative economic advantage of the LAT over the equivalent land plane in terms of direct operating cost and productivity is due to the overall airplane configuration based upon the use of the ACLG. A key characteristic of this dominant feature is the extension/retraction reliability of the elastic trunk compared to mechanical methods. The aircraft's performance advantage over the conventional amphibian is easily seen.

Improved crosswind landing capability is an important feature for this class of aircraft also. In this connection NASA has recently conducted a wheeled crosswind landing gear test series on a Twin Otter, substantially improving the airplane's capability in this respect. Several configurations were tried. The one preferred by pilots was the freely castoring wheelgear which approximates most closely to the ACLG case (Ref. 3). Prospects for the actual introduction of crosswind gear via castoring wheels are tempered by the associated additional complexity and weight/drag increments.

The strongest LAT advantage is versatility of operation, payload-access by water, etc., suggesting use in developing areas of the world.

For assessment of market potential, production and cost data on the above three aircraft are also given in Table VIII.

Short Haul Amphibian (SHA)

Description – A short haul amphibian was also studied. This is projected as a short range (1850 km, 1000 nmi) large capacity aircraft with ACLG. It is visualized as compatible to, or derived from the Boeing 737, having the same span and somewhat similar wing but with a big fuselage (eight abreast seating) and high by-pass turbofans (three T-34) located suitably for amphibious operation. It is a 1.75:1 scale-up of the LAT. Figure 23 is a 3-view of the design. Principal characteristics of this design are compared with Boeing 737 in Table IX.

Cushion air supply is by fan bleed from two of the engines. The fan air would be ducted forward along the bottom section of the rear fuselage to a single air entry port to the elastic trunk.

The fan bleed provides a low weight air cushion power system, with all power reverting to propulsion immediately after takeoff, and available for climb-out and cruise. The air cushion requirement for constant pressure and flow in takeoff and landing is met by using the excess pressure available from the propulsion engine fan at takeoff power to pump additional flow from outside, minimizing fan flow bleed and thrust drain; while in landing sufficient pressure is still available from the fan with the engines near flight-idle, with a greater proportion of the fan air diverted so that the whole air cushion flow is bled directly from the fan. Cushionborne control in taxi would be accomplished by use of differential fan bleed. The bleed arrangement is illustrated by the engine inboard profile, Figure 24 and described in the following.

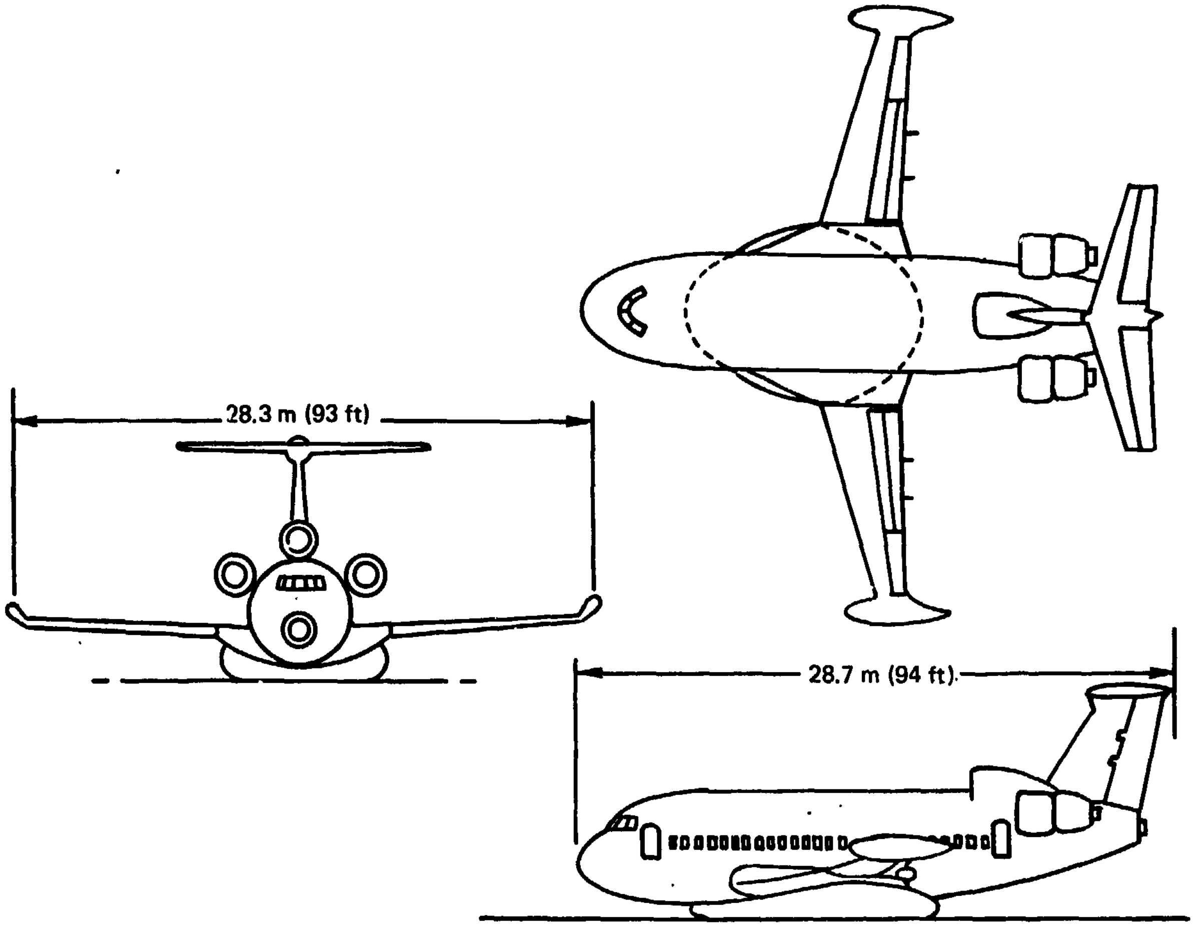

Figure 23. Short Haul Amphibian (3-View)

The air cushion flow requirement is first determined for takeoff. It is based on LA-4 and XC-8A test experience. An effective air gap 50% greater than the LA-4 is selected, to permit low drag traverse of surfaces somewhat beyond LA-4 capability. This gives a total cushion air weight flow requirement of 74 kg/sec (163 lb/sec). Only the two side engines would be used, thus the flow is 37 kg/sec (81.5 lb/sec)/per engine. The jet pump is assumed to increase flow such that the mixed stream is at the same momentum flux as the fan bleed (conservatively neglecting the potential for thrust augmentation) which gives a 1.62 pumping ratio, thus the bleed in takeoff is 23 kg/sec (50.5 lb/sec.) (17% of maximum fan flow for the two engines). The resulting total thrust drain is 8%, assuming 70% of the thrust comes from the cold flow.

In landing, the fan output pressure must maintain trunk pressure, setting a minimum rpm. The conditions are described in Figure 25 which plots T-34 fan flow and output and also total net thrust against fan rpm. The fan rpm needed is approximately 4100 and, at this rpm, a flow of 77.2 kg/sec (170 lb/sec) is available from each engine. Forty-eight percent of the fan flow would then be bled off to the air cushion to provide the total flow requirement of 74 kg/sec (163 lb/sec) without pumping. The available net thrust of each of the two engines without the bleed is 13.79 kN (3100 lb). but with the bleed this would be reduced to 4 kN (900 lb) which is a satisfactory minimum for final approach. All throttles can be used as usual for glide path control, increase of thrust being accompanied by an automatic bleed decrease, preventing increase of trunk pressure.

TABLE IX
COMPARISON OF SHA DESIGN AND BOEING 737-100

Customary Units

	SHA	Boeing 737-100
Passenger Capacity	140	103
Gross Weight (lb)	105,000	105,000
Span (ft)	93	93
Length (ft)	94	94
Fuselage Diameter/Width (ft)	17.5	12.33
Operating Weight Empty (lb)	59,900 (1)	58,000
Engines	3 x T.34	2 x JT8D
Engine Weight (lb)	4,281	6,310
Total Engine (SLS) Thrust (lb)	27,800*	28,000
Cruise Specific Consumption lb/hr/lb	0.67	0.79
Static Thrust/Gross Weight	0.265	0.266
Payload (lb)	29,700	21,800
Range With Full Payload and Allowances (nmi)	1,000	2,000
Wing Loading lb/sq ft	97.5	107
Cruise Lift/Drag ratio	14	16

*25,950 after cushion bleed

SI Units

	SHA	Boeing 737-100
Passenger Capacity	140	103
Gross Weight (kg)	47,628	47,628
Span (m)	28.3	28.3
Length (m)	28.7	28.7
Fuselage Diameter/Width (m)	5.33	3.76
Operating Weight Empty (kg)	27,170(1)	26,309
Engines	3 x T.34	2 x JT8D
Engine Weight (kg)	1,942	2,862
Total Engine (SLS) Thrust (kn)	124	1,245
Cruise Specific Consumption (kg/m/kg)	0.67	0.79
Static Thrust/Gross Weight	0.265	0.266
Payload (kg)	13,472	9,888
Range with Full Payload and Allowances (km)	1,852	3,704
Wing Loading kg/sq.m	477	524
Cruise Lift/Drag ratio	14	16

(1) The above SHA operating weight empty reflects a fuselage weight approximately 2300 kg (5000 lb) heavier than that of the 737 with off-setting reductions in landing gear and engine weight compared with that airplane (See Table XII for landing gear weight.)

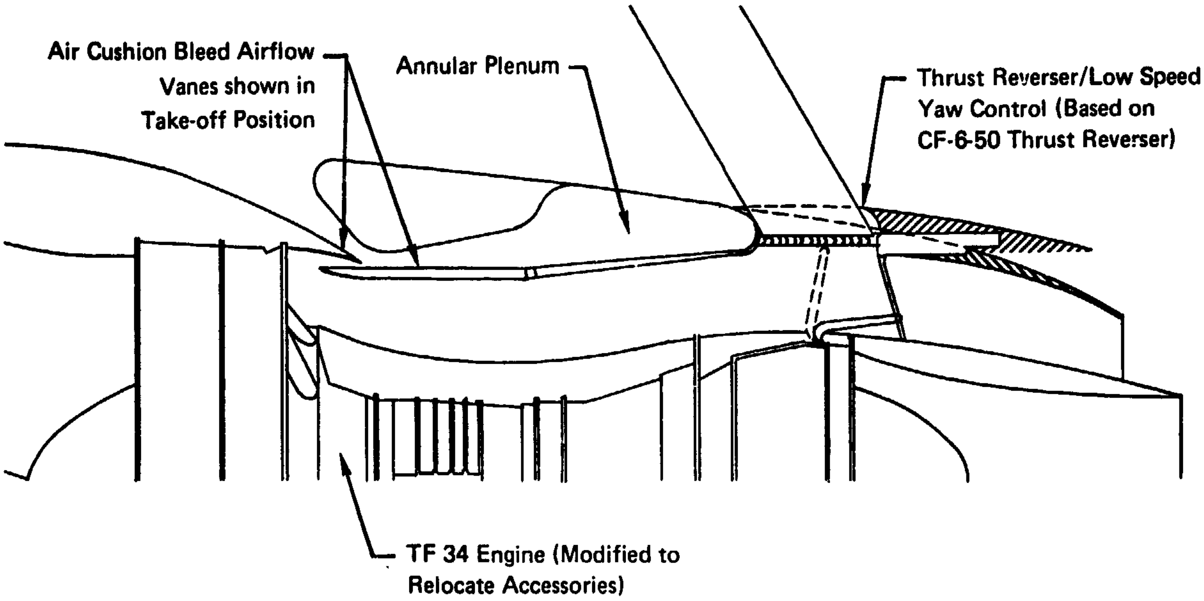

Figure 24. T-34 Inboard Profile Showing Fan Bleed and Flow Augmenter Scheme

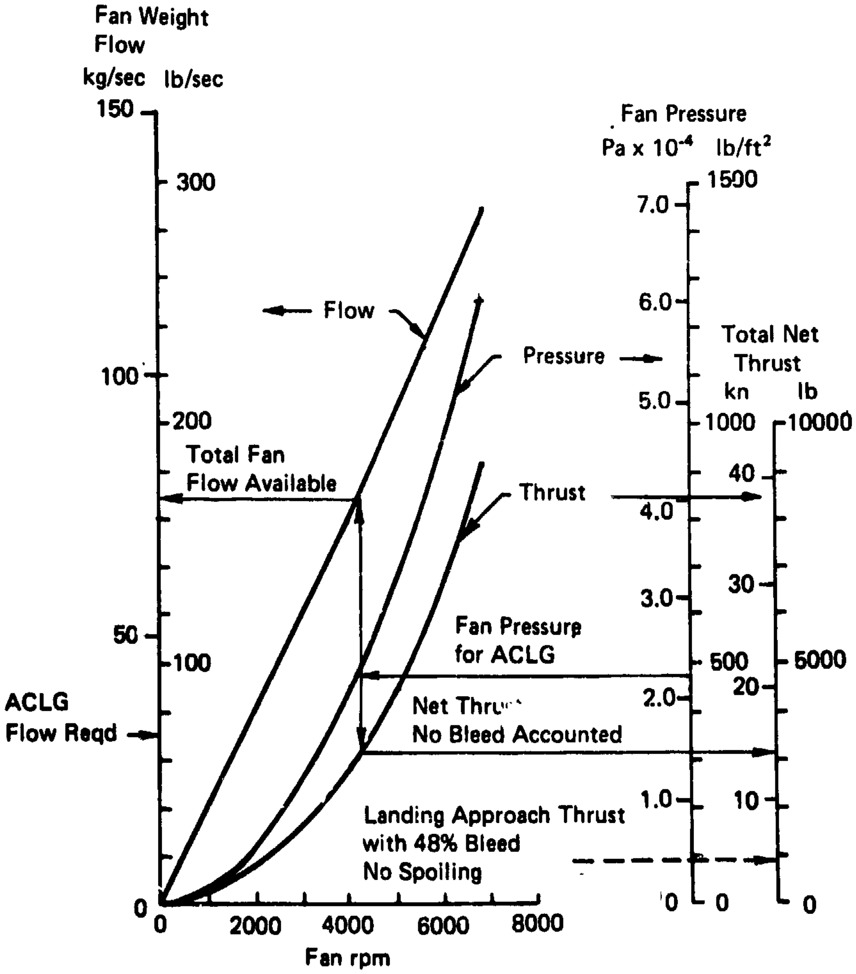

Figure 25. T-34-100 Bypass Flow Characteristics

Analysis – The advantages of ACLG in this application would be to improve takeoff and landing at the many thousands of developing small airports and also to permit the development of alternative downtown water front sites as pictured in the artists impression (Figure 4).

Figure 26 is an illustration depicting a crosswind landing attitude, with the aircraft headed 15 to 20 degrees off the runway centerline, appropriate to a 35-knot crosswind. In this application, where the airplane utilization is directed generally at the use of less well developed airfields, a crosswind gear again appears as a useful feature, possibly not enough to warrant development of castoring wheelgear for this class of aircraft, but a valuable plus for the ACLG. The following points are made:

Landings are currently not infrequently aborted because of crosswind.

The best runway alignment is often not the longest available.

Approach aids are often only available on the longest runway. In the developing system with smaller airports lagging in facilities, use of crosswind gear will show maximum advantage, enabling a single strip to be used in any wind condition.

Roll-out distance is decreased by heading into the relative wind at touch down, and speed margin for rough air can be reduced. With strong 90° crosswind, ground speed may be reduced 5 to 10% with resulting 10 to 15% reduction in roll-out distance.

The takeoff and landing at small airports can be improved in two other ways by ACLG:

Use of existing unpaved or low bearing capacity overrun or allowing low cost runway extension as unpaved surface or water.

Shortening takeoff and landing field length by the use of "suction braking" as described in Reference 4. A reduction of at least 25% is feasible.

Improved economy would be the result of the high payload/gross weight ratio resulting from restricting the aircraft to short range, providing a larger passenger capacity and using low specific consumption high-by-pass engines - providing the aircraft is suitably sized to available traffic on a sufficient number of routes. The example is intended to be futuristic (in common with most of those shown). It represents a continuation of the trend toward ever larger fuselage capacities on ever smaller wings and is a design permitting lengthwise growth and increased gross weight and range. No problem is apparent in increasing air cushion pressure within reason. A gross weight increase of 20% for example to 57,204 kg (126,000 lb) would increase cushion pressure to 11,158 Pa (233 lb/ft^2), and maximum hump wave-drag/weight ratio from 0.162 to 0.195, still giving a margin for the transient peak drag condition.

The short haul airplane concept envisages widespread use of less well developed airfields with shorter runways, with versatility to alternate with water landing sites or major airports. Safety aspects of the ACLG loom large. Additionally, economic improvement can accrue due to lower gear weight and cost on the one hand, and either reduced or more easily extended field length on the other.

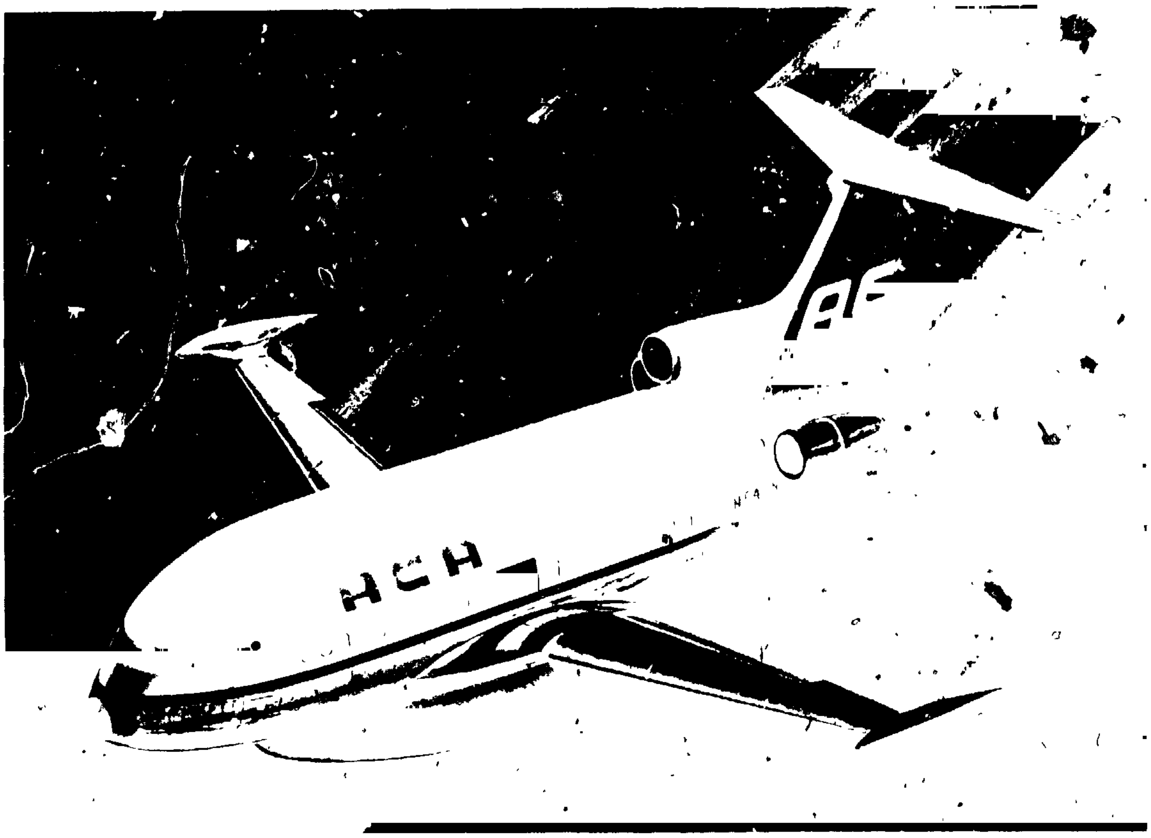

Figure 26. Short Haul Amphibian (SHA)

The ACLG appears to offer an overall safety advantage. The air cushion trunk is not subject to catastrophic deflation if punctured, the power source is duplicated and in the event of double engine failure the belly landing configuration is acceptable. The typical design can not have underslung equipment such as engines. Single engine failure does not affect the cushion operation since the required flow will be made up by taking a larger bleed from the good engine. The vanes will automatically and immediately adjust to maintain trunk pressure. A separate signal, indicating engine failure, would be used to set the vanes to the flight condition on the failed engine, preventing backflow. The hazard of partial wheelgear extension is avoided. An increment of safety results from the crosswind capability discussed previously and safe emergency landings on water are possible.

Retractable wheelgear reliability is questionably satisfactory. Table X, extracted from Reference 5, shows all non-fatal incidents reported in scheduled operations for the year 1973. Accidents resulting from wheelgear failure from whatever prime cause which would apparently either not have happened or been better tolerated by an ACLG equipped aircraft are marked with an asterisk. Twenty of the thirty-one starred happened to different aircraft types. The ACLG will add an increment of safety to overrunning or running off the runway incidents, and to ditching, forced landing, tire burst, and bogging down. All these predicaments are recorded in Table X.

TABLE X
NON-FATAL INCIDENTS

NON-FATAL INCIDENTS

Date	Carrier	Aircraft	Location	Injuries Crew	Injuries Pass	Total Occupants Crew	Total Occupants Pass	Phase	Circumstances
Jan 19	Trans-Nusantara	DC-3 (PK-EHC)	Pontianak	—	—	5	—	L	Burnt out on crash landing
* Jan 19	British Midland Airways	Viscount (G-AZLR)	Birmingham	—	—	3	—	L	Port undercarriage collapsed on landing. Positioning flight
Jan 19	Executive Transport	Learjet 23 (F-BSTP)	Nancy	—	—	?	?	L	Undercarriage destroyed
Jan 24	BEA	Vanguard (G-APEB)	Teesside	—	—	3	—	T/O	Damaged starboard wing tip during training take-off
Jan 24	Ethiopian Airlines	B.707	Lagos	—	—	9	104	L	Damaged port wing and undercarriage. Diverted
* Jan 30	SAS	DC-9 (LN-RLM)	Oslo, Fornebu	—	—	4	29	T/O	Overran after abandoned take-off
* Jan 31	Aerovias Nacionales de Colombia	B.707 (HK-1410)	Madrid	—	—	10	72	L	Nose leg off & lower fuselage damaged on touchdown
* Feb 5	Kar-Air	Twin Otter (OH-KOA)	Oulu, Finland	2	1	3	15	L	Unsuccessful force-landing on frozen lake
Feb 15	Kanaf Air Services	Islander (4X-AYT)	Beersheba	—	—	?	?	ER	Starboard propellor disintegrated in flight
Feb 17	KLM	DC-8	Cairo	—	—	?	137	ER	Engine fire. Returned to Cairo
Feb 18	North Cay Airways	Islander (N871JA)	San Juan	—	—	?		L	Serious damage?
Feb 19	BEA	Trident (G-AVFF)	London	—	—	?	54	ER	Section of flap detached
* Feb 21	BEA	BAC One-Eleven (G-AVMX)	Teesside	—	—	3	—	L	Landed wheels up
Feb 21	TWA	B.747	Las Vegas	—	—	?		Climb	Emergency landing after engine fire
Mar 5	Spantax	Convair 990 (EC-BJC)	Nantes	—	—	108		ER	Mid-air collision with EC-BII
Mar 12	Sabena	Caravelle	Land's End	1	3	?		ER	Airmiss. Caravelle took avoiding action
	World Airways	DC-8		—	—	?		ER	
Mar 15	Linea Aeropostal Venezolana	HS.748 (YV-C-AMC)	Maiquetia	—	—	?		?	Extensive damage
* Apr 3	BEA	Trident (G-ARPU,	Paris, Orly	—	—	6	112	L	Nosewheel failed to lock-down
Apr 4	Bristow Helicopters	S-61N (G-AZNE)	North Sea	—	—	2	?	L	Out of control landing on drilling rig Ditched
* Apr 7	Spantax	DC-7	Lisbon	—	—	6	78	ER	Engine failure. U/C failed on landing
Apr 8	Phoenix Airways	B.707 (HB-IEG)	Tel Aviv	—	—	?		L	Landed with engine on fire
* Apr 17	Iraqi Airways	Viscount (YI-ACL)	Mosul	—	—	?		L	Undercarriage collapsed
* Apr 22	British West Indian	B.707 (9Y8TDC)	Toronto	—	—	9	48	L	Nosewheel failed to lower
Apr 25	Aeromar	C-46 (HI-201)	Punta Caucedo	—	—	4	—	T/O	Engine failure. Ditched
May 4	Macair Charter	Islander (VH-MK[illegible])	Papua	—	—	?		ER	Propellor detached
May 7	PanAm	B.747 (N751PA)	London, Heathrow	—	—	?	232	G	Ground collision
	Aer Lingus	B.737 (EI-ASG)		—	—	?	84	G	
May 10	Thai Airlines	DC-8 (HS-[illegible]BU)	Katmandu	2	2	10	100	L	One fatality on ground
May 11	Qantas	B.747 (VH-EBB)	Sydney	—	—	?	366	T/O	Multiple bird ingestion
* May 19	Dan-Air	Comet (G-APYC)	Menston	—	—	7	110	L	Nosewheel failed to lower
May 26	Pakistan Intern'l.	F.27 (AP-AUW)	Risalewala	?		?		L	Aircraft destroyed
* June 7	Aerolineas Tao	Viscount (HK-1061)	El Eldorado	?		?		L	Wheels up landing
* June 9	British Midland	Viscount (G-BAPG)	East Midlands	—	—	4	58	L	Nosewheel collapsed on landing
* June 13	Maya	Islander (VP-HBX)	Belize	—	—	?		L	Heavy landing. Collapsed main U/C
June 16	Air France	B.707 (F-BHSX)	Buenos Aires	—	4	?	60	L	Engine fell off and fire broke out on landing
* June 20	Overseas National	DC-8 (N863F)	Bangor, Maine	33		?		T/O	Tyre blow started hydraulic fire
* June 21	BOAC	B.747	New York, Kennedy	—	—	?	153	L	Overran end of wet runway
June 24	Loftleider	DC-8	New York, Kennedy	38		9	119	L	Heavy landing. One engine detached
* July 3	Indian Airlines	Caravelle (VT-DPO)	Bombay	—	—	?		L	Noseleg collapsed & fire broke out following heavy landing
* July 6	Aerovias Nacionales de Colombia	HS.748 (HK-1408)	Bucaramanga	?		5	37	L	Overran runway. Three killed on ground
July 11	El Al	B.707 (4X-ATT)	Tel Aviv	—	—	?	84	L	Hydraulic failure. Nose leg collapsed
July 17	Sata	Convair 600 (HB-IMM)	Tromso	—	—	3	56	L	Heavy landing
July 28	Saesa	HS.748 (XZ-SAB)	Acapulco	—	—	3	—	L	Damaged during training
July 29	Air Bridge Carriers	Argosy (G-APRN)	London, Heathrow	—	—	2	—	T/O	Abandoned T/O with engine fire
* Aug 3	Urraca	Herald (HK-718)	?	—	—	?		L	Wheels-up landing
Aug 2	Garuda	F.28 (PK-GJT)	Sumatra	—	—	?		?	Severe damage. Circumstances not reported
* Aug 6	Qantas	B.707 (VH-EBN)	Sydney	—	-	?		Taxi	Undercarriage collapsed leaving apron
Aug 11	Air France	F.27 (F-BSUM)	Strasbourg	?	—	?	—	L	Scheduled freight flight
Aug 29	CSA	Tu-104 (OK-MDE)	Nicosia	—	9	8	62	L	Diversion landing after engine trouble
* Sept 4	Lufthansa	B.747	Delhi	—	—	?	360	Taxi	Bogged down before take-off
Sept 5	Air Vietnam	B.727 (XV-NJC)	Bangkok	4		54		T/O	Galley explosion
Sept 11	California Airmotive	C.990 (N7876)	Guam	?		?	—	L	Crahsed on airport
* Sept 11	Swissair	DC-10 (HB-IHA)	Zurich	—	—	?		L	Undercarriage failed to lock down
Sept 12	Lane Xang Airlines	DC-3 (XW-PKD)	Kampot	—	—	?		L	Serious damage
Sept 23	Air Algerie	Caravelle (7T-VAI)	Algiers	—	—	?		L	Serious damage
* Oct 5	Aerolineas TAO	Viscount (HK-1058)	El Dorado	—	—	?		L	Ran off runway. Substantial damage
* Oct 6	Trans Mediterranean Airways	B.707 (OD-FAX)	Bombay	—	—	?	—	T/O	Struck wall and damaged undercarriage
* Oct 6	Balkan-Bulgarian	Tu.134 (LZ-TUA)	Sofia	—	—	?		L	Undercarriage collapsed
Oct 20	Mexicana	B.727 (XA-SEN)	Mazatlan	—	3	?		L	Landed short of runway
* Oct 28	Piedmont Airlines	B.737 (N751N)	Greensboro, N.C.	1	3	4	90	L	Overran runway. Hit embankment
Oct 23	Nigeria Airways	F-27	Ibadan	—	1	?	?	L	Forced landing
* Oct 25	Span East Airlines	DC-6(N8145E)	Miami	1	—	3	—	L	Ditched in bay short of fuel
* Nov 15	Seaboard World	DC-8 (N8783R)	London, Heathrow	—	—	?	?	L	Wheel lost at Shannon. Diverted & damaged on landing
Nov 27	Delta Air Lines	DC-9 (N3323L)	Chattanooga	3	7	77		L	Hit ILS aerials. Caught fire
Nov 27	Eastern Air Lines	DC-9 (N8967E)	Akron-Canton	15		3	21	L	Overran runway and went down embankment
Dec 3	Air Union	DC-3 (XW PHV)	Phnom-Penh	?		?	?	T/O	No details. Serious damage
Dec 12	Fred Olsen	Falcon 20 (LN-FOE)	Norwich	3	6	3	6	T O	Multiple bird strikes
* Dec 14	Loganair	Skyvan (G-AWYE)	London, Gatwick	—	—	2	—	L	Port undercarriage collapsed
* Dec 15	Air Union	CW-20 (XW-PKK)	Phnom-Penh	?		?	?	L	Port undercarriage collapsed
* Dec 17	Iberia	DC-10 (EC-CBN)	Boston	16		14	154	L	Hit runway lights and burnt
Dec 17	Eastern Air Lines	DC-9	Greensboro, N.C.	—	1	86		T/O	Take-off abandoned. Small fire
Dec 20	Lufthansa	B.707 (D-ABCT)	Delhi	2	12	11	98	L	Landed short
* Dec 23	Cruzeiro do Sul	Caravelle (PP-PDV)	Manaus	—	1	7	50	L	Overran runway and caught fire,

Legend: T/O, take-off; C, initial climb, ER, en route; App. approach; L, landing; O, overshoot

*Incidents which would probably have been avoided or better tolerated with ACLG

The estimated air cushion landing gear weight and cost for the SHA are compared with Boeing 737 figures in Table XI. The air cushion figures are based on detail synthetic estimates. They include an incremental weight and cost for the engine bleed modification for ACLG. A parallel economic comparison between the Boeing 737 and the SHA design has not been made because a large part of the economic advantage would be due to the use of modern high by-pass engines, which coming into use on shorter haul aircraft such as the Boeing 757, for example, will probably make the 737 gradually obsolete in any case. The comparative engine weight and specific fuel consumptions are given in Table IX. As exampled, the integrated ACLG concept depends on bleed from a high by-pass engine (the air cushion being a high-flow, low-pressure type of device) for a low weight power supply, and, although the bleed system weight is chargeable to the air cushion, it can be argued that the engines are sized for climb and cruise, the ACLG power drain resulting in a longer takeoff ground roll, acceptable because of the relaxed surface requirements.

TABLE XI
SHA AND BOEING 737-100 LANDING GEAR COSTS

	SHA	Boeing 737-100
Gear Weight kg, (lb)	1,544 (3,400)*	1,989 (4,382)
Gear Cost ($) (1974 $)	217,000	322,000

*Includes the delta for engine fan bleed and a fuel allowance for cushionborne operation.

The reduction in landing field length which could be achieved by the cushion braking method outlined in Reference 6 is shown by the diagram, Figure 27. Its use could permit elimination of engine thrust reversers per se.

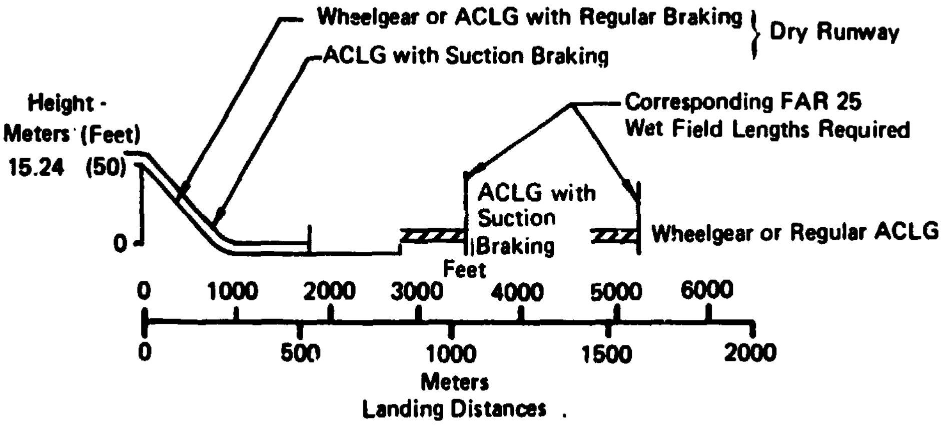

Figure 27. Landing Profile Comparison

Market potential for such an aircraft cannot be realistically assessed at this time. Because the application is slanted towards use of landing surfaces of great variety and low cost, it may be one of the most attractive; but, in common with the larger aircraft studied, there is no possibility SHA development would be undertaken until ACLG technology is further advanced. System reliability and potential life must first be established by extensive operation at smaller scale.

Medium Amphibious Transport (MAT)

Description – This shows the potential of an ACLG aircraft as a military/commercial freighter designed to accommodate side by side 8 x 10 ft cross section containers in two files as shown in the 3-view, Figure 28.

Characteristics

Aircraft:

Wing Area	228 sq m	- (2456 sq ft)
Max Gross Wt	158,900 kg	- (350,000 lb)
Eff Aspect Ratio		- 7.98
Power - 2 CF6-5 Engines at 51,000 lb Static Thrust ea		

Air Cushion:

Maximum Cushion Pressure	13,500 Pa	- (282 psf)
Cushion Area	115.3 sq m	- (1241.6 Sq ft)
Perimeter	37.9 m	- (124.34 ft)

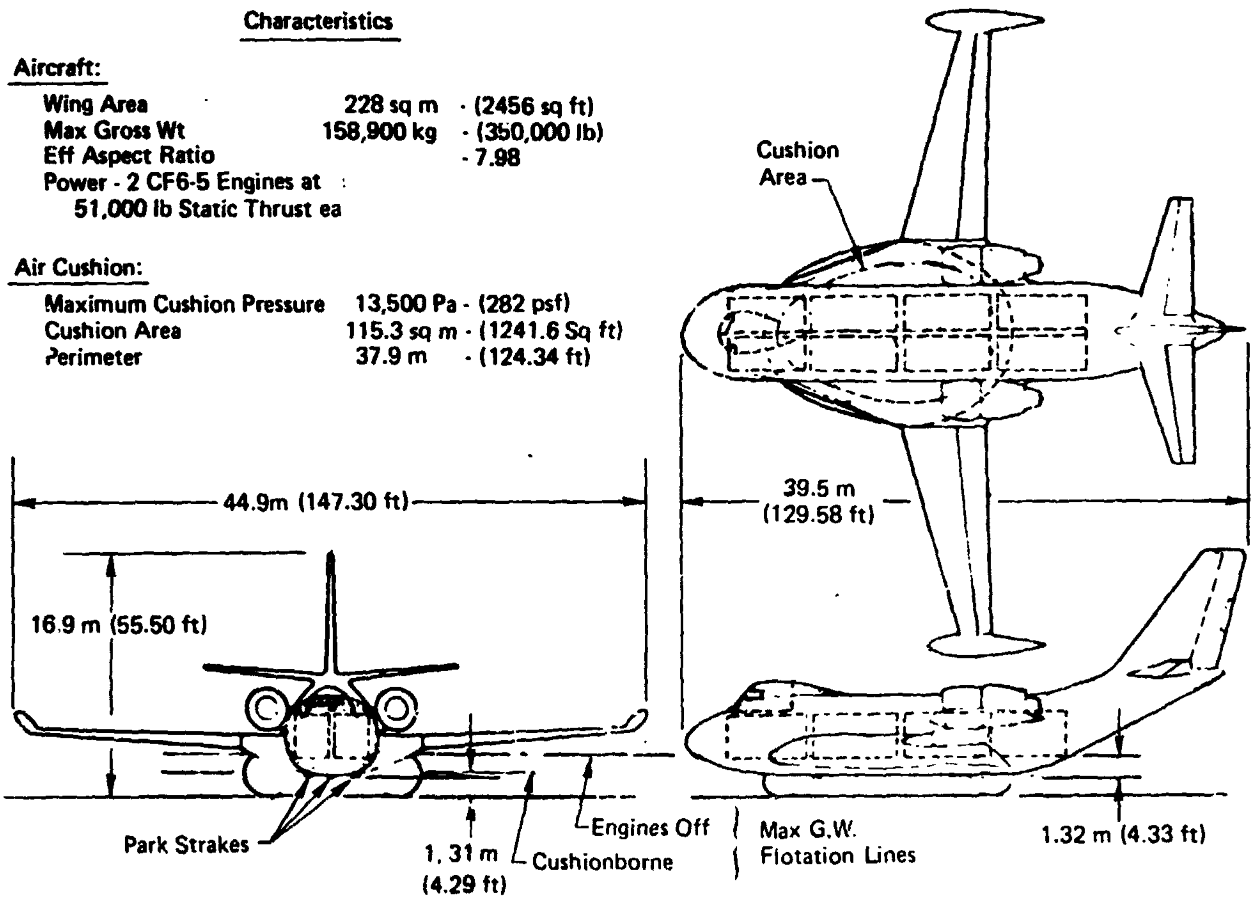

Figure 28. Medium Amphibious Transport 3-View

It is essentially a 4:1 scale-up of the GAA. The design follows a similar approach to parking on land or floating on water. The aircraft is powered by two, GE CF6-50E engines modified to bleed some of the by-pass fan air to supply the air cushion, similarly to the SHA.

The kneeling feature inherent to the air cushion permits parking with the fuselage bottom nearly at ground level. This brings the floor down to truck bed height for loading beneath the tail as shown in Figure 5 and Figure 28 (1.32 m) (4.33 ft).

The CF6-50 is particularly adaptable to the by-pass fan bleed scheme because the space between the inner wall of the by-pass flow duct and the core engine is largely empty, the accessories being housed in the forward duct structure and driven by a quill shaft as shown in the standard engine cross section, Figure 29(a). The modification would be to bring the inner wall in as close to the core engine as practicable and surround the fan flow duct with an annular collector and jet pump as shown in Figure 29(b). The estimated additional weight of the ACLG bleed including all ducting

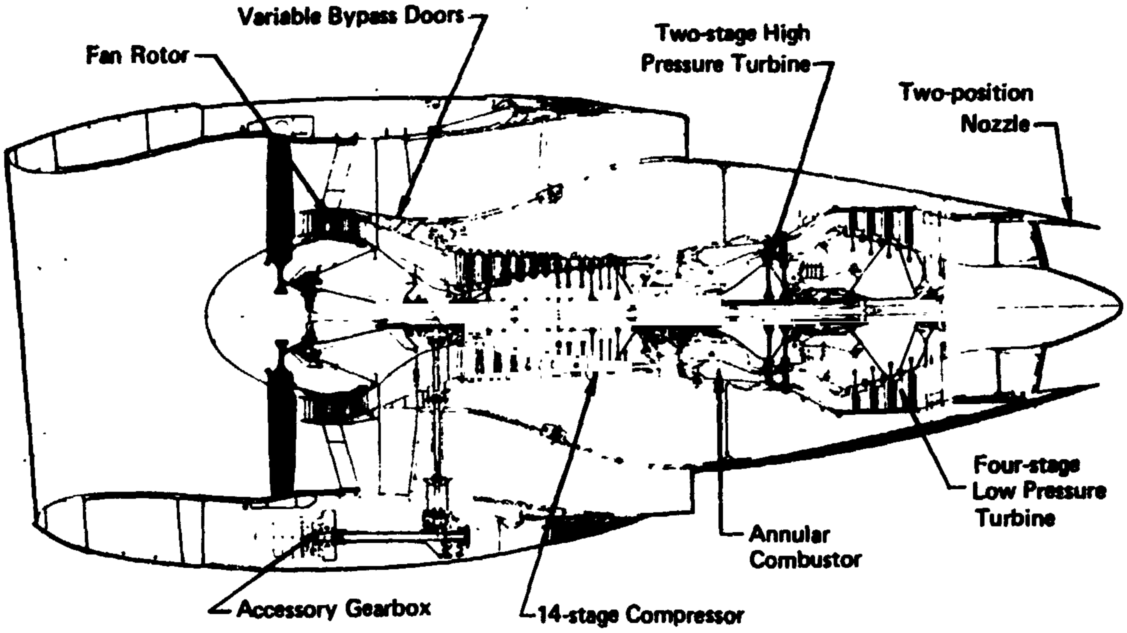

Figure 29(a). CF6-50 Standard Engine Cross Section

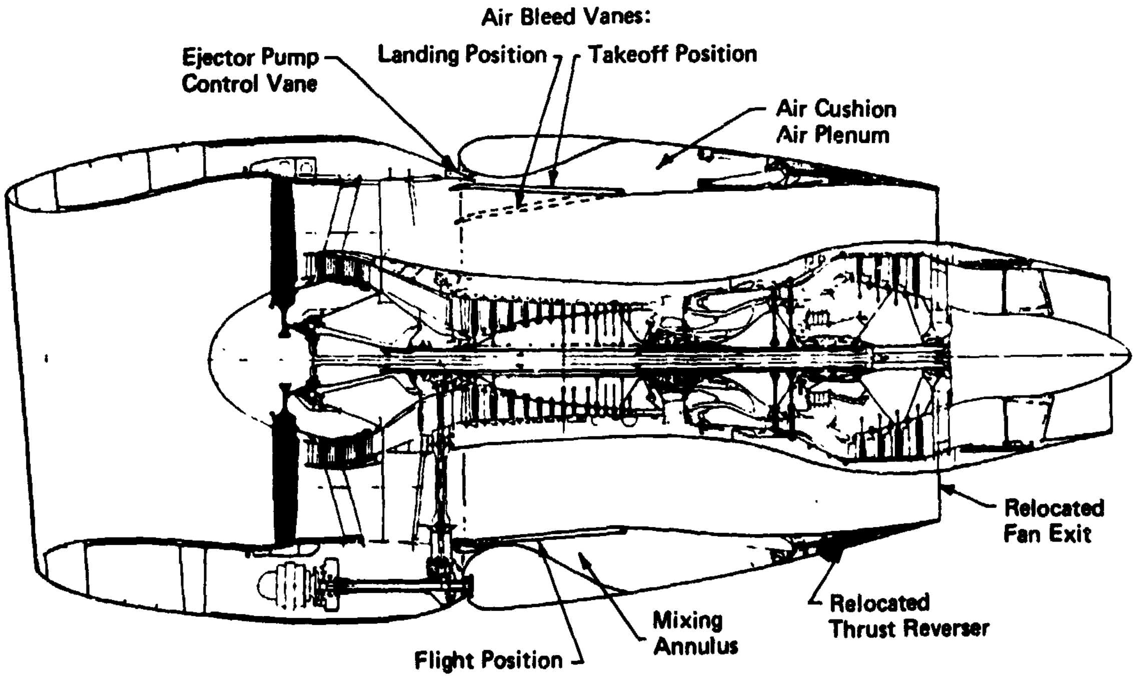

Figure 29(b). CF6-50 Engine Showing Proposed Modification for ACLG Fan Bleed on the engine side of the interface is 386 kg (850 lb), which is 10% of the engine weight. Probably the percentage increase in engine cost would be less than 10% because the alteration consists largely of sheet metal work.

Cushionborne yaw control in taxi would be accomplished by differential operation of the outboard sector of the thrust reverser. Modification to improve response rate would possibly be required. The engine failure case is similar to that of the SHA. The bleed control would respond to the pressure drop resulting from the stopped or spooling-down fan by increasing the bleed proportion on the live engine.

Analysis – The MAT design concept is similar in size to the YC-14, with wider fuselage and greater wing area, but using the same engines. A size comparison with the YC-14 is shown as Figure 30. Four to one scale-up from the GAA (simply assuming weight varies as span cubed) indicates a gross weight of 104,328 kg (230,000 lb). The maximum CTOL gross weight of the YC-14 is 107,503 kg (237,000 lb).

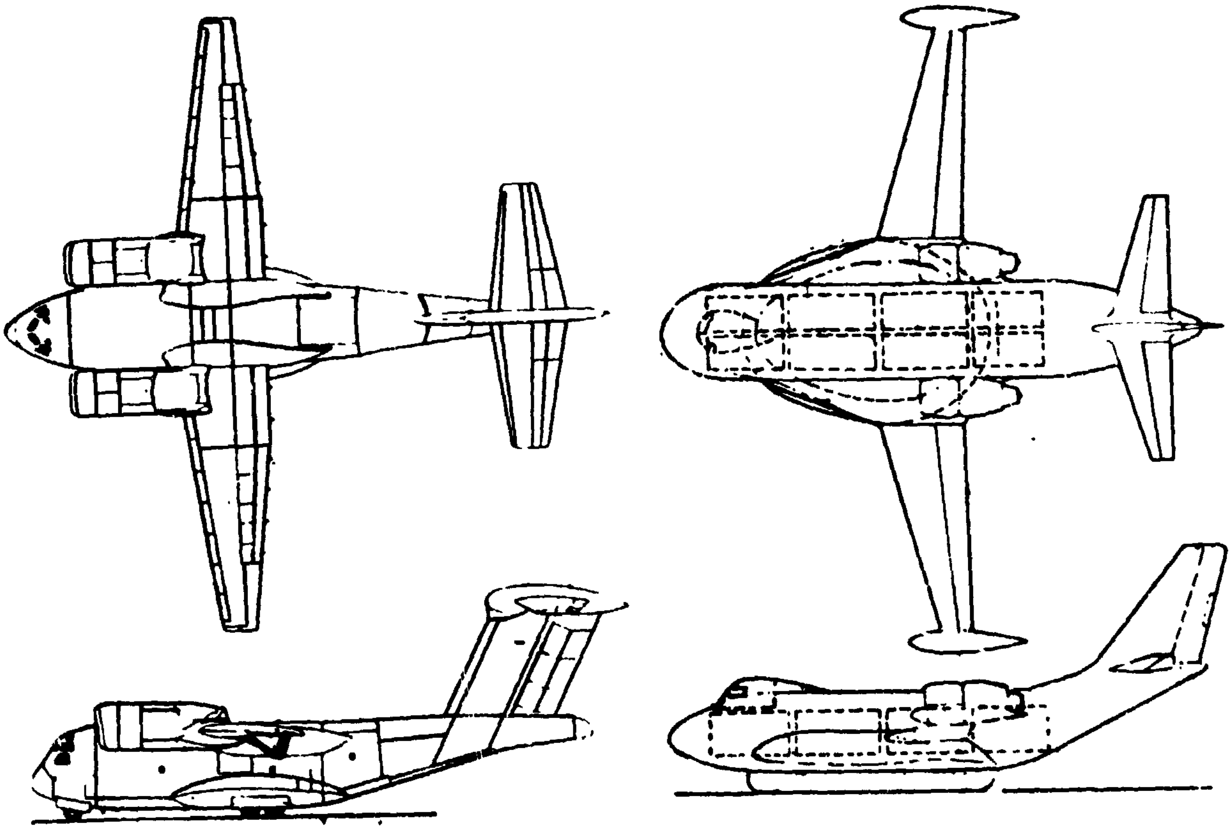

Figure 30. Size Comparison of YC-14 with Medium Amphibious Transport ACLG Concept

At 230,000 lb, the MAT fails to take advantage of the increased takeoff acceleration distance relative to wheelgear which it should be permitted to use because the air cushion makes the longer distance so much easier to provide, especially over water, and which will increase productivity. With the ACLG, STOL is not an objective. A maximum gross weight of 158,760 kg (350,000 lb) was therefore chosen. At this weight, the momentary low-speed 18.5 km/hr (10 kt) wave drag peak over water is about 2/3 of the available engine thrust and emergency floatation is also satisfactory. The estimated

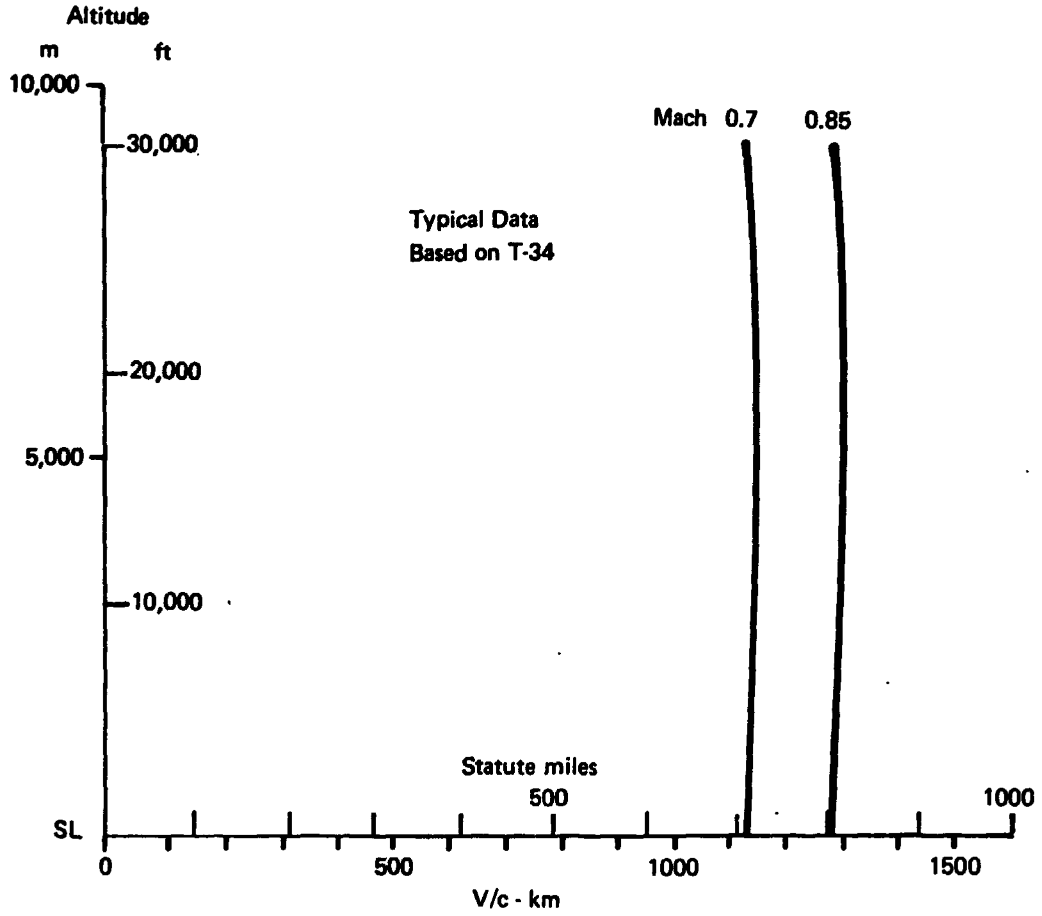

Figure 31. Variation of Range Factor (Thrust Horsepower per Pound of Fuel) with Altitude

waterlines floating cushionborne and air cushion off are shown in Figure 28. Floating cushion-off in the water at full gross weight will not be a normal operation. Wing loading is 693 kg/sq. m (142 lb/sq. ft), takeoff acceleration distance to rotation speed is 2286 m (7500 ft), climb minima are satisfactory and initial cruise altitude (at M = 0.75) is approximately 9,449 m (31,000 ft). Engine specific consumption per thrust horsepower (c/V) varies only slightly with altitude at constant Mach number so that lower cruise altitude is not disadvantageous. Figure 31 plots typical lb/thrust horsepower/hr versus altitude at two values of Mach number. The ACLG weight including the incremental power plant weight for fan air bleed is estimated to be 454 kg (1000 lb) less than the YC-14 gear.

The graphs in Figures 32 and 33 compare range-payload and operating cost (using ATA method) of the MAT and YC-14. Typical current air freight rates for large shipments (908 kg, 2000 lb or greater) are also shown. Productivity, expressed as a specific work capacity in ton-miles per annum per dollar of airplane first cost, is also compared. This can be multiplied by profit margin to obtain an ROI figure. The cost of the MAT was arrived at by ratioing empty weights.

This comparison principally shows the advantage in range-payload consequent on providing a long field length, which the AMST was designed to avoid. A wheeled aircraft designed for and provided with the same field length as the MAT concept would recover most of the differential shown. What then needs to be determined is the extent to which the requirement for STOL can be compro-

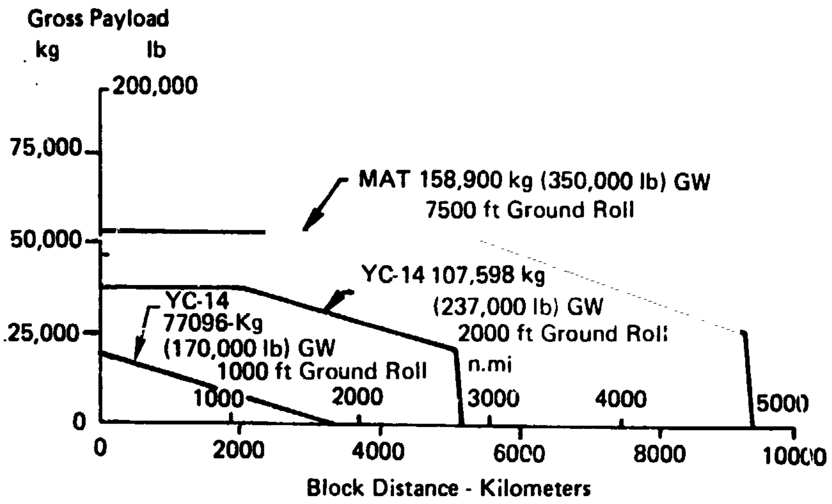

Figure 32. Estimated Range-Payload Comparison of MAT with YC-14

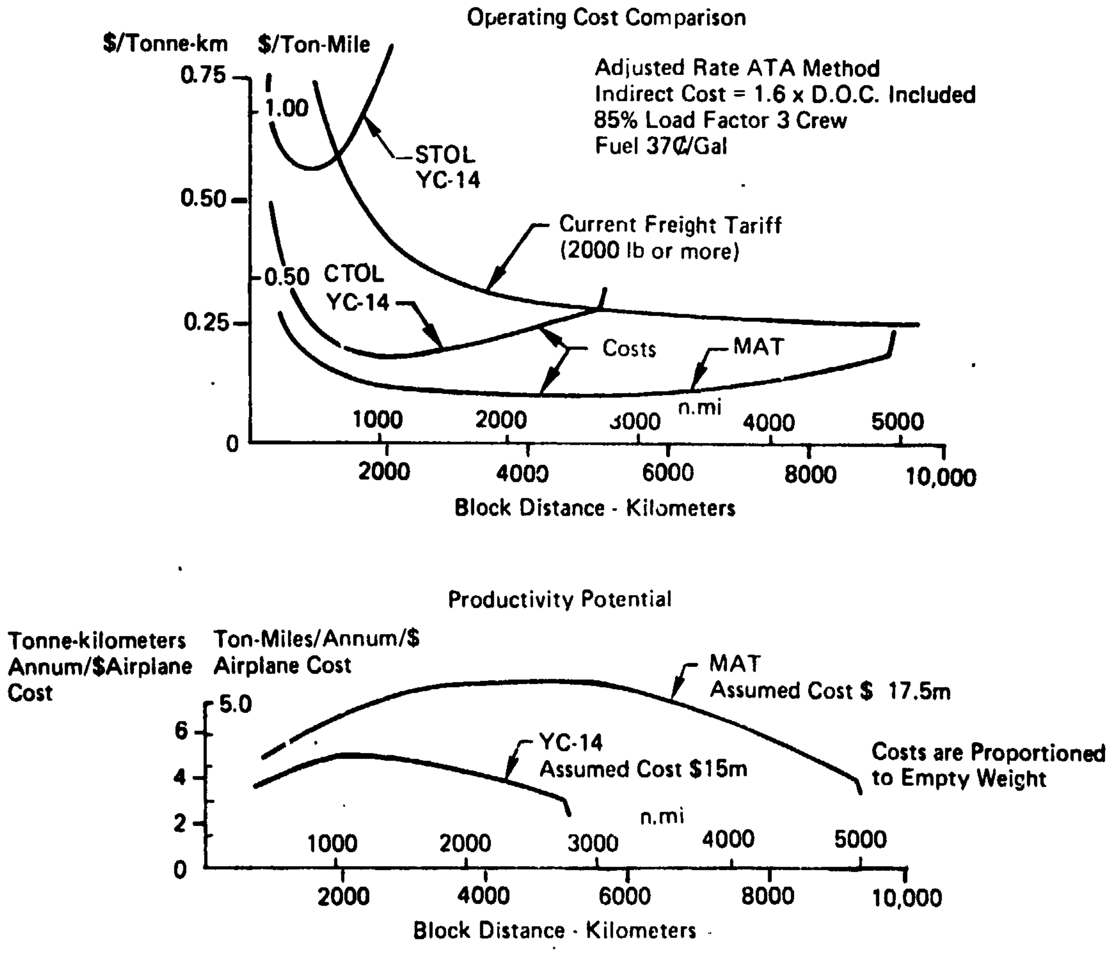

Figure 33. Cost Comparisons

mised by the ACLG capability for all surface landing. The runway distance (as opposed to the over-water distance or other clear space) which the ACLG aircraft is entitled to use should also be greater than for wheel gear, but a quantitative assessment is difficult. Survey of the underruns/overruns available at a sampling of U.S. airports shows that a 20% landing distance handicap for wheel gear may not be unreasonable. At some places, regular use of such overrun may be unacceptable - for example for noise reasons - but at others, distance available to the ACLG aircraft can be increased at low cost compared to making similar provisions for wheeled aircraft. If generally applicable, such an increment would have a large effect on overall economy.

Commercial market potential for this type aircraft is dependent on a developing air cargo business and could be large. Military potential could also be large. It appears to depend on the increase in effectiveness consequent on all surface capability, particularly amphibious. Currently (in the light of conventional amphibious landing gear) there is no military requirement for seaplanes or amphibians.

The potential is far term due to the technology development needed and because of present emphasis on possible AMST production. It would require acceptance of ACLG as a viable alternative to STOL.

Large Multi-Mission Amphibian (LMA)

Description – The large multi-mission amphibian is illustrated in Figure 34. It is projected as a very large commercial/military freighter and has been derived from a Boeing preliminary design called the 759-182A which was a comparator in the study of distributed load freighters (DLF) of Reference 8.

The approach taken was to modify the given 759-182A design minimally, for an ACLG installation similar in concept to the ACLG family of transport designs. The wide body (with greater fuselage lift) suggested containers be carried athwartships. This permits side-door loading, which is lighter in weight. Alternatively if compatibility with ground rail loading is necessary, five abreast could be carried in a three-lobe structure. The double-lobe cross section is shown in Figure 35. Each side is capable of accommodating a 3.66 m x 3.66 m (12 ft x 12 ft) rectangle. Alternative loads to freight containers have not been considered in detail but military payloads or passengers could evidently be accommodated. The highly-swept, thick-section inner-wing and also 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 problem at very large size, and is one reason for the DLF approach.

The 759-182A 3-view is compared with the LMA design 3-view in Figure 36. Both aircraft are powered by CF6-50 engines of approximately 23,014 kg (52,500 lb) SLS thrust each. Because the LMA is designed to be amphibious, the engines are located two 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 as described and shown for the MAT. The LMA is regarded as principally employing water for takeoff and landing but always loading and unloading on shore as shown in Figure 34. An aircraft this size, with a 2.0 to 2.5 m (7 to 8 ft) deep air cushion trunk will have no difficulty on 0.9 to 1.2 m (3 to 4 ft) waves. Generally, the ACLG aircraft will be able to use rougher water than the same sized flying boat hull. Rough water model tests were conducted by NASA on an XC-8A model landing on regular 5 ft. full-scale waves, reported in Reference 7. Table XII is taken

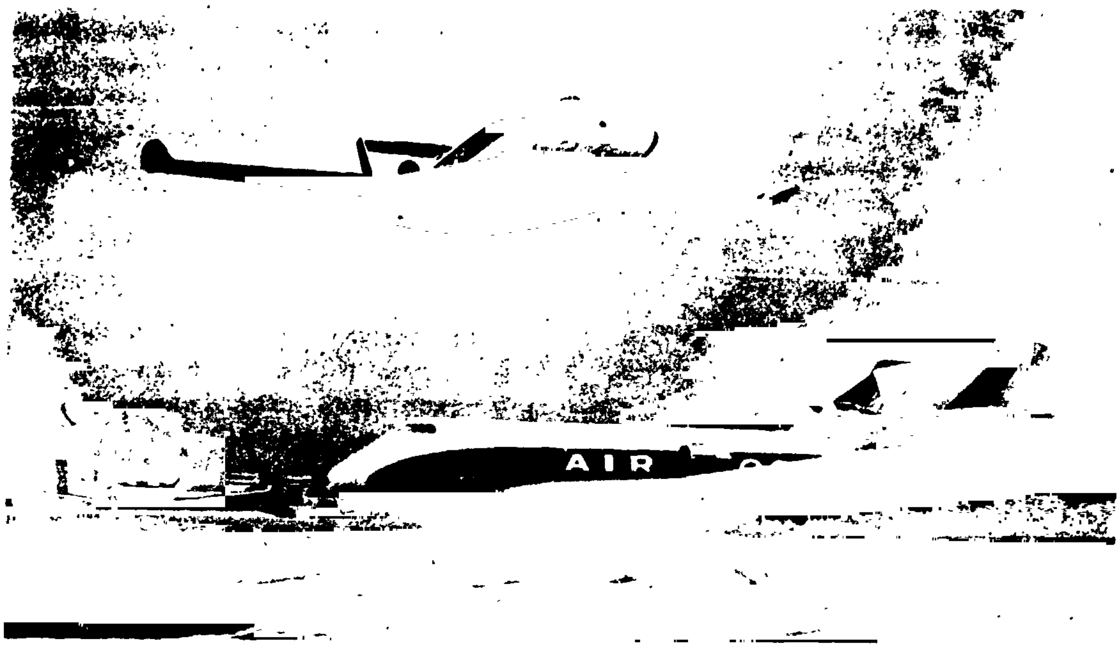

Figure 34. Large Multi-Mission Amphibian (LMA)

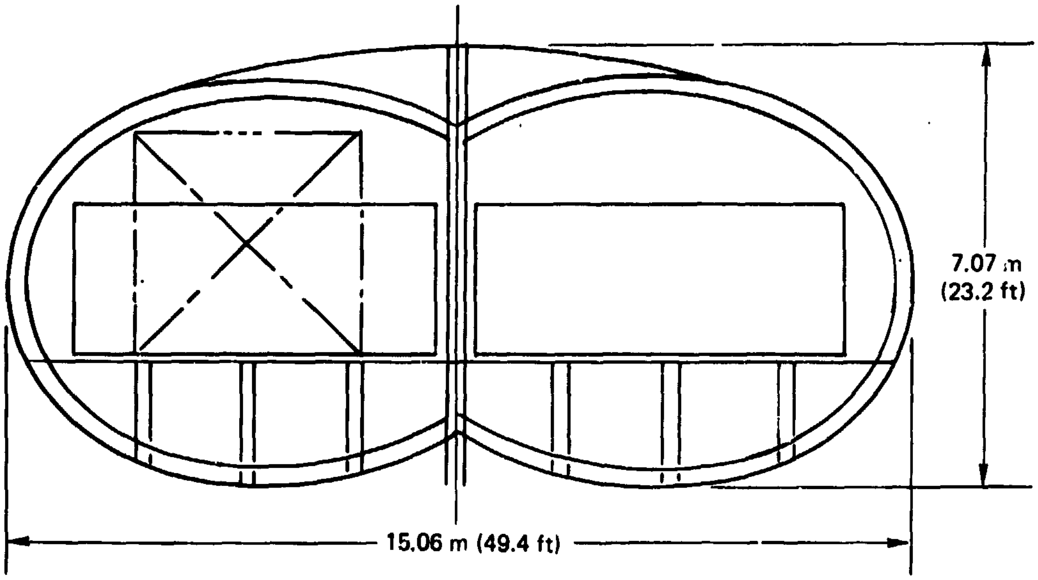

Figure 35. Typical LMA Cross Section

from Table III of the reference. Peak wave drag occurs at approximately 22 km/hr (12 knots) and is equal to 45% of takeoff thrust, decaying rapidly above this speed.

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 XIII The ACLG weight is further broken down in Table XIV. 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 is notable. The LMA is approximately a 3:1 scale up from the XC-8A Buffalo, based on significant dimensions, therefore, a cushion pressure three times greater would be expected. But, due to the large area cushion of the LMA the

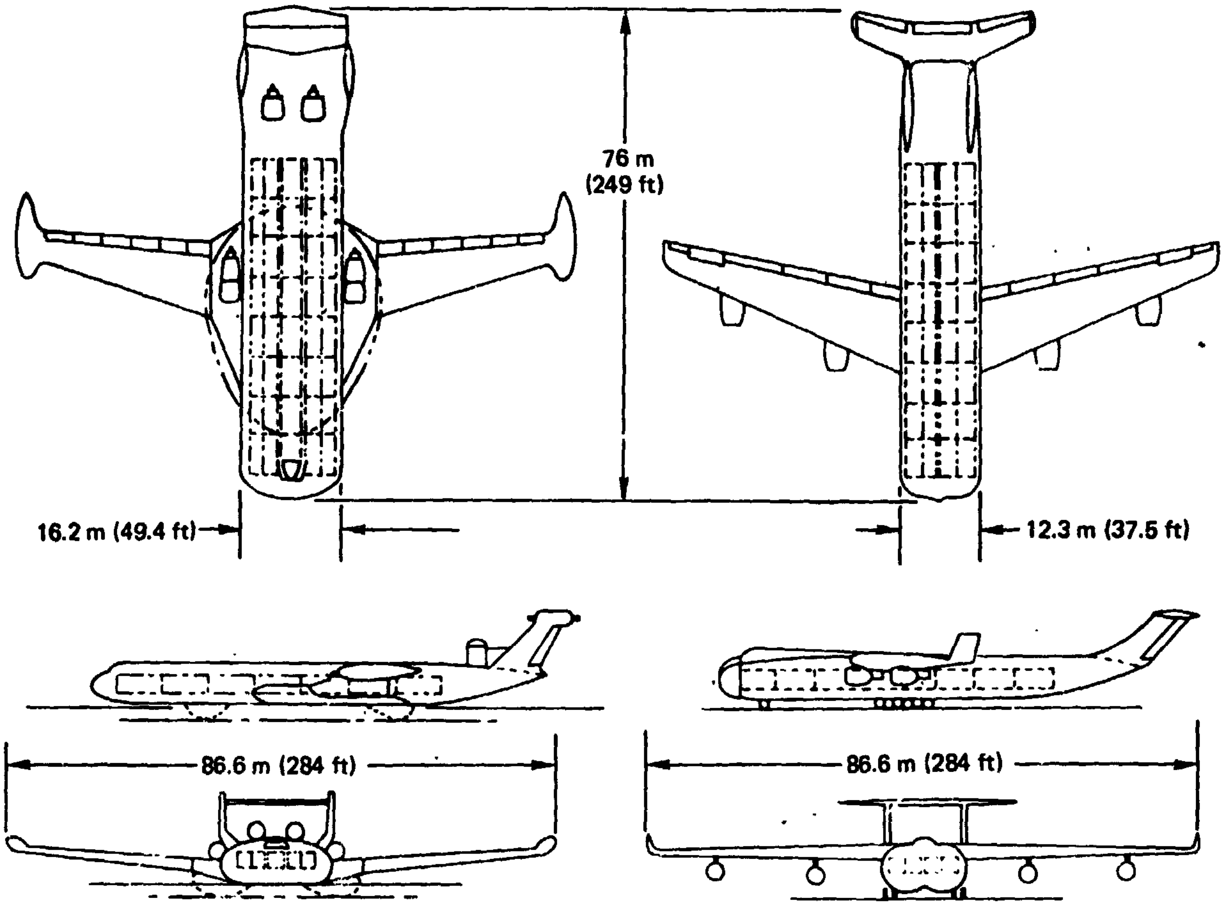

Figure 36. LMA/759-182A Comparison

TABLE XII
1/10 SCALE C-8 MODEL WATER LANDING TESTS, SIMULATED 5 FT WAVES

Full Scale Vertical Sink Rate		Maximum Vertical Acceleration at cg
m/sec	ft/sec	g Units
4.1	13.6	4.24
3.8	12.3	3.72
3.5	11.1	2.62
3.5	11.1	3.00

TABLE XIII
LMA/759-182A WEIGHT BREAKDOWN

	Boeing 759-182A		LMA	
	Weight - kg (lb)	**% GW**	**Weight - kg (lb)**	**% GW**
Structure Total	133,221 (293,700)		139,675 (307,928)	
(Landing Gear)	((56,880))	5.5	((41,278))	3.4
Propulsion	17,835 (39,320)		17,835 (39,320)	
Fixed Equipment	21,636 (47,700)		24,310 (53,595)	
Paint and Options	2,395 (5,280)		2,517 (5,550)	
Empty Weight	175,088 (386,000)		184,339 (406,393)	
Gross Payload	194,774 (429,400)		243,468 (536,750)	
Zero Fuel Weight	369,863 (815,400)	78.8	427,807 (943,143)	77.6
Maximum GW	469,623 (1,035,330)		551,120 (1,215,000)	

TABLE XIV
LMA
ACLG WEIGHT BREAKDOWN

Summary	kg (lb)	
Elastic Trunk	10,024 (22,100)	
Cushion Brake System	3,039 (6,700)	
Parking Skids	2,756 (6,075)	(0.5% W_G)
Trunk Attachment	1,929 (4,253)	
CF6-50 Modification	975 (2,150)	(12.5% W_E)
	18,723 (41,278)	
Comparative Data		
	XC-8A	LMA
Trunk Outer Radius R_{1max}, m (in.)	0.64 (25)	3.05 (120)
Trunk Pressure P_T, Pa (Psf)	16,375 (342)	23,461 (490)
Cushion Pressure P_C, Pa (Psf)	8,140 (170)	11,731 (245)
Trunk Material Tension, N/m (lb/in.)	10,683 (61)	71,452 (408)
Air Cushion Perimeter, m (ft)	19.8 (65)	75.9 (249)
Wave Drag/Gross Weight Dw/W	0.218	0.071
Displacement, m (ft)	0.82 (2.7)	1.19 (3.9)
Cushion Length, m (ft)	8.5 (28)	40.4 (132.5)

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 wave 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 provide the basis for a confident trunk weight estimate.

Analysis – The 759-182A design already capitalizes on the economic advantages of long takeoff using a field length of nearly 3658 m (12,000 ft) for a very high (41%) payload fraction at a moderate range of 6,667 km (3600 n. miles). It has a static thrust/weight 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 in Table XV, comparing the 759-182A with the LMA and also with the 747-200F. Part of the advantage in payload/gross weight for both the 759-182A and the LMA is due to reduced structure weight assumptions consequent on technology development anticipated before 1995, which is the earliest date envisaged for such aircraft. The increased payload/gross weight fraction is accompanied by a reducing static thrust to weight ratio as well as an increased field length. This will result in a lower initial cruise altitude capability (ICAC) but is not significant as far as cruise efficiency is concerned.

TABLE XV
COMPARISON OF PERFORMANCE CHARACTERISTICS OF THE LMA DESIGN WITH TWO BOEING AIRCRAFT

Customary Units	**Boeing 747-200F**	**Boeing 759-182A**	**LMA**
Gross Weight (lb)	820,000	1,035,300	1,215,000
SLS Thrust (lb)	210,000	209,200	210,000
T/W	0.256	0.202	0.173
TOFL (ft)	10,250	11,900	15,600
Wing Loading (lb/ft^2)	149	122	133
Gross Palyoad (lb)	260,000	429,400	536,000
PL/GW	0.32	0.41	0.44
Cruise L/D	18.1	21.58	20.4
Range (nmi)	3,200	3,600	3,600

S.I. Units	**Boeing 747-200F**	**Boeing 759-182A**	**LMA**
Gross Weight (kg)	371,952	469,612	551,124
SLS Thrust (N)	934,080	930,526	934,080
T/W	0.256	0.202	0.173
TOFL (m)	3,124	3,627	4,755
Wing Loading (kg/m^2)	728	596	649
Gross Payload (kg)	117,935	194,776	243,130
PL/GW	0.32	0.41	0.44
Cruise L/D	18.1	21.58	20.4
Range (km)	5,926	6,667	6,667

The increased takeoff field length 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 17.5% increase of gross weight compared with the 759-182A and results in a payload fraction of 44%, accommodating 40 instead of 32 6078 kg (13,400 pound) 2.44 x 2.44 x 6.1 m (8 x 8 x 20 ft) containers, with structure weight and drag consideration for the increased fuselage capacity and the substitution of ACL gear for wheelgear.

The waterfront basing made possible by the ACLG would permit operation of such a large aircraft without the same domino effect on facilities consequent on introducing a new land plane of the same size. The recent NASA Cargo Logistics Airlift System Study (Reference 9) established that present runways, taxiways, parking spaces, etc., at major airports are sized to accept the 747 or smaller aircraft. Notwithstanding this, the low footprint pressure of the ACLG aircraft and the wide area over which the load is spread may permit operation into fields currently unable to accept even the 747. The basing options require more detailed study than was feasible for the present report.

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 Figure 37. The fuel price used was that assumed for the 759-182A analysis and is considered low at this time but changing it will hardly affect the comparison. A.I.C. represents profit or return on the airplane investment. In Figure 37, cost is shown including A.I.C. as a fixed profit percentage. In Figure 38, the elements of operating cost are broken down and the effect of a reduced operating cost on profitability at equal tariff rate is displayed. Figures 37 and 38 show only direct operating cost. Indirect cost must be added. This may alter the comparison greatly, since it is possible that con-

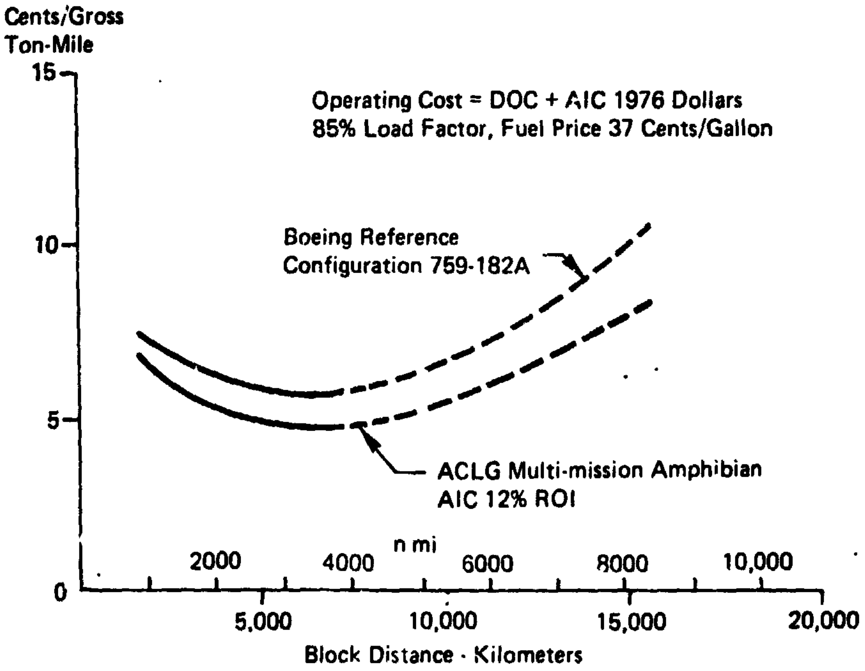

Figure 37. Operating Cost Comparison

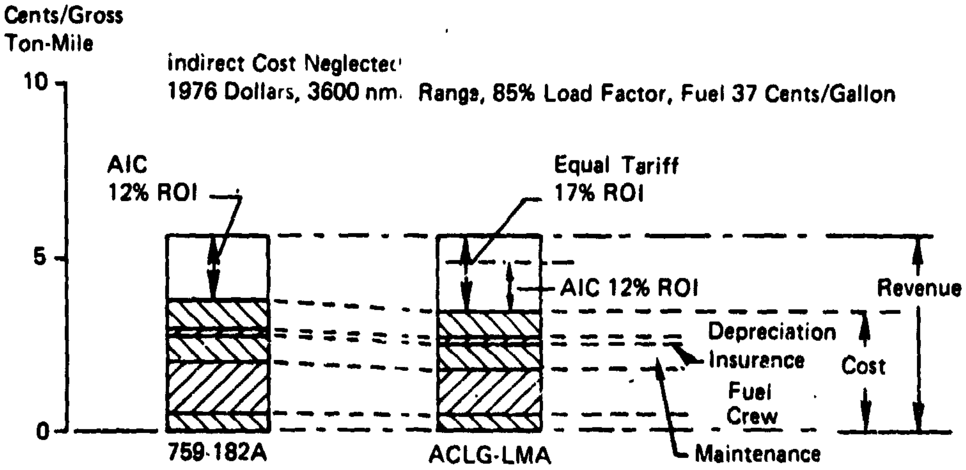

Figure 38. Productivity Comparison

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

Off-Runway Tactical Fighter (OTF)

Description A lightweight, subsonic (M = 0.9) design was chosen for this example to minimize technology risks. Its major role would be ground attack or primary jet trainer. Primary armament consists of one Oerlikon 30 mm machine gun with 625 rounds ammunition.

In order to provide good low altitude duration and enough range to patrol over significant segments of a 900 km (560 mi.) front, a high bypass turbofan Lycoming (ALF 502) is selected as the power plant which permits use of the same type of lightweight bypass-fan bleed system described for the SHA, etc. A similar low-speed cushionborne yaw control method, consisting of a fan thrust reverser/deflector, functionally split on the centerline and operated differentially could be used.

The design is outlined by the 3-view Figure 39 and principal characteristics in Table XVI and is illustrated by the artist's concept of Figure 40. The 3-view shows the gun and engine in silhouette. Another advantage of the ACLG which is especially useful in this application, is its internal volume economy. With no nosewheel or main gear to house, the installation of this large gun is much easier.

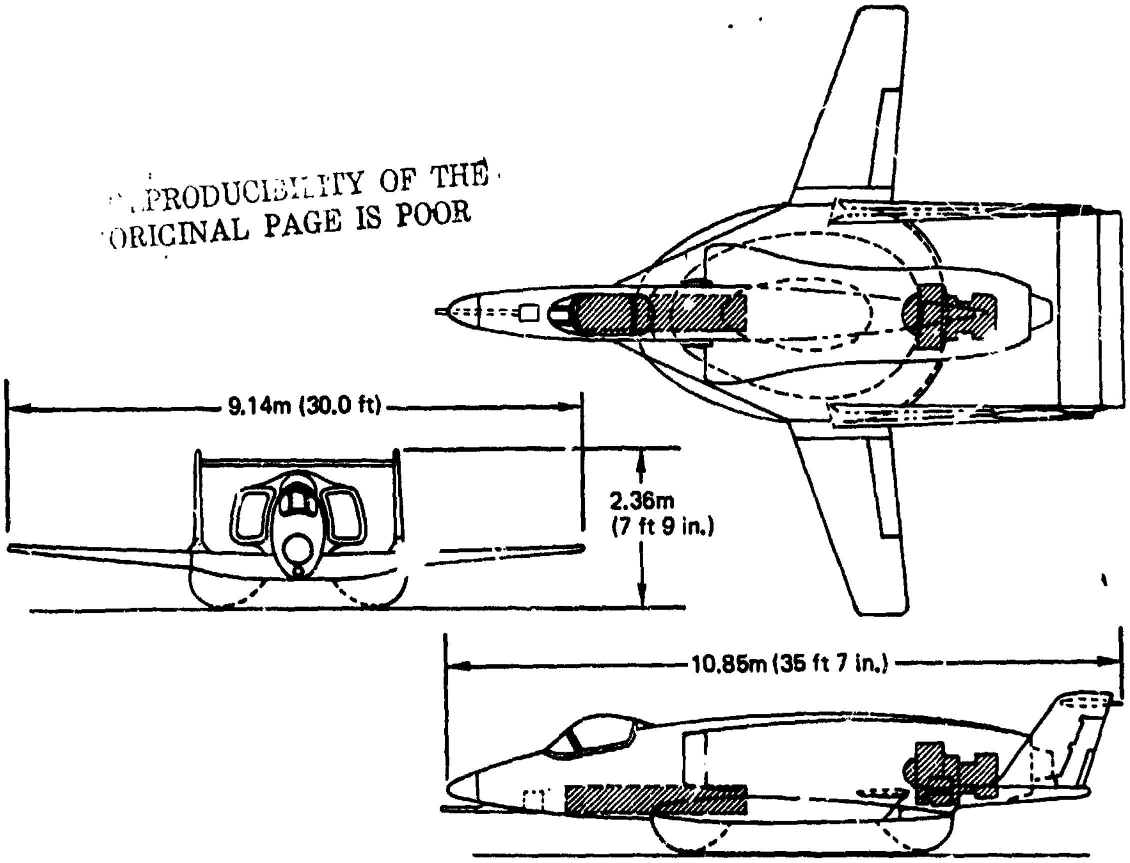

Figure 39. Off-Runway Tactical Fighter

TABLE XVI
OTF DESIGN PRINCIPAL CHARACTERISTICS

Gross Weight	6,350 kg (14,000 lb)
Engines	1 Lycoming ALF 502
Stratic T/W	0.55 (without Bleed)
Cushion Area	10.9 m^2 (117 sq. ft)
Cushion Pressure	5,746 Pa (120 lb/sq. ft)
Cushion Perimeter	12.1 m (39.7 ft)
Wing Area	15.8 m^2 (170 sq. ft)
Wing Loading	400 kg/m^2 (82 lb/sq. ft)
Cushion Airflow	25.9 kg/sec (57 lb/sec)

Figure 40. OTF Artist's Concept

Analysis – It is generally conceded that a CTOL aircraft will be lighter in weight and less costly than a V/STOL aircraft designed to perform the same mission. The OTF will permit the CTOL mode of operation without the associated requirements for a prepared airstrip, and is thus an alternative to V/STOL, and should be compared with a V/STOL aircraft such as the AV-8B from the performance viewpoint.

Comparison of the OTF with the AV-8B (Harrier) is invalid because the OTF is not designed to carry the same payload.* Range, endurance and speed envelope figures calculated for the OTF are plotted in Figures 41 and 42. Weight and performance summaries are given in Tables XVII and XVIII. There are a number of jet-trainer/light attack aircraft on the market worldwide, indicating intense interest in this size and type of aircraft internationally. Table XIX compares principal characteristics of those in the same class as the OTF design.

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* The Navy is conducting a close air support ACLG concept design study, carrying a comparable payload to the AV-8B for comparison with VTOL, RFP No. N2269-78-R-0383.

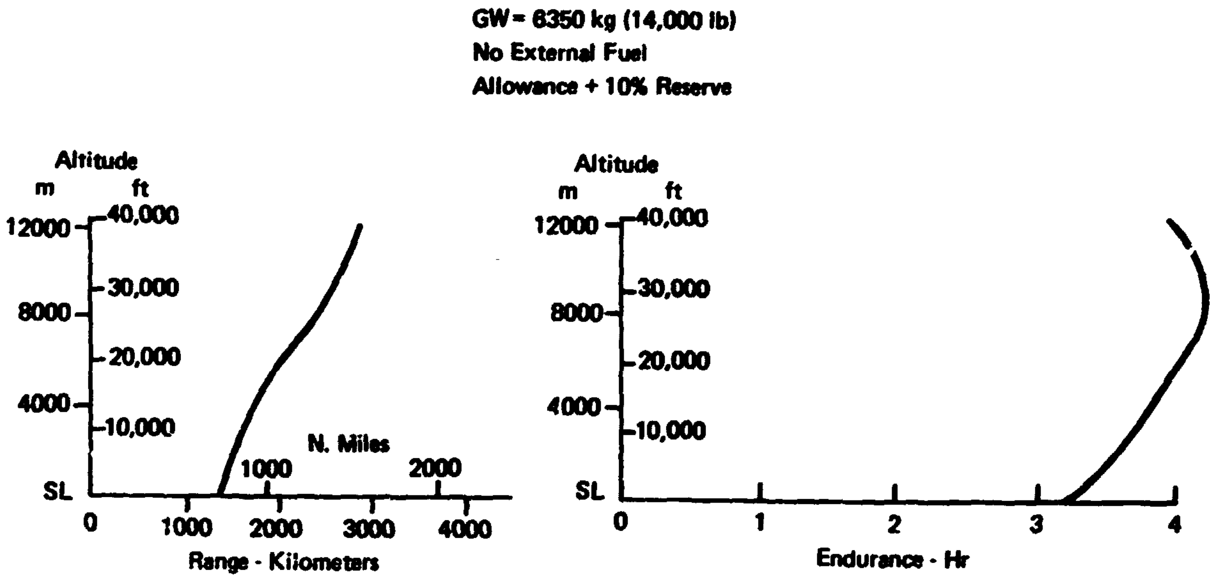

Figure 41. OTF Range and Endurance

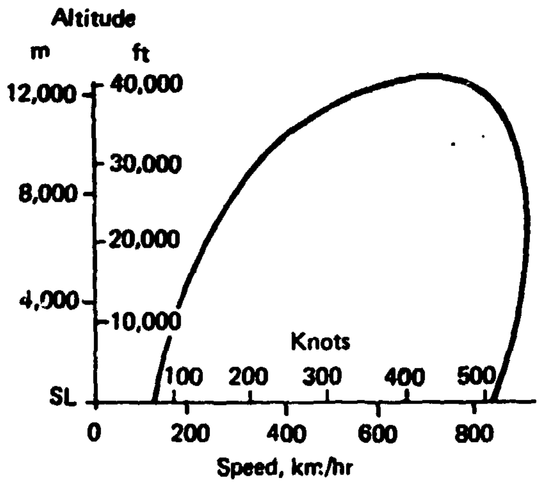

Figure 42. OTF Speed Envelope

TABLE XVII
OTF WEIGHT SUMMARY, KG (LB)

Structure (including ACLG 487 lb)	1,588	(3,501)
Power Plant	756	(1,667)
Systems	1,110	(2,447)
Empty Weight	3,454	(7,615)
Armament	1,030	(2,270)
Crew	98	(215)
Fuel and Oil	1,769	(3,900)
Gross Weight	6,351	(14,000)

Incorporation of ACLG into this type of low-cost, light-weight ground attack aircraft would provide a considerable increase in basing flexibility adding significantly to its operational utility.

TABLE XVIII
OTF PERFORMANCE AT 6,351 KG (14,000 LB) GW (NO EXTERNAL FUEL)

Maximum range with allowances +10% reserve fuel, km (nmi)	2,971	(1,604)
Maximum Endurance, hr		4.25
SL Rate of Climb, m/min (ft/min)	2,011	(6,600)
Cruise Ceiling, m (ft)	12,497	(41,000)
Cruise Speed, km/hr (kt)	963	(520)
Takeoff ground run, m (ft)	777	(2,550)
Takeoff to 50 ft, m (ft)	1,128	(3,700)

TABLE XIX
LIGHT TRAINER/STRIKE AIRCRAFT

Designation	Alpha-Jet	MB-339	A.37B	105 G	Hawk
Manufacturer	Dassault/Dornier (France/FRG)	Aermacchi (Italy)	Cessna (US)	Saab (Sweden)	Hawker Siddeley (UK)
Gross Weight, kg (lb)	7,250 (15,983)	5,895 (13,000)	6,350 (14,000)	6,500 (14,330)	7,755 (17,097)
Power Plant	Larzac 04-05 (Two)	Viper 632-43 (One)	GE J85-17-A (Two)	GE J85-17-B (Two)	Adour 151 (One)
Max Thrust kN (lb) (Total)	26.48 (5,952)	17.79 (4,000)	25.4 (5700)	25.4 (5,700)	23.75 (5,340)
Max Speed km/hr (kt)	1,000 (540)	898 (485)	816 (440)	970 (523)	997 (538)
Number Ordered/ Built	438	100	564	190 +	226

Remotely Piloted Vehicle (RPV)

Description – The advantages of ACLG for takeoff and for recovery of an RPV have been studied in detail in the Air Force's Jindivik retrofit program. The air cushion will provide a safe recovery mode at much lower cost than the Mid Air Retrieval System (MARS) currently employed, using helicopters.

The application to the Jindivik is shown in the 3-view and illustration - Figures 43 and 44. A simple powering scheme was developed using engine bleed air to drive a small turbine fan. Directional control cushionborne was achieved by a propulsive jet deflector using Coanda effect operating on a section of the jet stream, a system requiring no moving parts in the hot gas section.

For the basic landing system, an inelastic trunk was used, furled within a tight sheath as shown in Figure 44. For landing, the trunk inflates from within and spreads the sheath automatically. This is the basic system. To add a takeoff capability, a secondary dropaway trunk was used, seen on the ground also in Figure 44. This is released as soon as possible after takeoff and recovered. Damage to the trunk by dropping it is unlikely because of its flexible material construction so that very high percentage reuse is probable.

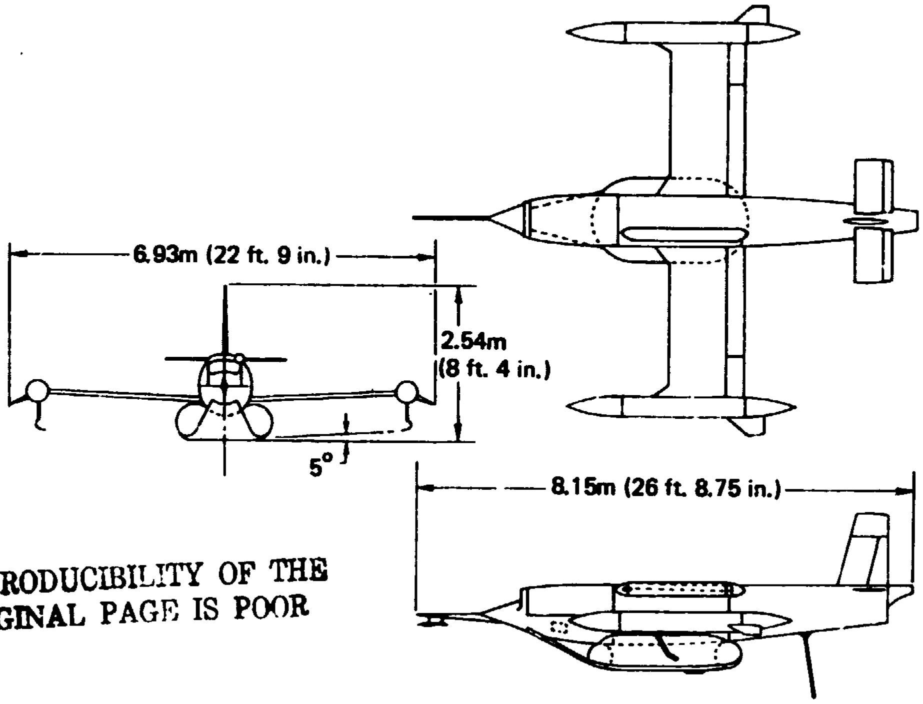

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Figure 43. Jindivik 3-View

Figure 44. Jindivik ACLG System

Principal characteristics are shown in Table XX.

TABLE XX
ACLG JINDIVIK PRINCIPAL CHARACTERISTICS

Gross Weight, kg (lb)	1,452	(3,200)
Landing Weight, kg (lb)	1,179	(2,600)
Span (Overall), m (ft)	6.93	(22.75)
Air Cushion Area, m^2, (ft^2)	1 74	(18.7)
Air Cushion Pressure at Landing Weight, Pa (lb/sq ft)	6,703	(140)
Air Cushion System Weight, kg (lb)	46.3	(102)

Analysis – RPV recovery costs by ACLG were studied and compared with the mid air retrieval system in Reference 10. A summary of the results is given in the chart, Figure 45. In this study, the application example was the Ryan 147-G.

Assumptions: 1000 Recoveries; 1 Recovery/Day
Vehicle Life = 20 Flights
Installations and Modifications during Vehicle Manufacture
*ACLS used Grd Based Landing Aids for Night and All Weather Operations

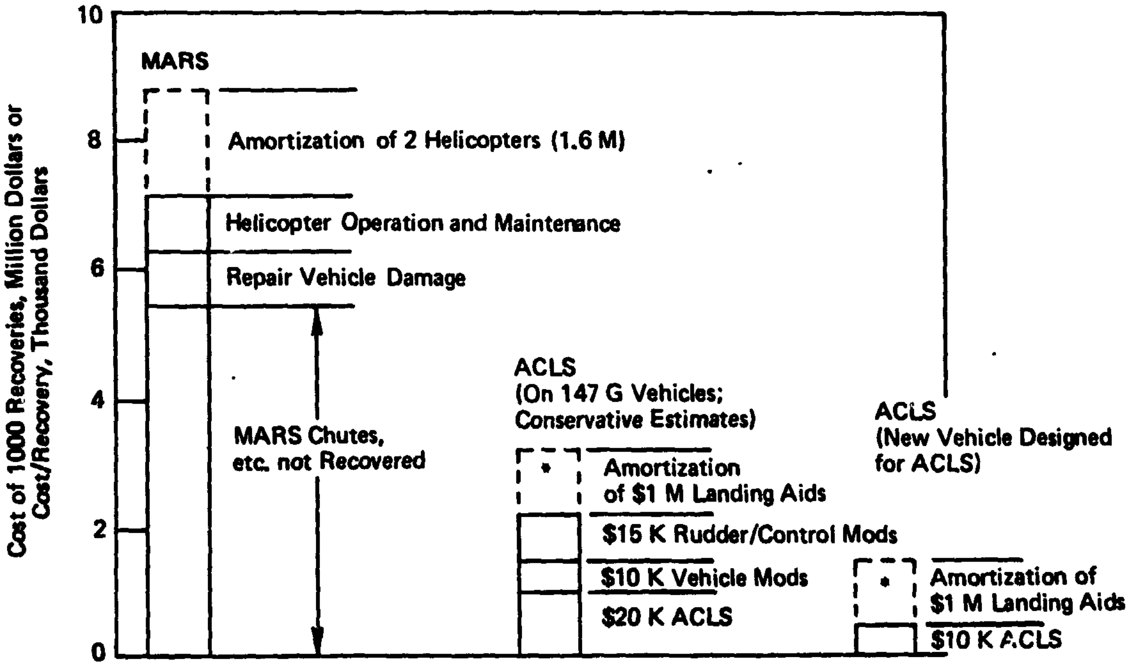

Figure 45. RPV Recovery Costs

The maneuver tolerance of the ACLG is particularly important in this application, including crosswind, extreme attitudes and impact damping. In addition, the suction braking method can usefully be applied to stop the vehicle in a small distance. There is an accompanying potential for using steep-approach landing and rapid deceleration with vertical acceleration factors higher than could be accepted by a manned aircraft for RPV recovery in small spaces, such as the decks of non-aircraft ships.

The market potential for the RPV application is considered far term because the fundamental need for this type military aircraft has not been widely accepted. The life cycle cost advantage that

ACLG technology offers an advanced RPV operational system was defined in the Boeing study of Reference 11.

Wing In Ground Effect (WIG)

Description – Wing in ground effect studies related exclusively to overwater operation have recently been conducted by the Navy (Reference 12).

A principal advantage of the WIG concept is the realization of very high lift to drag ratio while cruising in ground effect. This may be achieved if the height above the surface is significantly less than the wing span and if end plates which project downwardly to the surface are used. This suggests a rectangular air cushion with sidewalls could be incorporated with the WIG.

A reduced requirement for propulsive thrust with resulting improvement in overall efficiency can be achieved because of the WIG's high L/D in ground effect, the long takeoff available over water and the ACLG's ability to make safe emergency landings in any clear area. An exploratory type aircraft with a single engine and installed thrust/weight ratio of 0.15 is, therefore, projected to illustrate this possibility.

A preliminary conceptual design drawing is shown in Figure 46, with principal characteristics in Table XXI. This design features a rectangular planform with semi-rigid retractable sidewalls and

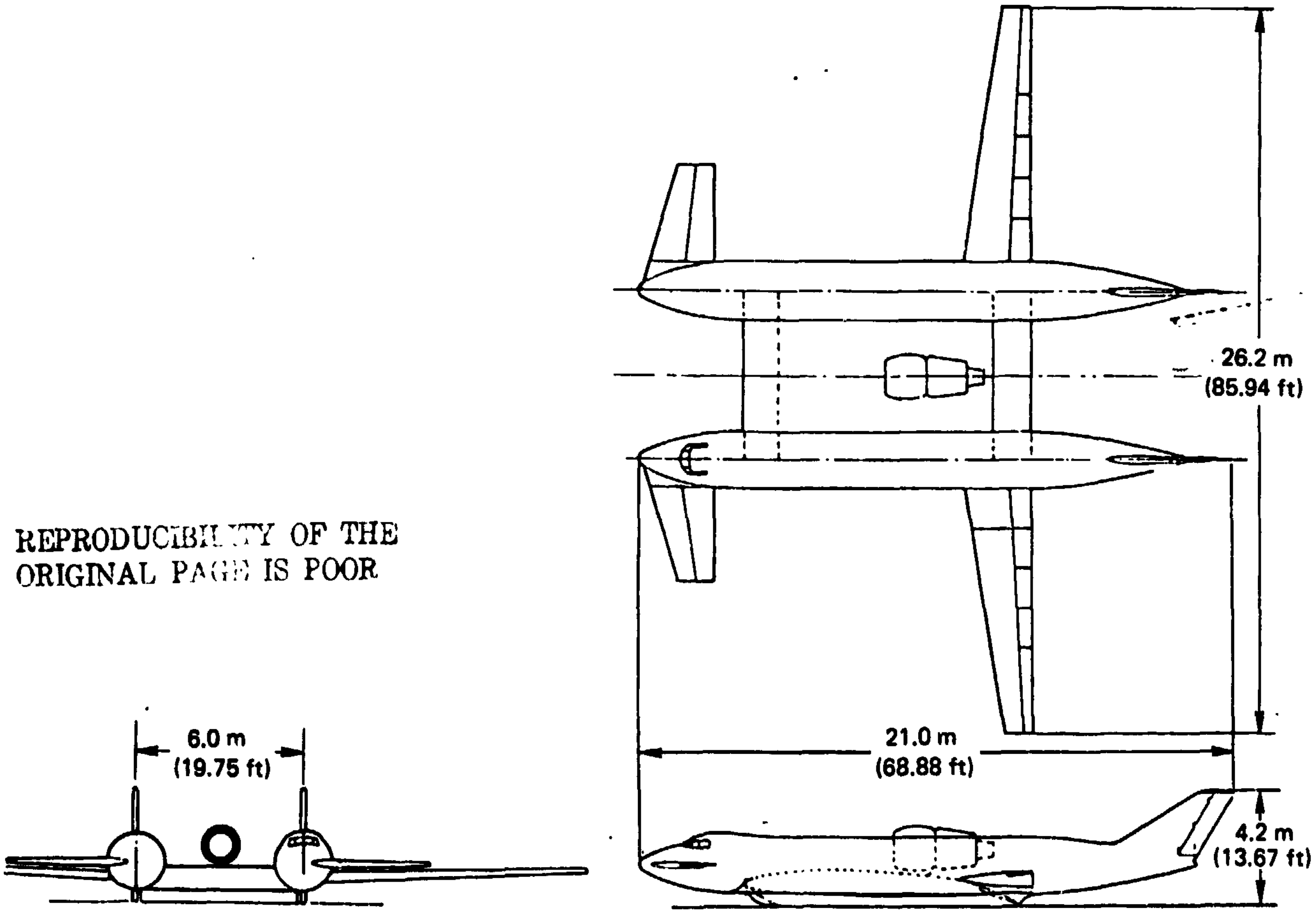

Figure 46. Preliminary Conceptual Design of WIG

TABLE XXI
WIG CHARACTERISTICS

Characteristics	
Gross Weight	27,215 kg (60,000 lb)
Wing Area	97.5 m^2 (1,050 sq. ft)
Wing Span	26.2 m (85.94 ft)
Length Overall	21.0 m (68.88 ft)
Height Overall	4.2 m (13.67 ft)
Cushion Area = S_c	63.5 m^2 (683.6 sq. ft)
Cushion Pressure = P_c	4,213 Pa (88 lb/ft^2)
Power Plant - One TF34 with Fan Bleed	

hinged inflated flexible seals fore and aft. Air cushion powering by fan bleed similar to previous concepts is proposed.

Analysis – The principal advantage of integrating ACLG into the WIG concept is to allow beaching or land operation. A second advantage is that the ACLG seals and end plates can be naturally shock absorbing, therefore no large structure weight penalty is needed to protect against rogue wave impacts during overwater cruise.

The market potential for the WIG application is considered far term because the fundamental need for this type of aircraft has not been widely accepted in the United States. Almost the entire worldwide research and development in WIG aircraft is being conducted in the Soviet Union. The Admiral of the Fleet of the Soviet Union, S.G. Gorshkov, is reported to have indicated that WIG vehicles will play a significant future role in various naval missions, to include ASW, Reference 13.

SURVEY AND EVALUATION

A survey of potential ACLG use was conducted by soliciting the views of planners, airframe manufacturers, civil operators and government agencies on the subject. This was performed in two stages. First, during the selection of the candidate designs, discussions were held with certain key organizations to guide this selection. Then a preliminary brief was prepared and circulated to about 60 recipients requesting comments. Numerous valuable comments were received and are addressed in this report, both by modifying the designs shown or amplifying design information, and by adding a technology scenario and conclusions based on the responses. The author is greatly indebted for these comments as is acknowledged elsewhere in the report.

The evaluation findings included in the circulated brief were generally concurred with and lead to the following comments on present market potential for ACLG technology.

1. ACLG could provide the following benefits to runway operations from present airports: (1) takeoff and landing safety in case of landing short, veering off, or leaving the end of the runway; (2) increased payload capability from making a longer takeoff run from presently available runway extensions, and possibly from reduced landing gear weight also; (3) easier opera-

tions from ice and snow cover; (4) capability of a very large aircraft (one million pounds or more) to operate on present airports with runways limited to 45.7 m (150 feet) wide and taxiways limited to 22.9 m (75 feet) wide. It is considered doubtful that these benefits would justify the technology investment required for an ACLG land transport aircraft.

2. Off-runway operations from roads or cleared fields could benefit from ACLG to some extent, but the new technology investment risk may not be warranted in view of other more conventional technologies such as soft, oversized tires or expandable tires. Small aircraft can more easily be fitted with large tires that give off-runway capability. As larger aircraft sizes are considered, the ACLG technology becomes more attractive.

3. Very large aircraft (one million pounds or more) can benefit substantially from ACLG in terms of weight savings, airport availability and airport construction costs. The deficiencies of tires on present day large aircraft are apparent from recent accidents. Although these problems can be solved, the basic inefficiency of supporting much larger aircraft on tires is recognized.

4. The most attractive general use for air cushion technology on aircraft is for amphibious and triphibious aircraft. No landing gear is available today that can provide an efficient way to operate from land, water, and snow. The result is inefficient operations using heavy and high drag combinations of wheeled gear, seaplane hulls or floats, and snow skis. Because of the constraints on wheel gear size and weight all efficient aircraft operations are conducted from paved runways. The number of landing sites available to an aircraft equipped with ACLG is very large. This new capability would have an enormous effect on certain future military and commercial operations.

Based on the above, these tentative conclusions are drawn regarding potential customers for ACLG aircraft:

1. The ACLG will find its initial use in foreign countries more than the U.S. The number of ACLG equipped aircraft that could be sold to foreign free world aircraft operators from 1990 on may exceed the ACLG aircraft sold in the U.S. by an order of magnitude. The growth of aviation worldwide is related to Gross National Product growth. The recent NASA CLASS study (Ref. 9) indicated, for example, that the ratio of all-cargo ton miles flown by 44 foreign airlines to that flown by U.S. international airlines should increase from 3.3 in 1977 to 6.2 in 1990. The worldwide use of ACLG is expected to be even higher in developing countries and areas of the world with a less developed airport system than the continental U.S. Interest in waterfront and similar off-runway operations with amphibious vehicles is more intense today in the USSR, Japan, Germany, United Kingdom, France, and Canada than it is in the U.S. Nevertheless, a U.S. lead role in the development and manufacture of ACLG aircraft is considered to be easily achievable at this time and also to be in the best national interest.

2. The best near term ACLG application is considered to be for a general aviation amphibian. Such an aircraft would have worldwide sales potential for private, government, and entrepreneur uses. Less technical development is needed for general aviation than for any other ACLG use on manned aircraft. Furthermore, additional development at small scale is a necessary preliminary to any similar large-scale application.

3. The U. S. Marines are potential customers due to their association with waterfront and with off-runway aviation. A lightweight, close air support aircraft is considered a good candidate for early technology development emphasis. A large worldwide market exists for a two-seat trainer/ground attack fighter, equipped with one or two turbofan engines. As a fighter the air-

craft would be equipped with one seat and an antitank gun. Runway denial is a serious concern for many Air Forces. The ACLG aircraft could be operated independently of paved surfaces.

4. The potential use of ACLG for other U.S. military missions is somewhat confused by presently defined roles and missions. Army aviation is considered the lowest priority application due to their current helicopter concentration. Air Force fighter use is considered long term because of the present production emphasis on F-15, F-16, and A-10. Air Force tactical transport use is considered quite attractive but far term because of the present emphasis on possible AMST production. Air Force strategic transport use is considered very attractive but also far term, due to the technology development needed and because of MAC's emphasis on the C-141 stretch, C-5 rewing and eventually a new C-XX conventional aircraft design which must have strong appeal to the U.S. scheduled airlines (who operate on assigned routes between existing airports). The basic interest by the U.S. Air Force in using water for a runway is recognized as very low and possibly it has to be a Navy mission.

The U.S. Navy Aviation, however, has primarily focused on operations of small aircraft from ships. As ships become smaller, the interest has moved to VTOL aircraft. Land based naval aviation has not been widely considered. Nevertheless, it appears at this time that enlarging the Navy's role and mission to consider land based waterfront aircraft operations of larger aircraft than can fit on ships may be as likely as expanding the Air Force's role and mission to use of water runways and waterfront basing. In either case, a basic modification of today's accepted roles and missions would be required to accept a weapon system with the basing versatility of the ACLG equipped aircraft.

5. The ACLG technology appears attractive for use on two new military aircraft concepts - the advanced remotely piloted vehicle (RPV), and the wind in ground effect (WIG). The Jindivik technology program demonstrated much of the low-cost, near-term ACLG technology with inelastic trunk materials that could be used for a large, turbojet-powered, land based RPV. The WIG equipped with ACLG would gain amphibious advantages and may use new ACLG concepts based on SES technology and possibly inelastic trunk materials. Both the RPV and the WIG uses for ACLG are considered lower priority now because the fundamental military need for these new aircraft has not yet been widely accepted.

Relative to the ACLG designs shown, the following opinion ratings are thought appropriate.

First Level Interest - Large multi-mission amphibian
General Aviation amphibian

Second Level Interest - Off-runway tactical fighter

Third Level - Medium amphibious transport

TECHNOLOGY DEVELOPMENT SCENARIO

Overview

The ACLG applications considered cover radically different aircraft types and fall into different categories defined by size, weight, wing loading, etc. Ten categories were established by NASA for study as shown in Table XXII.

TABLE XXII
CATEGORIES ESTABLISHED BY NASA FOR STUDY

	Aircraft Descriptions		ACLG Capability	
ACLG A/C Category	**Gross Weight 1000 lb**	**Other**	**Land Only**	**Amphib. or Triphibian**
1	Wt <50	Wing Loading <50 psf	X	
2				X
3	Wt <50	Wing Loading >50 psf	X	
4				X
5	50 <Wt <250	Wing Loading > 50 psf	X	
6				X
7	250 <Wt	Conventional Config.	X	
8				X
9	50 <Wt	*Unconventional Config.	X	
10				X

*(e.g., spanloaders)

In the study, it has become clear that in most cases except the dense aircraft examples of fighter and RPV, the added attraction of over water capability is available to a land only version, provided a suitable aircraft configuration is chosen (no underwing engine, etc.). Such a configuration may be required in any case for a land only version to avoid engine ingestion problems. The most attractive ACLG applications are thus all amphibious and even the fighter, though not truly amphibious (it will not float), can operate over water cushionborne.

A considerable ACLG technology base covering the analysis of landing dynamics, stability and control, and trunk stress strain and the synthesis of a trunk material system, and a braking system has been built up since the introduction of the concept in 1963, and its reduction to practice in 1967. But to proceed through major engineering development programs, further expansion of this base will be needed. In the following discussion, detail is given to the significant technology items in the current base and also the deficiencies recognized and problem areas foreseen. The development timetables required by NASA are then projected on the assumption that initial use will be for ACLG application which will entail only problems which are straightforward in solution. The timetables are generated from the two alternative readiness dates of 1982 and 1985 specified by NASA for Categories 1 and 2 aircraft (less than 22,680 kg (50,000 lb) gross weight and less than 244 kg/m^2 (50 lb/sq ft) wing loading).

Since it was determined that the technology requirements for providing a land only version are not necessarily less demanding than those for an amphibian, the ten categories have generally been considered as five pairs in developing the scenarios.

As an initial overview, the following Table XXIII gives a broad picture of previous and projected technology development, by identifying significant "design firsts". The eight study candidates are used to example the future.

TABLE XXIII
ACLG APPLICATIONS

Aircraft	ACLG Design Firsts
A. LA-4 1,134 kg (2500 pounds) Feasibility testing (1967-1968) Single reciprocating auxiliary engine driving fan	First ACLG - concept feasibility proven (elongated doughnut planform, with tail control in propeller wash) One way stretch trunk material Pillow brakes Two-way stretch trunk material Suction braking
B. XC-8A (Buffalo) 18,597 kg (41,000 pounds) Advanced development testing (1973-1974) Twin turboprop Twin auxiliary shaft turbines driving fans	Duplicate auxiliary engines, requiring trunk pressure control valves Replaceable trunk wear plugs Static floatation bladder parking Twin beta prop control
C. Jindivik Drone 1,452 kg (3,200 pounds) Exploratory development testing (1975) Single Turbojet Main engine compressor bleed air (dual mode)	Drop away takeoff, and prepackaged landing inelastic trunks (integral pressure vessels) ACLG air from main engine - air diverted directly for landing and via pneumatic driven fan for takeoff Cushion vent for distributed braking Inward air injection at trunk ground tangent Jet exhaust yaw control
1. General Aviation Amphibian (GAA) 1,633 kg (3,600 pounds) Business, private, civil government, and military use worldwide Single reciprocating Main engine hydraulic transmission driving fan	Ovoid planform under low wing, wide body. Wing-tip skids eliminated Variable displacement hydraulic pump for ACLG power Parking skids Long life elastic trunk (400 hours) Quick change trunk mounting
2. Light Amphibious Transport (LAT) 5,670 kg (12,500 pounds) Business, military, and civil government uses worldwide Twin turboshaft, single prop (twin pack) Main engines shaft drive fan	Shaft drive of fan from free turbine main engine
3. High Density, Short Haul Amphibian (SHA) 47,628 kg (105,000 pounds) Carry passengers to downtown waterfront sites in densely populated areas Three turbofans Main engine fan air (dual mode)	None Use OTF design (presumed to precede this) for ACLG power source and for high forward speed elastic trunk design; use scaled up GAA trunk planform

TABLE XXIII
ACLG APPLICATIONS (CONT'D)

Aircraft	ACLG Design Firsts
4. Medium Amphibious Transport (MAT) 155,759 kg (350,000 pounds) Carry military cargo or side by side 8 x 10 ft containers Twin Turbofan Main engine fan air (dual mode)	None - use scaled up SHA design
5. Large Multi-Mission Amphibian (LMA) 551,120 kg (1,215,000 pounds) Military and civil cargo, U.S. Air Force strategic missile carrier, U.S. Navy missions worldwide Four turbofans Main engine fan air (dual mode)	None - use scale up MAT planform design. No apparent weight limit for ACLG technology.
6. Off Runway Tactical Fighter (OTF) 6,350 kg (14,000 pounds) Antiarmor, 30mm, Ground attack; also trainer Single turbofan Main engine fan air (dual mode)	Integrated ACLG air supply by bleed from main engine fan. Air diverted directly for landing and via ejector for takeoff High speed (subsonic) in flight retention of an elastic trunk High takeoff and landing speeds and high energy absorption brake system
7. Remotely Piloted Vehicle (RPV) 1,452 kg (3,200 pounds) Air Force, Navy, and Civil government use - flying preprogrammed paths Single turbojet Main engine compressor bleed air (dual mode)	None - use basic Jindivik design
8. Wing in Ground Effect (WIG) 27,216 kg (60,000 pounds) (approx.) U.S. Navy antisubmarine warfare, special military missions Turbofan Main engine fan air (dual mode)	Adaption of SES planing seals fore and aft to an amphibious takeoff and landing system with shock absorbing side hulls. Elastic trunk material not required for side hulls or fore and aft planing seals. Side hulls used for parking, braking, in-flight end plates, and open water power off displacement stability.

Discussion of Current Technology Base

General – Eight technology items are first discussed:

1. Trunk inflated shape and load prediction,
2. Trunk flutter prediction and suppression,
3. Aircraft landing dynamics analysis,
4. Cushionborne stability and control analysis,
5. Air lubrication effect,
6. Cushion powering and surface performance prediction,

7. Cushion powering mechanisms,
8. Low speed ground control mechanisms.

These are seen as previous ACLG problem areas that have been or are being adequately enough addressed for near-term engineering developments to proceed. They will need further development far term for ACLG to be applied to larger aircraft.

A second group of three items is then also discussed. The following are the three technology items identified as near term development needs:

9. Trunk material,
10. ACLG flight effects,
11. Braking.

Key aspects of these items (which have also been extensively addressed) are identified as crucial to near-term engineering development and have the most urgent need for technology extension. Details of the eleven items are discussed as follows.

Trunk Inflated Shape and Loads Prediction – Prior to the XC-8A program no analytical methods were available for predicting inflated, three-dimensional shapes or analyzing material loads. During that program semi-rigorous methods were developed by Bell. These methods have show excellent agreement with test data. A computer code ASNAP (Axisymmetric Seal Non-linear Analysis Program) is now available. It has the following capabilities:

1. It accommodates a three-dimensional toroidal shape.

2. It accepts non-linear large strain orthotropic material properties.

3. It computes the non-linear relationships between trunk shape, load and water surface load.

4. It provides peripheral and vertical loads including also material strain effects on shape.

5. It includes "water carry" effects.

This program is adequate for intermediate term trunk design (through Category 4). Eventual improvements are visualized such as the development of exact bi-axial strain calculation. Figure 47 is an example of load analysis correlation with test, using this program.

Trunk Flutter Prediction and Suppression – Also developed by Bell during the XC-8A program was the computer code FLAP. This is a mathematical model of a two-dimensional slice of the ACLG trunk appropriately loaded with a proportion of the aircraft weight and free to heave (vertical motion). Complete trunk membrane dynamics are represented. This model successfully predicted XC-8A aircraft and trunk dynamic behavior. Trunk flutter was a continuing problem in the XC-8A program and ground resonance was also encountered. This prompted the development of the FLAP program by Bell. The USAF is currently developing a similar new program with increased capability through a contract with Foster-Miller Associates.

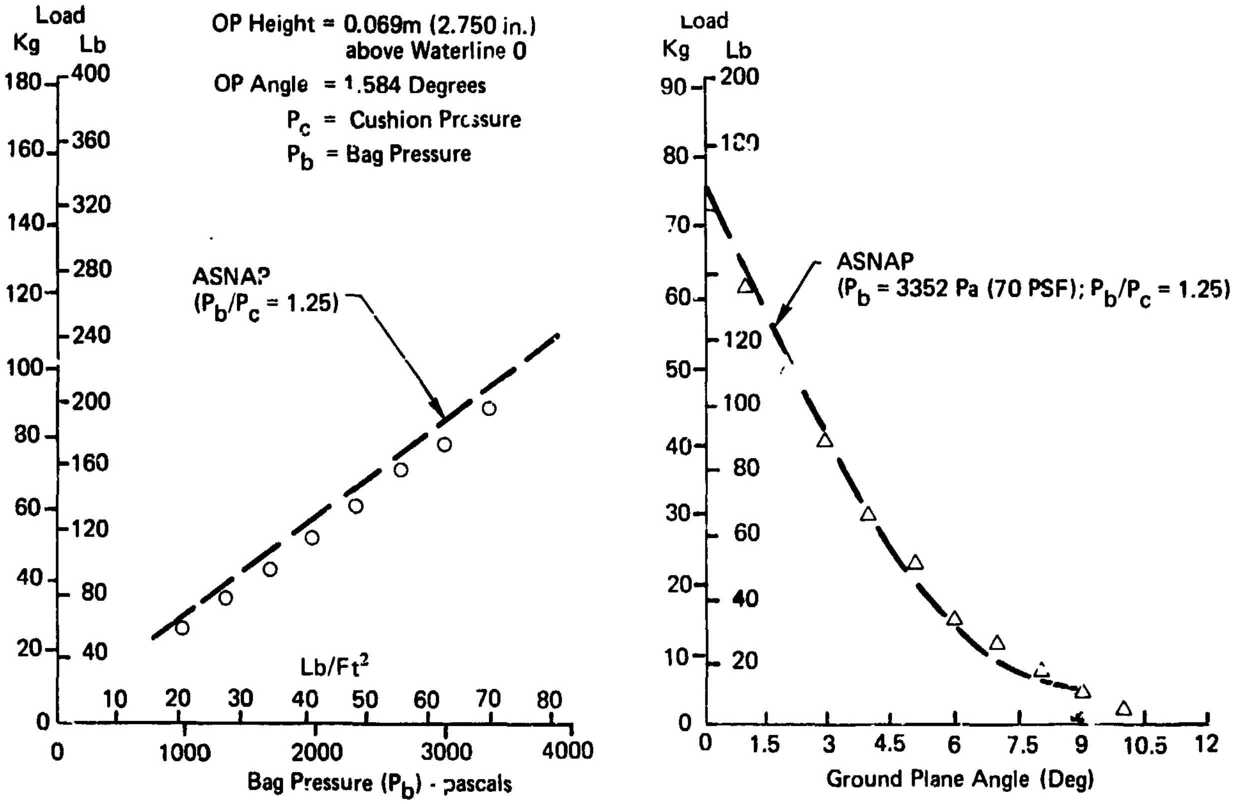

Figure 47. ASNAP Analysis Correlation to Measured Loads
1/6-Scale SES Three-Dimensional Bow Seal

The FLAP program is illustrated by the diagram - Figure 48. It has the following capabilities:

1. It accepts general non-linear material plastic and damping properties.
2. It incorporates fan characteristics and rigid body motion effects.
3. It includes surface contact effects (friction, etc.).
4. Geometry variations such as strakes, internal diaphragms concentrated masses, etc., can be analyzed.

The model accurately predicts vibration modes and frequencies. Table XXIV is indicative of its predictive capability. References 20 and 21 are analyses of XC-8A behavior made by using this program.

In this area refinement of computer code technique together with evaluation of geometrical and pressure related stability boundaries and relationships is seen as a near-term requirement which may be fulfilled by the current USAF program. The extension of the methods to include the complete trunk rather than a two-dimensional slice is an eventual technology goal. A considerable effort will be required to reach this goal; it is postulated as being reached at the Category 6 stage (aircraft of over 22,680 kg (50,000 lb) weight and over 2,394 Pa (50 lb/sq ft)).

Aircraft Landing Dynamics Analysis – The above analytical models provide the essential information for an educated design of the trunk itself. Additional analyses of cushionborne and cushion-inflated-airborne aircraft behavior are relevant to the design of the ACLG as a system. Of primary importance

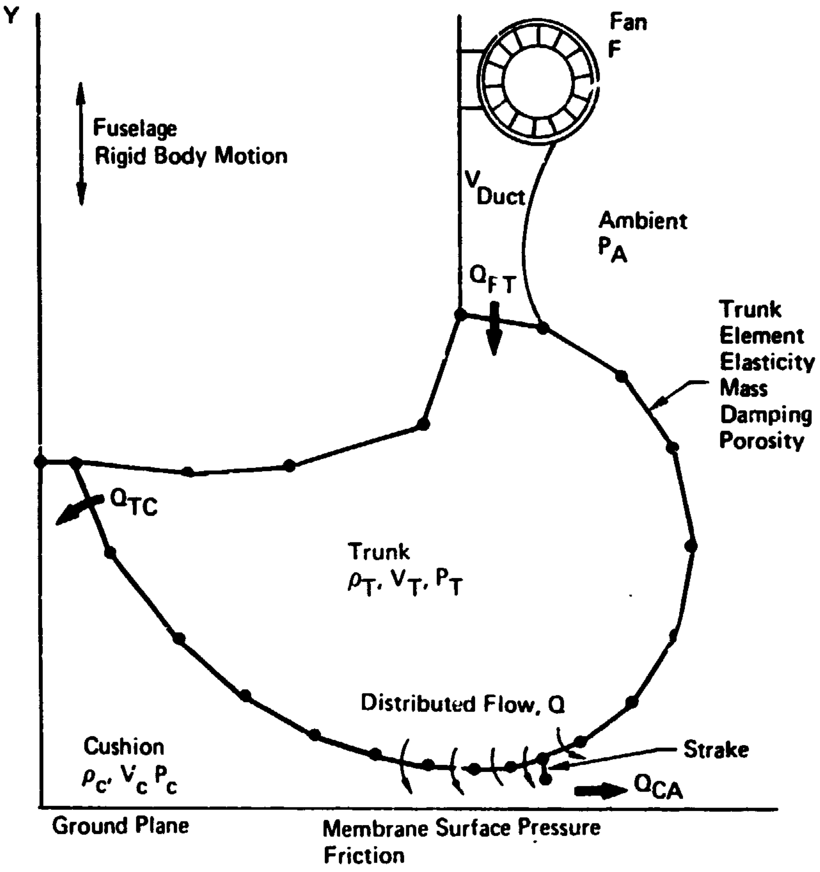

Figure 48. ACLG Flutter Analysis Idealization

TABLE XXIV

MATH MODEL SIMULATIONS OF 1/4-AND FULL-SCALE ACLG TRUNK FLUTTER

1/4 or Full Scale	Case No.	Cross-Section	Trunk Pressure Pa (psf)	Cushion Pressure Pa (psf)	Fuselage Clearance cm (in.)	Air Gap Under Trunk cm (in.)	Internal Diaphragm ?	Flutter of Trunk ?	Math Model Flutter ?
1/4 Scale	1	Fwd	3,909 (81.64)	1,569 (32.76)	24.8 (9.75)	1.9 (0.75)	No	Yes	Yes
	2	Fwd	3,909 (81.64)	1,569 (32.76)	24.8 (9.75)	1.9 (0.75)	Yes	No	No
	3	Side	2,988 (62.4)	1,465 (30.6)	24.6 (9.70)	1.0 (0.4)	No	Yes/No ①	Yes
	4	Side	3,909 (81.64)	1,569 (32.76)	24.6 (9.70)	1.0 (0.4)	No	Yes	Yes
	5	Side	3,909 (81.64)	1,569 (32.76)	24.6 (9.70)	1.5 (0.6)	Yes	No	No
	6	Side	4,096 (85.54)	1,569 (32.76)	24.6 (9.70)	1.5 (0.6)	Yes	No	No
XC-8A Full Scale	7	Side	15,322 (320.0)	6,224 (130.0)	110.5 (43.5)	5.1 (2.0)	No	Yes	Yes
	8	Side	16,375 (342.0)	6,943 (145.0)	92.7 (36.5)	5.1 (2.0)	Yes	No	No
	9	Fwd	16,375 (342.0)	6,943 (145.0)	96.5 (38.0)	5.1 (2.0)	No	Yes	Yes
	10	Fwd	16,375 (342.0)	6,943 (145.0)	91.4 (36.0)	5.1 (2.0)	Yes	No	No

① One side only.

are the landing impact energy absorption and damping characteristics of the landing gear. These characteristics have been extensively researched and the current technology base includes several computer codes which have been correlated with various dynamic model drop tests, and give reliable results. High sink rate landings were also accomplished in both the LA-4 (2.0 m/sec, 6.0 ft/sec) and XC-8A (2.6 m/sec, 8.0 ft/sec) programs, verifying energy absorption capability. The 12 ft/sec impact velocity limit of the XC-8A was verified in model tests.

One such computer code is the Bell ACLSDY program which is a three-degree-of-freedom pitch-plane program. The program includes fan pressure/flow characteristics as well as aerodynamic lift and pitch control moments. Inputs of trunk shape, trunk and cushion pressures are provided from calculations performed using ASNAP which are incorporated as a table look-up. Outputs in terms of aircraft applied loads and attitudes through the landing maneuver are obtained.

In this area the USAF is also procuring an ACLG landing dynamics program incorporated in the generalized EASY airplane dynamics computer code from the Boeing Company, and NASA has generated a similar program through a contract with Foster-Miller Associates (Reference 14).

These analytical tools are probably more sophisticated than the comparatively simple methods used in the design of current generation light general aviation aircraft and certainly appear adequate for Category 1 and 2 designs. Further near-term developments are not apparently necessary.

Cushionborne Stability and Control Analysis – Analytical methods for verification of cushionborne stability and control have also been developed. Static stability and damping is estimated by slight modification of landing dynamics programs and a computer code for analysis of aircraft cushionborne behavior in winds was developed by the de Havilland Company as a three-degree-of-freedom yaw plane model. Again it is probable that this type of analysis goes beyond what is required for Category 1 and 2 development. However, complete visual simulator representation - as was accomplished by the USAF in the XC-8A program - is undoubtedly a desirable tool for pilot training in ACLG characteristics, and would form part of any major development program. This latter is not regarded as an ACLG technology development item.

Air Lubrication Effect – Air lubrication effect has been explored by systematic static laboratory tests and confirmed by full-scale tests in the LA-4, Jindivik and XC-8A programs. The air lubrication effect during takeoff rotation and during taxi over concrete with the various center of gravity center of pressure offset distances within the airplane longitudinal center of gravity range is an item to be closely monitored in any new development program.

The laboratory tests established the low friction characteristic when lubricated vis-à-vis the case when the trunk is pressed to the ground at trunk pressure, for a series of membrane to ground clearance values provided by stand-off wear plugs. Figure 49 from Reference 15, summarizes some key results. Wear plugs were tried on the XC-8A program, but their future potential needs further confirmation.

Cushion Powering and Surface Performance Prediction – The prediction of cushion flow required to prov[illegible] given surface performance for given trunk and cushion pressure remains an empirical process. At the present stage, no analytical method has proved possible; therefore, the performance of the LA-4 and the XC-8A are used as the guide, especially the former, which was operated on a variety of surfaces. Generally, it can be assumed that a given effective air gap beneath the trunk is related to given surface performance. It has been assumed that large airplanes do not require a greater air gap than small ones for traversing the same surface. On this basis, the power requirement varies as $cP_c^{3/2}$ where c is the cushion perimeter and P_c is the cushion pressure. Alternatively flow requirement for given air gap is proportional to $c\sqrt{P_c}$.

At the present time, tests have been insufficient to relate the cushion power required accurately to a specific surface.

The development of operational type test experience is seen as an on-going technology need; however, for Categories 1 and 2 the extrapolation from the LA-4 is small. Reliable estimates can be made at this scale.

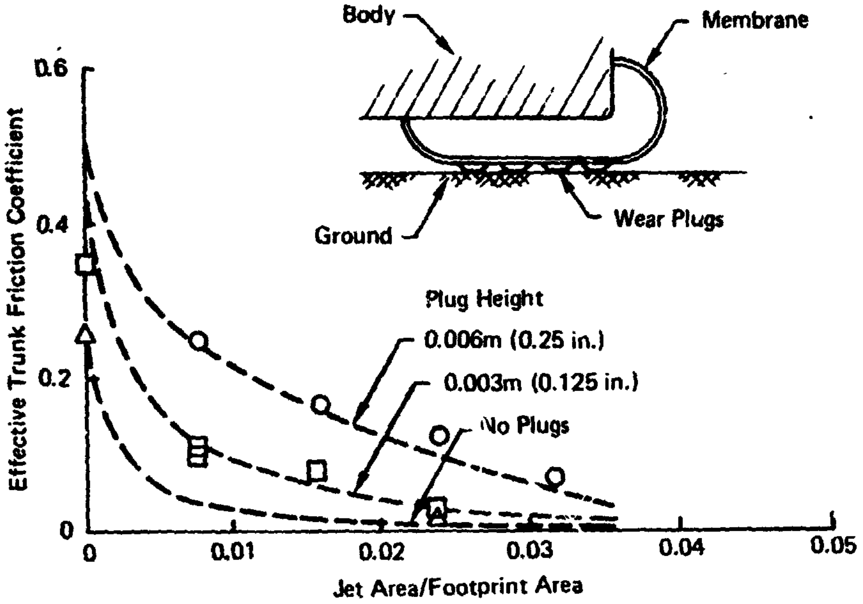

Figure 49. Air Lubrication Test Results

Cushion Powering Mechanisms – Mechanisms for providing the necessary air supply to the air cushion at minimum weight and cost is a technology area also requiring further development. The provision of separate auxiliary power units as adopted in the LA-4 and XC-8A programs is expensive in both cost and weight since their weight must properly be charged to the ACLG subsystem. Bleed from the propulsion engines in some form as suggested in this report will provide a better matched integrated system, in some cases accepting a penalty in increased takeoff ground run as an appropriate corollary to the relaxed airfield surface requirement. Where the ACLG power is integrated with propulsion the propriety of charging the extra weight of the delta ACLG power to the ACLG system (as was done in previous analyses with separate power units) is questionable. As discussed earlier, the 1,633 kg (3,600 lb) GAA considered as a wheeled aircraft would be adequately powered for takeoff by a 325 HP engine. However, altitude performance would demand a supercharged (heavier than unsupercharged) engine. For ACLG matching, a larger, 400 HP, unsupercharged engine is used having adequate capacity for the same altitude performance.

Again, in the case of the LMA, if field length is held to what it would be without the ACLG bleed, by using larger engines, altitude cruise performance would not be improved. A 7% larger total propulsion power would be needed adding 0.15% to gross weight.

The development requirement in these cases is one of establishing by detail analysis that existing state-of-the-art technologies can be applied. High risk technology development does not appear to be required, although certainly the dual mode mechanisms exampled here will require design and test development through the normal engineering cycle.

Low Speed Ground Control Mechanisms – Ability to accept a crabbed attitude and its crosswind advantages has been discussed previously. For adequate maneuverability rapid and responsive control of yaw attitude is essential. Since the total momentum reaction of the air cushion flow is small and its use deprives the air cushion itself, it is probable that aircraft's primary propulsion means, rather than cushion flow diversion, must be used for low speed control below aerodynamic control speeds. In taxi, this control may be reinforced by differential braking.

The mechanism chosen for low speed yaw control will vary with the airplane design. The LA-4 had both differential braking and the blown rudder commonly effective on small seaplanes. The XC-8A primarily relied on differential propeller pitch (β - prop). The Jindivik incorporated a Coanda jet exhaust deflector.

Where engine fan bleed is used for air cushion, as suggested in this report, an integrated system for ground control also appears appropriate and can be designed to operate independently of the thrust, forward or reverse. This type system will require technology development which is therefore seen as important for Categories 5 and above.

The following are the three near-term technology items not currently being addressed:

Trunk Material – The principal component of the air cushion is the flexible trunk for which retraction is the first requirement. Retraction of an inelastic flexible trunk within metal doors was at first extensively considered, and various schemes have been proposed. Bell has constructed a small-scale working model of a completely internal trunk within metal doors and demonstrated satisfactory deployment (though not retraction). This was followed by full-scale construction of a large inelastic trunk section and hinged retraction door, designed for a C-130 retrofit. The disadvantages identified for such systems are excessive weight and poor extension/retraction reliability due to the mechanical complexities involved.

A manually stowed inelastic recovery trunk for RPV's which avoids these disadvantages, has been developed on the Jindivik by the USAF (Figure 44). This system is not retractable in flight and, therefore, is only used for landing. To supplement it with a takeoff capability a secondary dropaway takeoff trunk is added. The disadvantage is the need to recover the takeoff trunk and re-stow the landing trunk, a procedure which is unacceptable in commercial applications and also limits practicable size.

Because of these inelastic trunk disadvantages, the major ACLG trunk material development effort has been devoted to elastic material, for external retraction. Through the LA-4 and XC-8A Buffalo programs an entirely new, reinforced-rubber, high-stretch material system, having comparable strength/weight ratio to the best available inelastic materials, has been developed. No fundamental technical barrier to its further development and use over the full spectrum of potential aircraft application has been identified. Computations of trunk weight throughout this report are based on this type of material.

The most important unknown at the present stage of development is in-service trunk life. Trunk life may be limited by fatigue, environmental conditions, or abrasive wear.

Relative to fatigue, use of rubber in a partially stretched condition increases rather than decreases its dynamic fatigue life and reduces its sensitivity to cut propagation, etc. This is shown by Figure 50, taken from Reference 16, which presents the results of a thorough series of fatigue tests on a typical soft rubber formulation. Two conditions are of interest in the ACLG application. The first is high cycle fatigue due to random strain variations with the trunk inflated. The strain target will be in the order of 130% in future designs, as discussed in this report. With an additional oscillatory 25% imposed to allow for flexing in operation, the fatigue life is 100 times greater when maintaining the 130% strain level than it would be if the oscillation were applied to unstretched rubber. The second condition is the low cycle fatigue due to repeated inflation and deflation from an initial stretch condition retracted taut on the surface: for which the maintained strain may be 10% to 20%. The incremental strain will be approximately 120% and fatigue life will be increased 3 to 10 times compared with cycling from a slack condition. Figure 50 also shows the short fatigue

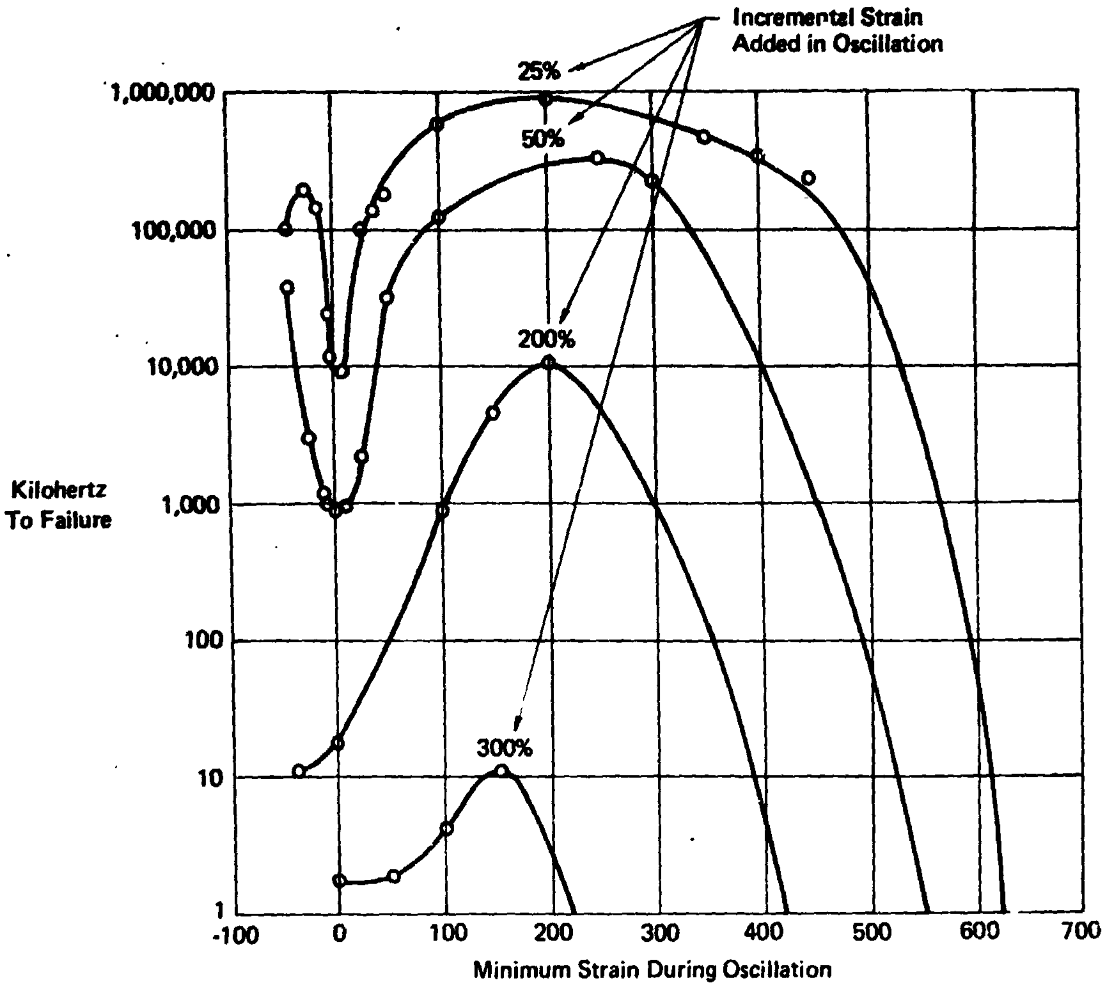

Figure 50. Rubber Fatigue

life to be expected if the rubber is operated close to its ultimate strain limits. The XC-8A trunk design required operation at strain levels too close to ultimate limits. This led to cracks developing in the surface skins with progressive deterioration, excessive maintenance and short life. For a perspective on XC-8A trunk maintenance Table XXV is included. Detail information on manhours expended in particular maintenance activities is not available, so the table shows principal activities and days expended only, from a daily record of a period which included the change from first to second trunk.

Relative to environmental tolerance it is widely recognized that natural rubber is prone to oxidation and cracking from ozone attack. However, significant advances have recently been made in the protection of rubber. A new surface-penetrating anti-ozonant called Age Master was used in the LA-4 and XC-8A programs. This was found to be effective, providing excellent results in ozone chamber testing and in actual trunk applications; apparently providing good protection for at least four years. Relative to other environmental effects such as exposure to cold temperatures, immersion in salt water, etc., the basic rubber properties are satisfactory.

The probable limitation on trunk life is abrasive wear. To retain flexibility and high strain characteristics, use of a soft rubber carcass is indicated, which will not itself be hard wearing. Though little wear will be expected on some surfaces, particularly water and snow, abrasive wear will be encountered on hard surfaces because of local imperfections, despite the air lubrication de-

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TABLE XXV
XC-8A PARTIAL HISTORY

216 Day Workday Period Feb 13 - Dec 31 1974

	Days
Tests	39
Aircraft Display	1
Adverse Weather	11
Aircraft Maintenance	
Airplane	5
APU	1
Wheelgear	21
Propeller	20
Preflight	5
ACLG Maintenance	
No. 1 Trunk	21
No. 2 Trunk	9
ASP-10	13
Parking Bladder Valves	11
Cushion Trim Valves	8
Cushion Brakes	5
Trunk Change and Configuration Mods	38
Instrumentation	8

scribed earlier, particularly if sharp loose material is present. Sustained operation on these surfaces is essential if the ACLG aircraft is to link with existing facilities, particularly low-quality runways at minor airports. The LA-4 was operated sparingly on such surfaces and landed once on soft sand without significant degradation of the very thin rubber skin of its trunk (approximately 0.25 mm, 0.01 in. stretched), permitting some cautious optimism in regard to air lubrication preventing wear. However, its total taxi distance was only in the order of 30 miles. Also, some progress has been made in protecting the trunk by incorporating hard wearing elements in the ground tangent region, which was accomplished by using point-attached wear plugs in the XC-8A trunks (Reference 17). However, XC-8A runway operations were very limited and such wear as was experienced was probably mainly the result of excessive nose-up trim. These data are insufficient for any realistic life predictions to be made. Therefore collection of systematic data on in-service wear and trunk life is seen as the primary need in the development of ACLG trunk material. Acceptable trunk life is related to trunk cost; high cost and long replacement time can prevent a satisfactory maintenance interval from being acceptable.

With regard to cost, the material constructions used to fabricate this initial ACLG elastic material are described in References 17 and 18. The reinforcing material used is nylon tire cord which appears satisfactory for the foreseeable future. The elastomer is a simple blend of natural rubber. Some improvements in rubber formulation can be expected near term. Both raw materials are low cost and have been widely used in tire manufacture. Because the trunk weight is comparable to tire weight and because the trunk is fabricated as a flat sheet, it is logical to expect (a priori) that manufacturing techniques development will allow the ACLG trunk to be quantity-produced at a lower cost than the aircraft tire set. At present, manufacturing methods are in their infancy; the XC-8A constructions were very unsophisticated, principally by hand. This, plus design complications accepted for prototyping in order to minimize operational risk, resulting in very high costs for the three XC-8A trunk sheets made. On the other hand, a low-cost fabrication technique was reached on the LA-4. Detail analyses of cost have been made at Bell and show that the high XC-8A trunk costs were the result of many detail causes. The costs used in the application studies have been based on improved design and also on reasonable near-term improvement of manufacturing technique. Cost estimates are based on detail analysis mainly using current construction experience. Predicted cost (1974 $) of the finished elastic sheet for the GAA is $1,200 and for the SHA $45,000.

Despite the results achieved with elastic material development, only a few variations of basic construction parameters have been explored and it is unlikely that present constructions even approach optimum. Much remains to be done relative to basic selection of elastomer compounds, reinforcing cord materials, sizes, spacing, plies, orientation, adhesives, processing, etc. To an extent, the material design can be analyzed and a computer code is available for calculating cord wrap/diameter/extension characteristics.

In general, successive laboratory experiment in parallel with full-scale operational experience is seen as a major ACLG technology development need.

Flight Effects – Aerodynamic characteristic effects of the inflated air cushion have been investigated through a number of wind tunnel tests and through flight tests of the LA-4 and XC-8A. Analytical methods for drag and pitching moment prediction are also available. Generally, for the configurations so far adopted, it has been found that the flight drag of the inflated air cushion is similar to that of extended wheels.

Unexpected problems can occur such as the snaking oscillation in yaw initially encountered on the XC-8A. This was due to an unsteady flow separation phenomenon. In this instance, the oscillating separation point was fixed by introducing a flow trip attached to the trunk. Such effects are not readily amenable to analysis, but can be shown up by wind tunnel testing. The inflated trunk may also affect the longitudinal or directional stability and influence the maximum lift. On the XC-8A, wind tunnel tests showed a small increase in directional and little effect on longitudinal stability or lift but this may be changed with a configuration of trunk extending beneath the inner wing. Favorable lift effects are probable, but stall characteristics of a low wing with swept trailing edge may not be satisfactory, depending on body configuration. Thus, it appears that wind tunnel tests of a typical configuration are a necessary preliminary to Category 1 and 2 development, and will give valuable insight into the probable characteristics of similar configurations at larger scale.

Braking – Braking is seen as an essential feature of any land-based or amphibious aircraft. It does not appear feasible to rely entirely on reverse thrust or other deceleration means such as drag parachutes, for either commercial or military operations.

The pillow braking method adopted for the LA-4 and XC-8A program is effective and achieves the three functions: first, that of venting cushion support to ensure a ground contact load, secondly, of providing a skid at the ground interface and, thirdly of 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 elastomeric skid material will limit the maximum interface temperature to a much lower value than is currently achievable in conventional wheel brakes. Further, in the pillow 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.

This disadvantage was overcome in the Jindivik program by spreading the braking over the whole trunk footprint at the rear and reducing interface pressure to trunk pressure, with greatly reduced wear rate. This was necessary because of the high landing speed and greatly increased energy absorption requirement per square foot of cushion planform.

In larger, faster, aircraft the energy absorption requirements will become much more demanding. This is illustrated in Table XXVI which lists energy absorption rate comparisons for several of the ACLG aircraft studied. 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) and available contact area tends to vary at the square of scale. This problem appears as a technical barrier to high-energy land-landing with the LA-4/XC-8A pillow brake system. It would not, however, impact a primarily water-landing aircraft - for example the LMA as presented in this report which would only require braking at low speeds overland.

TABLE XXVI
COMPARATIVE LANDING KINETIC ENERGY
ABSORPTION PARAMETERS

	GAA		MAT		LMA		OTF	
Landing Weight, kg (lb)	1,630	(3600)	136,000	(300,000)	454,000	(1,000,000)	6,350	(14,000)
Landing Wing Loading kg/sq m (lb/sq ft)	112.5	(23)	596	(122)	538	(110)	402	(82)
Stalling Speed, km/hr (knots)	111	(60)	226	(122)	215	(116)	204	(110)
Stopping Energy ÷ Aircraft Weight Joules/kg (ft-lb/lb)	478	(160)	1,980	(660)	1,785	(596)	1,606	(536)
Total Stopping Heat $\frac{\text{kg - calories}}{1000}$ $\left(\frac{\text{Btu}}{1000}\right)$	0.19	(0.74)	64	(254)	193	(766)	2.43	(9.65)
Cushion Area, sq m (sq ft)	6.68	(72)	115.5	(1,242)	461	(4,960)	10.9	(117)
1/2 Total Heat ÷ Cushion Area kg-cal/sq m (Btu/sq ft)	13.85	(5.1)	277	(102)	210	(77.3)	111	(41)

Various methods can be suggested for increasing brake energy absorption:

a. Increased contact area,

b. Alternative high temperature interface materials,

c. Water cooling,

d. Techniques for rejecting a greater proportion of the heat directly to the ground.

This problem is not thought to be significant in Categories 1 and 2 and would not impact the LAT for example in Category 4. However, on the pillow braking scheme similarly to the trunk, data are currently insufficient to enable realistic life projection and further development concurrent with it is seen as a near-term requirement. For the OTF and for larger aircraft, significant additional development is required, unless water basing forms the main thrust of ACLG progress.

The introduction of suction braking, with a much greater feasible stopping rate, aggravates the energy absorption problems. Suction braking is an attractive feature for inclusion in the ACLG because a low-weight system can be introduced easily, using the existing large area cushion cavity for suction and the trunk to mount the interface skid surfaces. Decelerations of 2 to 3 g can probably be achieved on high friction dry runways. Normal dry deceleration rates could be achieved on wet or slippery runways. This feature provides an unequivocal advantage over wheel gear, which is unable to duplicate this performance.

Methods of satisfactorily combining the suction braking with high energy absorption skids have yet to be developed. The basic feasibility has been shown by LA-4 tests and some theoretical approaches are discussed in Reference 19. If treated as an emergency method for stopping on slippery surfaces, the energy absorption requirements would not exceed those of the regular braking method.

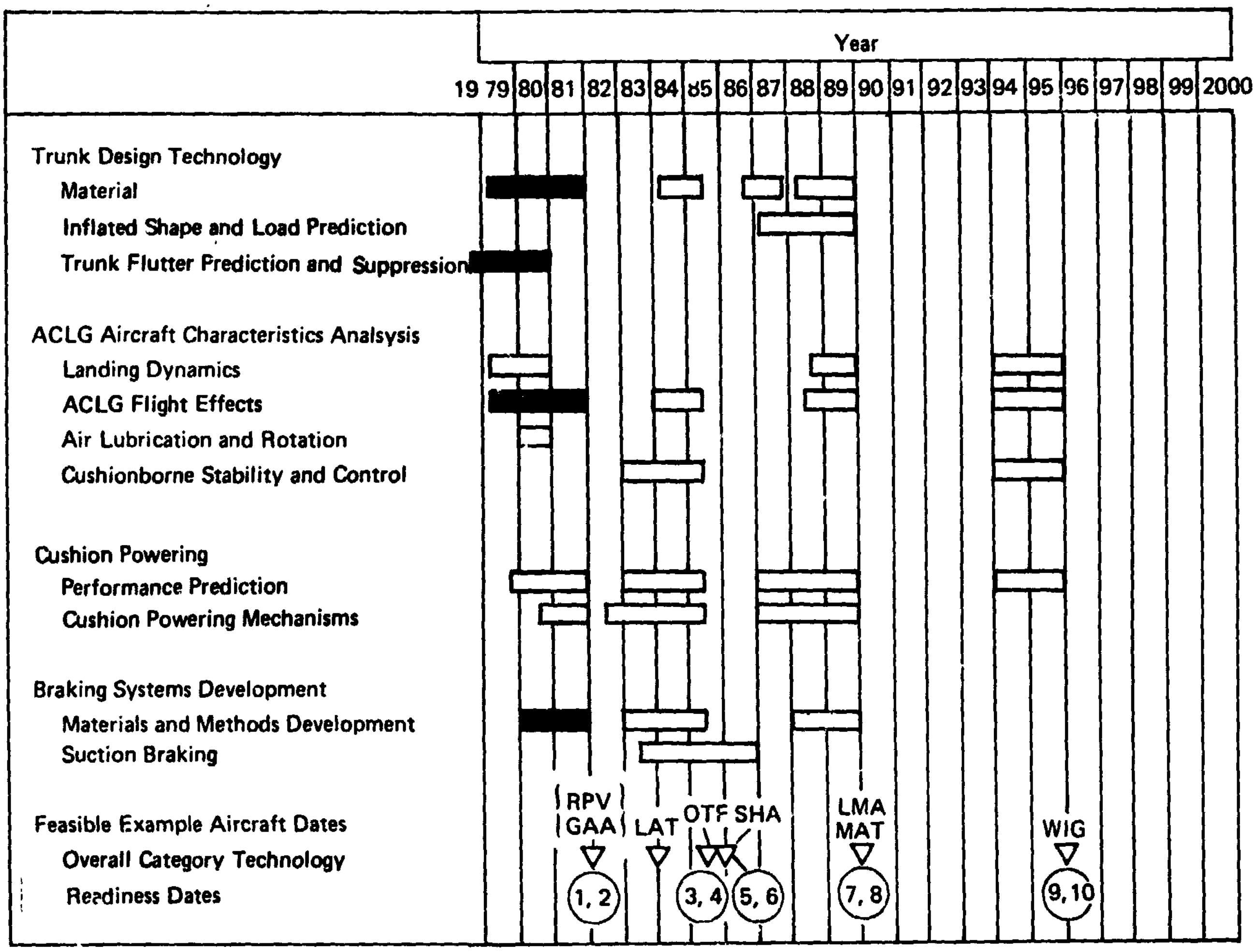
Development Timetables

Based on the foregoing discussion, pacing technology development items can be identified for the aircraft examples studied in each category. Table XXVII summarizes these projections. From Table XXVII, technology development timetables have been developed using the NASA designated technology readiness dates for Category 1 of 1982 and 1985 and are shown in Tables XXVIII and XXIX, respectively.

TABLE XXVII
TECHNOLOGY DEVELOPMENT REQUIREMENTS

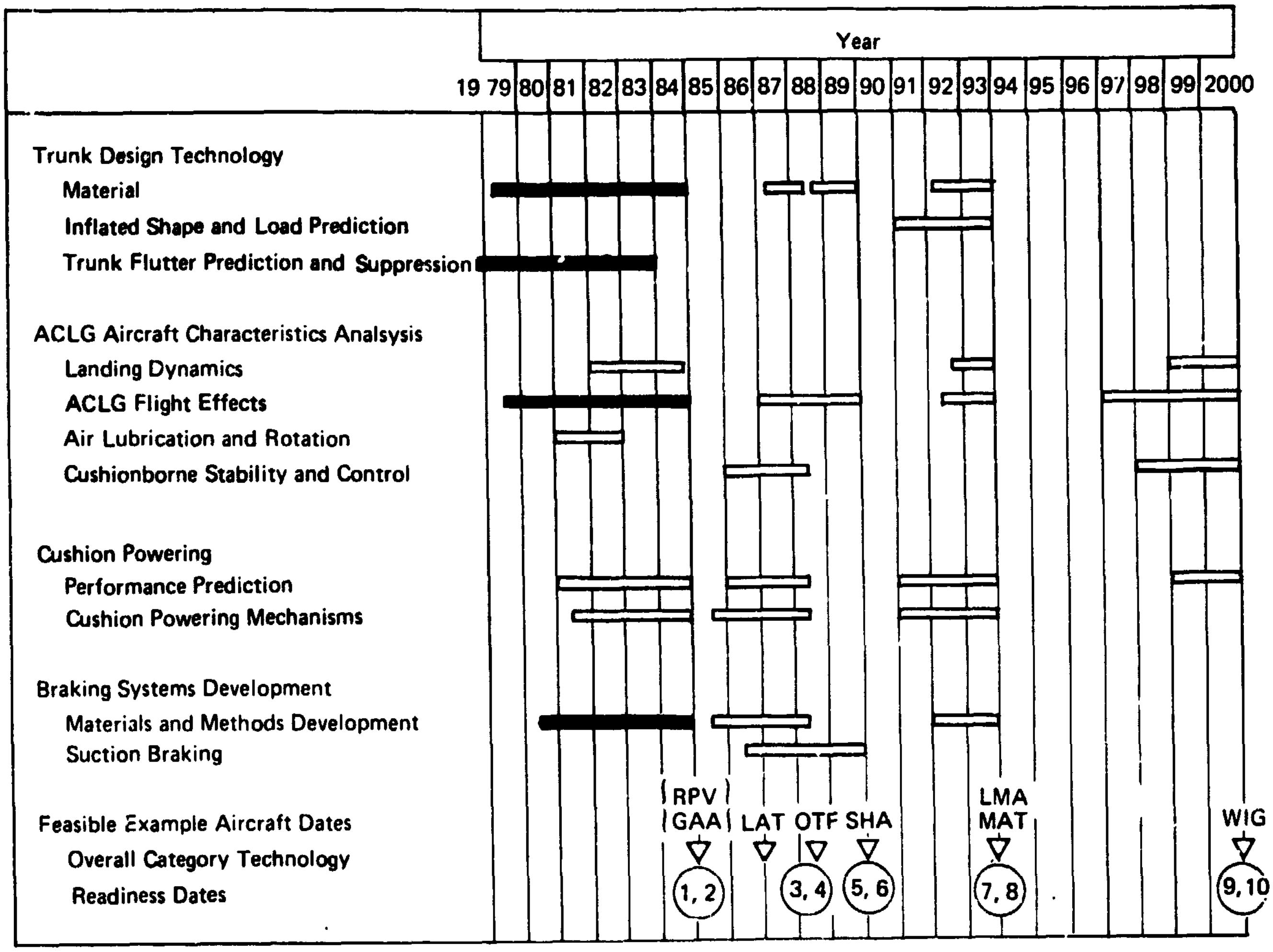
Aircraft and Category	Technology Development Requirements
GAA 1, 2	Trunk and Brake Material - Life Aerodynamic Characteristics Flutter - Ground Resonance
LAT 1, 2	Integrated Power System
SHA 5, 6	Trunk Material Cushionborne Stability and Control Power Correlation Suction Braking
MAT 7, 8	Trunk Material Stress Prediction Braking
MMA 7, 8	None - Follows from SHA and MAT
OTF 3	Aerodynamic Characteristics Integrated Power System Braking Materials and Methods
RPV 3	Inelastic Trunk Life Aerodynamic Characteristics
WIG 10	Ground Resonance Landing Dynamics Aerodynamic Characteristics Power Correlation

TABLE XXVIII
ACLG TECHNOLOGY DEVELOPMENT TIMETABLE



The worldwide market need for these 8 applications was covered in a qualitative manner during discussions with the key organizations visited. The conclusion arrived at is that the applications could be used in approximately the time phasing indicated by the technology development, with the exception of the RPV technology which will be ready long before the market applications develop.

TABLE XXIX
ALTERNATIVE ACLG TECHNOLOGY DEVELOPMENT TIMETABLE



CONCLUSIONS AND RECOMMENDATIONS

It is generally concluded that the dominant feature of ACLG is the provision of a superior amphibious/triphibious capability. Other desirable features displayed in this report such as cross-wind landing, soft ground performance or improved ground-accident tolerance, while good in themselves, are unlikely to lead to the adoption of ACLG. Possible exceptions to this conclusion are the fighter and RPV applications.

In these circumstances the most attractive near-term use is as replacement for existing amphibious aircraft. A large part of the population of these aircraft is employed in areas such as Canada and Alaska, where the economy is strong enough to support them and the conditions require their use.

The ACLG aircraft will also be sufficiently competitive with the land plane to greatly stimulate the market for amphibians, including larger aircraft, particularly in countries with less developed ground transportation systems. The present demand for amphibians and float gear on small aircraft is reportedly increasing at a greater rate than general aviation sales despite the recognized penalties in performance, weight and cost. (Aviation Week, Dec. 11, 1978, p 63).

The majority of amphibious aircraft in use are small aircraft. The largest in production is the specialized Canadian CL-215 water bomber (19,731 kg (43,500 lb) and no very large amphibian has ever been built. The ACLG introduces a new economical water/land basing option that does not seem possible of achievement any other way. This opportunity can be seen throughout the spectrum of designs presented and is particularly attractive for very large aircraft. It may eventually lead to the use of ACLG as a mainstream competitor to conventional wheel gear.

No fundamental technical barriers to ACLG development are foreseen, with the possible exception of high-energy absorption braking methods, but a number of areas where the technology is inadequate for any production embodiment have been identified. Chief among these is flexible trunk life definition which can only be achieved through extensive ground testing in an operational context. Continuation of the elastic trunk approach is recommended, particularly because during the 14 years of desultory ACLG development that has taken place, no general-use viable alternative to the elastic trunk as a means of extension/retraction has been proposed. Second tier problems of membrane stability (retracted and inflated) and aerodynamic effects are technology areas requiring increased analytical depth and model test.

Expansion of the technology base in the above areas is necessary to provide the impetus to embark on any solidly founded enterprise projecting an aircraft dependent on ACLG. Previous experience and current studies show that the ACLG can only provide the transport efficiency increment necessary to its adoption on one basis; first that it is the sole means of takeoff and landing, and secondly that it is incorporated in the design from the start and not as a retrofit, since only in this way can the projected benefits in weight and cost be realized.

Whatever class of aircraft is considered or selected as the most attractive end-objective, the initial technology advancement will be most cost-effective if accomplished at the smallest meaningful size. Small size trunk and brake development tests on a suitably configured ground test vehicle are therefore recommended using a scale appropriate to an available vehicle. In addition, analytical membrane dynamics technology should be advanced and the resulting capability used to aid the design and also to validate the behavior of the small size trunk and make predictions for other designs. The recommended tests will also provide validation for trunk weight and cost predictions. They will not provide data on the important second tier problem areas of in-flight membrane stability and general trunk in-flight areodynamic effects. Wind tunnel tests of a generally representative configuration are, therefore, also recommended.

Concurrently further design and operational studies of those configurations identified as most attractive by the present report should be conducted, in order to broaden the basis for the above efforts.

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1. Report No.
CR 159002

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Air Cushion Landing Gear
Application Studies

5. Report Date
March 1979

6. Performing Organization Code

7. Author(s)
T. Desmond Earl

8. Performing Organization Report No.
7605-927002

9. Performing Organization Name and Address
Bell Aerospace Textron
Box 1
Buffalo, NY 14240

10. Work Unit No.

11. Contract or Grant No.
NAS 1-15202

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, DC 20546

13. Type of Report and Period Covered
Contractor Report
January 1979 - March 1979

14. Sponsoring Agency Code

15. Supplementary Notes
NASA Technical Representative
Lt.-Col. J.C. Vaughan

16. Abstract

A series of Air Cushion Landing Gear Applications was studied and potential benefits analysed in order to identify the most attractive of these. The selected applications are new integrated designs (not retrofits) and employ a modified design approach with improved characteristics and performance. To aid the study, a survey of potential users was made. Applications were evaluated in the light of comments received. A technology scenario is developed, with discussion of problem areas, current technology level and future needs. Feasible development timetables are suggested. It is concluded that near-term development of small-size ACLG trunks, exploration of flight effects and braking are key items. The most attractive applications are amphibious with very large cargo aircraft and small general aviation having the greatest potential.

17. Key Words (Selected by Author(s))
Landing-Gear
Air Cushion

18. Distribution Statement
Unclassified - Unlimited

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages

22. Price*

*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.