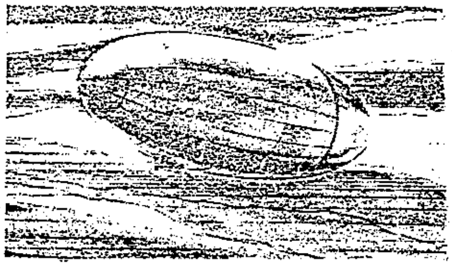
AIR BUOYANT VEHICLES: ENERGY EFFICIENT AIRCRAFT



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Introduction

Continuing the development of Metalclad airships after half a century of delay caused by disasters of skeletal fabric-covered airhsips, the AIRSHIPS INTERNATIONAL, Inc., (AI), has investigated as a part of its comprehensive program, also the comparative merits of feasible modern airships in juxtaposition to the best jet air freight transports.

Similar comparisons have been made in recent past, almost always with the last historical airships of 40 years ago and latest jet transports with, not surprisingly, unfavorable results to airships. At AI, we have carried out design studies on airships as they would perform if they existed now. Two of these projected airships are compared with the best wide-body jet transport we have today for carrying freight; comparison was made on the route between LAX and JFK airports.

The study is significant not only in its economic comparisons but also and especially, it its analysis of energy consumption by lighter-than-air (LTA) and heavier-than-air (HTA) transports. Airship development has been neglected for too long a period of time; the long experience with ZMC–2, half a century ago, established and proved the principles of Metalclad hull construction which emerged during the same period as the skeletal, fabric-covered airships were failing. All failures of large airships of 40 years ago were caused by inherent inadequacies of fabric-covered skeletal airships, aggravated in large displacements of hulls.

For the background of the substance of this paper, it is essential to state that rigid and pressurized Metalclad airships will not be fragile, non-redundant structures familiar from the past, but compared to historical airships, will be stronger for actually lower structural weight, more rigid, even without pressure and highly structurally redundant. Furthermore, as aerodynamic bodies, they will have low drag due to the precision of their form at high speeds of 130 mph and more in time, projections that could not be made for fabric-covered hulls. They will be strong also locally over the whole hull surface, a merit never attained by any past airhsip. These are desirable qualities among many others, including control by power thrusters with lower energy requirements than the drag of fins and control surfaces and their high weight. Metalclad airships will not depend on ground crews but possess complete self-control in turbulent atmosphere as well as at standstill. Projected Metalclad airships will be capable of continuous, dependable service in all weather, comparable to similar performance of present jet transports. Without these expectations based on realistic design and construction, comparisons arrived at in this paper would not have been put forward at all.

Advances in all disciplines of technology through the last fifty years have been so significant that thanks to them, modern Metalclad airships can be confidently expected to meet all demands of high intensity transport operations not only as flying, weight carrying structures but equally as much by their propulsion and control power plants, with substantial energy conservation and reduced rate of emission of pollutants from combustion.

Energy Conservation by Airship Transport

Although economic merit of projected modern airhsips is the result of desirable qualities and characteristics of their hull structure as much as of their power plants, this paper responds principally to the propulsion of airhsips; the text and the summary tables of comparisons inevitably include also results of economic studies and comparisons with jet transports.

HTA transport airplane has experienced a revolutionary success due to the basic fact, known to us 50 years ago but persistently not recognized by aircraft industry until almost 30 years later that a jet engine, unlike a piston engine, is capable of generating high thrusts, propel an airplane rapidly to elevated altitudes and operate there in low ambient air temperature at high thermal efficiency; there, with its high, thrust, it can drive an airplane economically at high speed through low density atmoshpere over long distances with unprecedented dependability and durability of its power plants.

This quantum advancement in air transport is not available to airships; to be viable, development of LTA transport has to devise ways and means for meeting modern air transport challenges and at the same time, become economically attractive Turbomachines that have made the airplane such a powerful transport vehicle also possess the already demonstrated capability of serving airships comparably as well, but in different ways with similar end benefits. In propulsion of airships, turbomachines will have to use a combination of two compound thermodynamic cycles, each with its own fluid; one cycle in which air permits high elevated temperatures and transfers its rejected heat into the second, low temperature cycle with a fluid of low boiling point, permitting the use of low heat rejection temperature. Compound cycle systems of gas-steam turbines have been in use for some time already with highest sustained efficiencies yet achieved in thermal power plants. Further advances are in sight with newly developed lower boiling point fluids and also and particularly, with contra-rotating (CR) in place of single-rotating (SR) turbomachines now in general use. CR turbomachines are the most efficient of all turbomachines; they are also the lightest in weight as well as highly compact, require fewer stages than SR machines and are by their nature, shaft output machines. Thermal efficiencies of 45% already have been reached and maintained with compound thermodynamic air-steam cycles with SR machines at moderate temperatures, although at outputs too high for airship use. It is not wishful thinking to expect thermal efficiencies of 50% from compound cycles with CR power plants with maximum cycle temperatures lower than now used in jet engines and with newly developed fluids for this prupose, having lower condensation point than water.

Further energy conservation in airship propulsion will be due to either removal of the hull bounday layer (BL) and use of its mass for propulsion thrust by fans in tunnel ducts producing momentum of cold air jets of high propulsive efficiency, or accelerating BL on truncated hull by external stern propellers. Airship hull aerodynamics has been a neglected area of analytical as well as experimental investigation for a long time and creative work has to be done to advance this science to the level of now highly developed airplane wing aerodynamics. Expected gains in the reduction of hull drag should be rewarding, particularly with Metalclad hulls with their surface smoothness and precision as well as stability of form at all, including the highest speeds. At high Reynolds' numbers of projected airships, with BL control or even partial removal, it is expected that hull drag coefficients of approximately (.008), based on volume)$^{2/3}$, may be established.

An onerous inadequacy of past airships was the problem of maintenance of constant weight/lift equilibrium as fuel was consumed in flight. It demanded either valving of lifting gas to maintain level altitude, which was costly, especially with Helium lifting gas, or devices were developed for condensing water vapor from piston engine exhaust gases. The condensers for this purpose were relatively heavy, increased the hull drag and additional plumbing and tanks were required; the process itself was untidy due to unavoidable inclusion of carbon particles.

Future airships, using gas turbines, cannot achieve practical water recovery by condensation to compensate for the weight of burned fuel, due to small water weight part in the turbine exhaust; however, gas turbines are well capable for combustion of gaseous Hydrogen fuel (GF), burning together with liquid fuel (LF) in a proportion determined for lifting of liquid fuel weight. This relation requires, at 5,000ft altitude, (16.66)ft^3 of Hydrogen GF to lift one pound of LF, for maintaining constant weight/lift equilibrium no matter how fast or how far an airship may travel. Products of the joint combustion of GF and LF contain smaller amount of pollutants per unit of power output than in the case of combustion of LF alone. This is a welcome advantage even at relatively low power outputs required by large airships; at low altitudes of flight, it can be reasonably expected that this pollution will be scrubbed out by rains. The massive pollution generated by jet airplanes is less likely to be "rained" out at higher altitudes at which these airplanes have to fly. The merits of GF-LF combination of fuels are advantageous to airship propulsion in at least two other additional respects; one, is the higher effective heat content of the GF-LF combination per unit of lifted weight of LF, a gain of 30+% for an average case; the second gain is in the higher specific lift of Hydrogen compared to Helium (approximately 7.0%), resulting in a relatively smaller required lift volume of GF to lift LF than if Helium were to lift the greater LF weight without GF lift. Advantages of GF-LF combination in airship propulsion not only elegantly resolve the old problem of weight/lift equilibrium but also are favorable to increase of payload of airships and with appropriate design, provide for valving of less expensive gas in case of unavoidable necessity, e.g., in strong rising thermal currents.

The volume of GF, even for long-range flights, is only a small fraction of the total lifting gas volume in the hull and membrane cells containing GF are to be located inside Helium cells, with ample space around them even when partially deflated due to GF consumption; the GF cells will still float in Helium volume, at the end of a trip. At no time shall the GF cell membranes come in contact with either Helium cell membranes, or with Metalclad hull shell. Hydrogen has been propagandized into a terror gas since the day of Hindenburg disaster; it is nothing of the sort and compared to all hydrocarbon gases in daily use, it is safer than any of them due to its physical properties not eleborated here, due to the limitations of this paper. Hydrogen is not advocated for lifting gas, althouth in Metalclad airships, it probably would be safer than it had been in historical rigid airships. In AI design studies, the containment of GF is worked out with great care; in case of ultimate disaster in which the hull metal shell, the Helium cell membrane and the GF cell membrane are assumed to be punctured, escaping GF would be surrounded by much more voluminous escaping Helium streams preventing contact with air. The system of using GF is considered safe under all, including the worst imaginable accident that may arise.

Hydrogen as GF is a more expensive fuel than LF, although the escalating costs of the latter are reducing the difference; yet, as table No. I shows, the total cost of GF + LF per typical trip of MC-80 airship, the least favorable case, is less than one half of the cost of LF for 747F, for identical payload. In spite of higher cost of GF than LF, the total cost of trips/year of MC-80, transporting the same payload as 747F, is lower by almost 19%. The total amount of GF + LF is barely one third of the amount of LF consumed by 747F, ref.: Tables I, II and III. Energy consumption of airships at (.75) fuel input and ground speed of 100mph, including propulsion, electric and control power is, in general below one third of fuel consumption required by jet airplanes for transporting equivalent payloads over the same distance.

LF consumption per year of operations, for equivalent payload and trip distance, is only 29.62% for MC-80 and 23.75% for MC-100, of LF required by 747F for identical service. These are promising projections, encouraging to resumption of airship development.

Overall Economic Comparisons

Conservation of energy by airships is a part of overall airship operational economy and for completeness, general economic comparisons are also included in this paper. Comparison of economics of powered transportation has not been paid much attention to and is in disarray. Inquiring into it has revealed absence of uniform and all-inclusive parameters and standard formulas that could be relied upon. In the AI study, the established parameter, dollars/ton mile, was defined by a dimensional equation given below, called the Cost Intensity Parameter, π .

Slide I

$$\pi = \left[\frac{1}{V_m}\right]\left[\frac{1}{G_{pl}}\right]\left[\frac{\Sigma\ S}{T}\right] \text{, dollars/ton mile}$$

Where: π, dollars/ton mile, Cost Intensity

V_m, miles/hours, speed of vehicle; it is a tower-to-tower speed of airships

G_{pl}, tons, payload (freight)

ΣS, dollars, summation of all operating costs per calendar year

T, hours, total flying time/year.

This first bracket, $(1/V_m)$, is inverted mean speed of travel, including climb to flight altitude as well as descent from it. In jet airplanes, V_m is lower than the travel speed, due to high altitude of flight and lower speeds of climb and descent than the cruising speed of flight. In airships, this parameter is relatively higher, although the travel speed itself is lower than of airplanes.

The second bracket $(1/G_{pl})$, is inverted payload; the fuel for the trip is implicitly contained in G_{pl}, because in essence, G_{pl} is the difference between the actual useful lift and fuel weight.

The third bracket (Σ S/T), is the summation of all yearly costs of operation of an air or any other vehicle, divided by the total flying or travel hours during the whole year.

The equation for the cost intensity converts the cost/time ratio into the cost intensity parameter π . The amazing result of research into cost/time parameter was the absence of any consistent schedule cost items per year; there is no publicly available list of such items. Doubt exists that there are any reliable numbers on this, although privately confidential cost numbers may be complete and relaible. AI assembled a list of cost/year items which is still imperfect but at least, it is sufficiently complete to be useful, as follows:

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1. Liquid fuel
2. Gaseous fuel
3. Flying crew cost, including reserve crews
4. Amortization
5. All taxes
6. Interest
7. Insurance
8. Fringe benefits
9. Management and G & A
10. Landing fees
11. Licensing fees
12. Cost of provisions
13. Ground personnel at terminal stations
14. Maintenance costs, including gas purification
15. Terminal leases and warehouse rents
16. Unlisted costs

Σ S/year, Total operational cost per calendar year of transport

Item 16, takes care of unlisted costs which may be numerous but individually small; currently 11% of the total has been used for this item.

Slide III

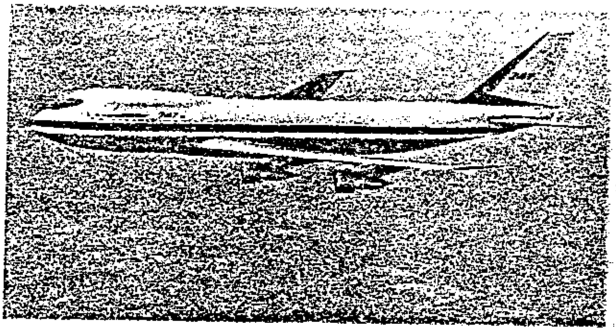

Fig. 1 747F

Tables I, II and III were computed comparing economically probably the best jet transport in freight service, the 747F with Metalclad airships MC-80 of equivalent payload and MC-100 carrying a higher payload per trip. Total flying time of 747F was taken as 3,650 hours/year and of airships as 6,000 hours/year, because airships, due to their lower speed, spend less time on ground than airplanes. Similarly, the amortization period is longer for airships than for airplanes due to their more severe rate of utilization than of airships.

Slide IV

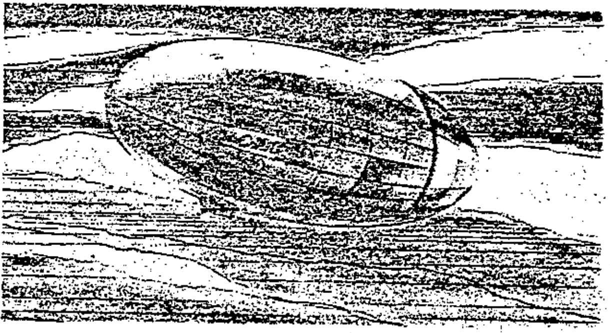

Fig. 2 MC-100

Tables I and II compare the airplane and two airships on a one trip basis. Table III contains comparisons on a yearly basis, transporting equivalent payload/year in all three cases. Since the total number of trips/year is lower for airships than for airplanes, the LTA transport requires more than one airship to carry the same yearly payload of an airplane. Cost computations reveal that the results on an annual basis are the same as on a single vehicle basis, with a negligible error.

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TABLE I

Los Angeles – New York
Air Distance, 2,561.93 Statute Miles

Item	Dimension	747F Airplane @33,000 ft	MC-80 Airship 5,000 ft	MC-100 Airship 5,000 ft
Gross weight	tons	321.256	216.681	270.851
Total amount of fuel used, LF GF	tons	55.45	16.313 1.3362	18.929 2.1307
Total amount of fuel per trip	tons	55.45	17.6492	21.0597
Payload per trip	tons	90.00	90.116	129.366
Mean travel speed	mph	510.68	100.00	100.00
Trip time, block to block	hours	5.01671	25.6139	25.6139
Σ S/T, cost per time	$\frac{\text{dollars}}{\text{hour}}$	6592.29	1078.73	1227.10
π, cost intensity	$\frac{\text{dollars}}{\text{tonmile}}$	.14343	.119705	.094855
π_{747F} / π_{MC_x}	---------	1.00	1.198195	1.512101
π, for equivalent payload	$\frac{\text{dollars}}{\text{tonmile}}$	.14343	.119551	.067666
π_{747F} / π_{MC_x}, for equiv. payload to 747F	---------	1.00	1.19974	2.119662
Total cost of one trip	dollars	33,071.6	27.636.3	31.437.4
Total amount of fuel for one trip	tons	55.450	16.313	21.06
Total cost of one trip for equiv. payload of MC-100	$\frac{\text{dollars}}{\text{trip}}$	47,537.10	39,673.30	31.437.40
Merit factor of cost, based on 747F	---------	1.00	.83458	.66132

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TABLE II

(continuation of table 1)

Los Angeles – New York

Air Distance, 2,561.93 Statute Miles

Item	Dimension	747F Airplane @33,000 ft	MC-80 Airship 5,000 ft	MC-100 Airship 5,000 ft
Total cost of fuel per one trip	dollars	16,552.23	8,009.62	9,204.16
Cost of fuel per tonmile	$\frac{\text{dollars}}{\text{tonmile}}$	.071787	.034693	.02777
$\frac{\text{Cost of fuel per tonmile}}{\text{Cost of fuel per tonmile MC-100}}$	—	2.58496	1.24925	1.00
$\frac{\text{Cost of fuel per one trip}}{\text{Cost of fuel per trip MC-100}}$	—	1.79834	.87022	1.00
$\frac{\text{Cost of fuel per one trip 747F}}{\text{Cost of fuel per one trip MC-80}}$	—	2.06654	1.00	1.149138
$\frac{\text{Cost of fuel per one trip}}{\text{Cost of fuel per one trip MC-100}}$	—	2.58494	1.24924	1.00
$\frac{\text{Fuel used by 747F per trip}}{\text{Fuel used by MC}_x\text{ per trip}}$	—	1.00	.31829	.3798
Fuel burned per ton of payload	$\frac{\text{tons}}{\text{ton}}$	.61611	.19585	.16279
Fuel burned per gross weight	$\frac{\text{tons}}{\text{ton}}$	.1726	.08145	.07775
$\frac{\text{Fuel burned per ton of payl. MC}_x}{\text{Fuel burned per ton of pl 747F}}$	—	1.00	.31788	.26422
$\frac{\text{Fuel burned per gross wieght MC}_x}{\text{Fuel burned per gross weight 747F}}$	—	1.00	.4719	.45046
Cost per mile of one trip	$\frac{\text{dollars}}{\text{mile}}$	12.91	10.79	12.27
Cost per mile of trip with payl. equiv. to MC-100	$\frac{\text{dollars}}{\text{mile}}$	18.56	15.49	12.27
$\frac{\pi\ \text{MC-80}}{\pi\ \text{MC-100 or 747F}}$	—	1.1982	1.00	.7924
$\frac{\text{Payload}}{\text{Gross weight}}$	—	.28015	.41689	.47763
$\frac{\text{Fuel used per trip MC-100 or 747F}}{\text{Fuel used per trip MC-80}}$	—	3.14179	1.00	1.19324
$\frac{\text{Cost of fuel per tonmile MC-100 or 747F}}{\text{Cost of fuel per tonmile MC-80}}$	—	2.0692	1.00	.80045
$\frac{\text{Weight of fuel per trip GF + LF}}{\text{Weight of fuel per trip 747F}}$	—	1.00	.3273	.379798

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TABLE III

Los Angeles – New York

Equivalent payload of one 747F per one year

Air distance 2,561.93 Statute Miles

Item	Dimension	747F Airplane @33,000 ft	MC-80 Airship 5,000 ft	MC-100 Airship 5,000 ft
Number of trips per year for equivalent payload per year	$\frac{\text{trips}}{\text{year}}$	727.6	234.2	234.2
Number of vehicle units required for equiv. payload per year	———	1.0	3.103	2.161
Total cost of operations per one year	$\frac{\text{dollars}}{\text{year}}$	$24.063(1))^6$	$20.242(1))^6$	$15.9136(10)^6$
$\frac{\text{Total cost per year } MC_x}{\text{Total cost per year 747F}}$	———	1.0	.84123	.66133
Total amount of LF consumed per one year	$\frac{\text{tons}}{\text{year}}$	40,345.42	11,948.63	9,581.90
$\frac{\text{LF consumed per one year } MC_x}{\text{LF consumed per one year 747F}}$	———	1.0	.29616	.23750
Total amount of GF consumed per one year	$\frac{\text{tons}}{\text{year}}$	0.0	1,344.91	1,078.56
Total cost of fuel consumed per year	$\frac{\text{dollars}}{\text{year}}$	$12.0434(10)^6$	$5.86673(10)^6$	$4.65915(10)^6$
$\frac{\text{Total cost of fuel per year } MC_x}{\text{Total cost of fuel per year 747F}}$	———	1.0	.48693	.38686
$\frac{\text{Total amount of fuel per year } MC_x}{\text{Total amount of fuel per year 747F}}$	———	1.0	.32949	.26423
Total amount of fuel per year	$\frac{\text{tons}}{\text{year}}$	40,345.42	13,293.54	10,660.46
π, cost intensity over a year period	$\frac{\text{dollars}}{\text{tonmile}}$	.145656	.122531	.09632

Conclusion

Energy as well as overall economic comparisons of airplane and two airships by means of cost intensity parameter π indicate that Metalclad airships can now be constructed and operated with an economic superiority to jet transports. It deserves to be emphasized that modern Metalclad airships will be as dramatically advanced in their capabilities and performance with respect to fabric-covered historical rigid airships as a 747F is now with respect to fabric-covered transport airplanes of 1925.

Comparisons displayed in Tables I through III are based on computer printouts of actual flights of 747F and on design studies of MC-80 and MC-100. In favor of 747F is the high speed of all jet transports and this may be an important advantage and at times, justified value in spite of its cost. 747F was used for comparisons only by way of example without intent of adverse reflection on this airplane, which is one of the most excellent in service today. Larger displacement airships would compare to jet airplanes still more favorably, in spite of the efficient flying of jet transports at high altitudes; this is indicated already in comparisons between the MC-80 and MC-100.

Only one principal reference is attached, because apart from its thoroughness of treatment of the subject, it also contains as complete a list of references dealing with air transport as has ever been assembled.

Reference:

Mark D. Ardema, Ames Research Center, NASA, Moffet Field, California, "Economics of Modern Long-haul Cargo Airships", 1976.