

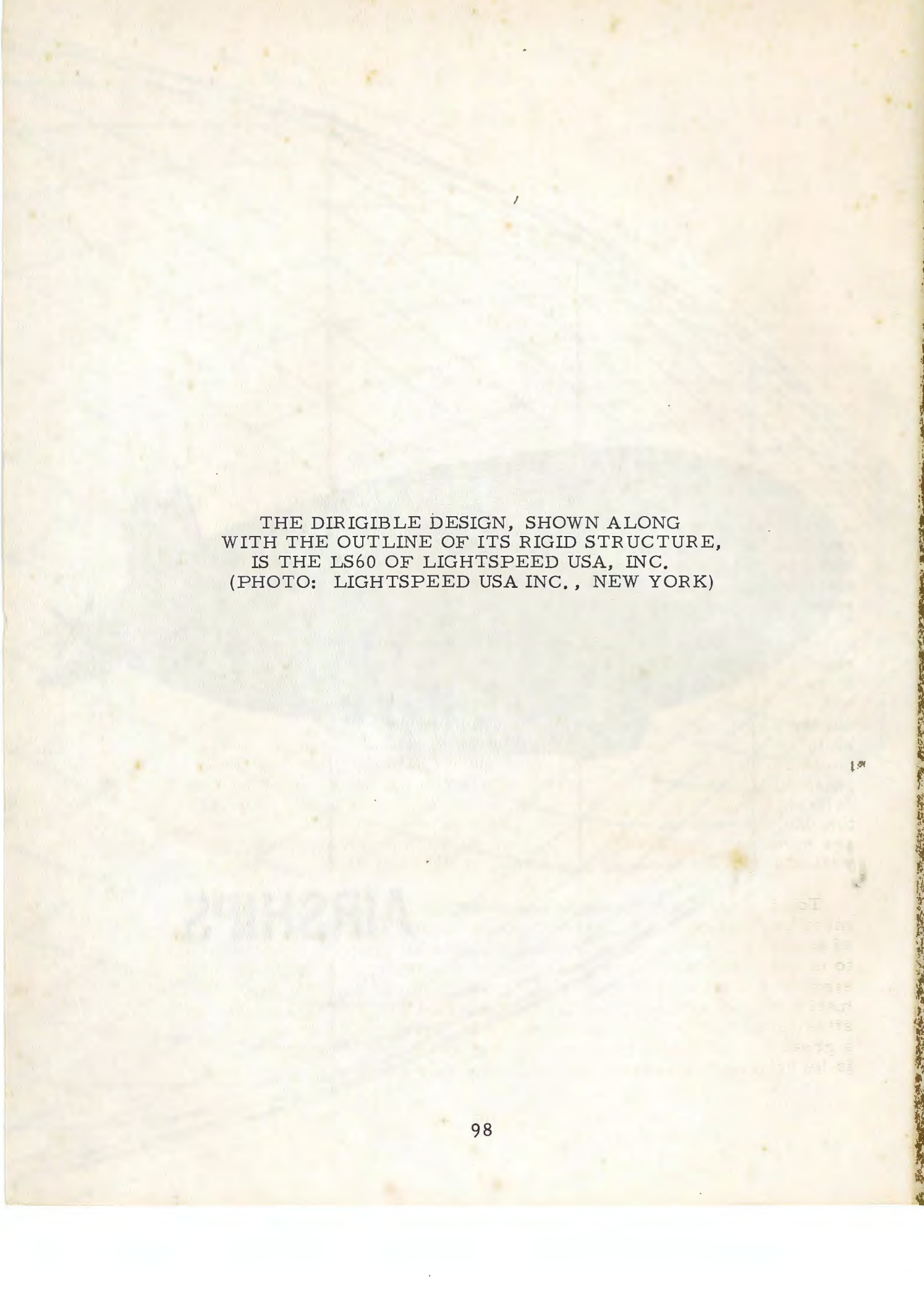
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A I R S H I P S

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AIRSHIPS



THE DIRIGIBLE DESIGN, SHOWN ALONG
WITH THE OUTLINE OF ITS RIGID STRUCTURE,
IS THE LS60 OF LIGHTSPEED USA, INC.
(PHOTO: LIGHTSPEED USA INC., NEW YORK)

The Potential Uses of Airships

The airship or dirigible, which is held in the air by a lifting gas (like a balloon) and moved forward by a motor (like an airplane), was once more common than it is today. Rather few have been used for sightseeing, advertising, and surveillance service since World War II. But recently a few people have begun to think about the uses airships might have in at least some developing countries, and interest has started to revive. So far Venezuela has ordered 22 airships to be built over a period of ten years (not delivered when this was written), the first new order for more than a decade, and perhaps a half dozen other countries are considering the question.

The first article to follow tells what an airship is; the second article analyzes several specific purposes for which airships could be used today in developing countries. This introductory statement supplies a general description of their weaknesses and strengths in different uses.

Airships are too large and expensive to be used without good reason to believe that they would have superiority over other modes of transport for some defined purpose. The knowledge and skills required to build them and operate them still exist; but they have not been kept in practice, so that manufacture would be initially more costly to absorb the development costs than it could become later if more of them were made and used. Even a small blimp with a 2 ton payload capacity would cost over a million dollars; the larger airships might be \$25-50 million, with 100-300 ton payload capacity. Probable operating costs per ton-kilometer are harder to predict in general terms, but they would surely be well above those for trucks or buses, railways, or ocean ships.

Total operating and capital amortization costs in various uses must be compared with those of ground transportation, and those of airplanes or helicopters. Factors such as speed, convenience to users, reliability, and dependence on investments in infrastructure must be considered along with vehicle costs in estimating the advantages of different transport modes. The most striking advantage airships can offer is that they do not require a great deal of infrastructure: neither roads nor railroads have to be built and maintained; and unlike airplanes they can land and

take off from any small cleared area. This not only makes the airship cheaper for uses where infrastructure has not yet been built, but it makes for flexibility--it can go almost anywhere without much preparation, which is a great convenience for passengers or cargo shippers. So if these qualities are important, the airship's chief competitor is the still more costly, hard-to-maintain helicopter, which is not as suited to long distance flights as the airship can be.

From this perspective, the next question would be: where does one find the conditions in which the airship's advantages are of value? In the developed industrial countries the construction of roads, railway lines and airports as well as supply facilities for spare parts and the availability of skilled labor, etc. are widely spread. In thinly populated areas this may be less true, but it is easy for the richer countries to build new facilities wherever new needs arise. In the densely settled portions of developing countries rail or road access is usually to be found; many rural roads may not be of the best quality, but where they exist goods and people are more cheaply moved on the ground than in the air. So one must look to the less settled portions of the developing countries to find airship uses. There are two kinds of reasons why transport of people and goods may be needed in the absence of roads: 1) mineral or oil deposits have been found in remote locations; 2) areas with rich agricultural or forestry potential may be unsettled and unconnected. In both cases difficult terrain, and often heavy rainfall, may raise the costs of road building and maintenance to very high levels.

For example, a simple, non-paved road in the northeast section of the Amazon costs in the range of \$75,000 to \$90,000 per kilometer to build. The maintenance of this road with tropical rains costs over \$12,000 per kilometer per year. This however does not mean that the road is usable throughout the year. When it rains transit stops for mud makes the road impassible. These remote areas are the most probable areas of comparative advantage for the airship. They are not the only possible uses in which airships might compete if they were more easily available, but they are the areas where the prospect of airship competitiveness could be reliable enough to stimulate the growth of manufacture, and the development of operating and maintenance skills.

For settled areas, airships may find special niches where they are suitable. Their normal cruising air speed of around 100 miles per hour (160 km. p. h.) makes them slower than airplanes but faster than ground or ship movements. For short distances, where speed differences are less decisive, the advantages of ground transport in low cost and availability are usually overwhelming. Airships might compete in cost with planes for long hauls of over 1,000

miles in some circumstances, though not with surface vehicles: if the speed difference from airplanes is not decisive but the speed advantage over surface movement is, as with some kinds of cargo like perishable agricultural products, there might be an opening for airships. There may also be some specialized uses for airships in shorter flights, discussed below. All these applications would require exacting cost estimates; cost components, and comparative advantages, can shift over time.

One final point: if an undeveloped area is to be opened, it could be argued that a road ought to be built so that settlements can grow up along and near it. Even though airship transport may be demonstrably cheaper, faster and easier to inaugurate, the developmental stimulus from building a road will be greater in the long run than that from airship use; this would be because airship transport could leave intermediate areas between terminals in isolated stagnation. Perhaps the best reply to that objection is that both forms of transport may be seen as complementary. Airships can focus on: exploratory stages of growth, on areas where road building is prohibitively expensive, where resources are not expected to last indefinitely (e.g. mines and oil wells), where transport demands are shifting in location or infrequent in given places (e.g. forestry), where various kinds of uncertainty as to soils or other local aspects prevail--in short, in conditions which will not or may not justify road (or rail) investment. While airship service is underway, feeder roads to airship terminals would grow up with settlement; low quality connecting roads may in time appear; and eventually all-weather roads for heavy trucks may become justified. But by the time this occurs, if it does, the airship could have made its contribution: either to the avoidance of premature or unjustified road investments (mistakes are easy to make), or to communications with areas where major roads never will be justified if the airship could be used as an alternative.

Gordon Donald
Editor, Development Digest

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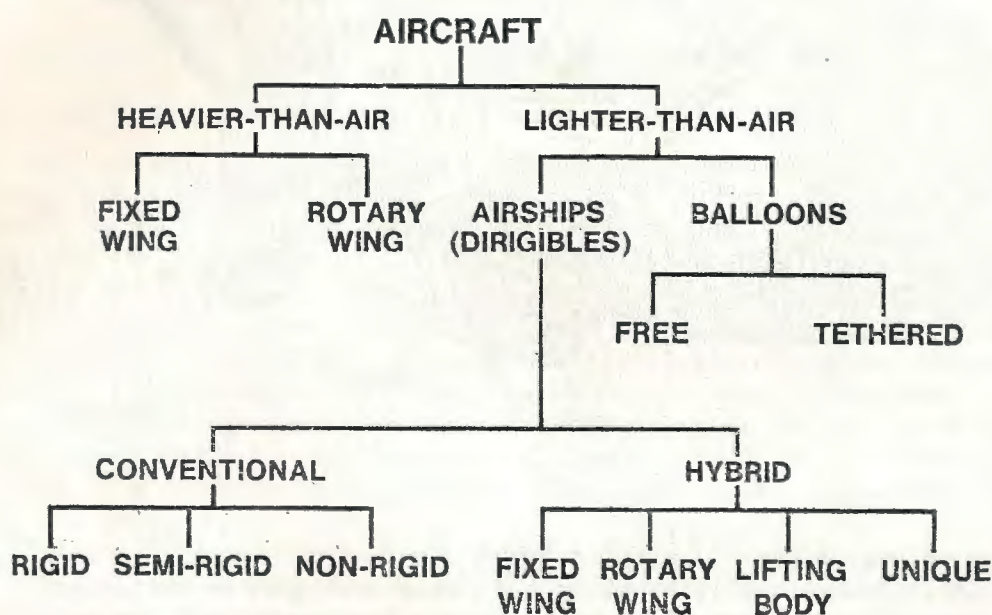
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they are related to each other. For this purpose, Figure 1 classifies the different types of lighter-than-aircraft (LTA). An LTA is an airborne vehicle which obtains all or part of its lift from the displacement of air by a lighter gas. LTAs are conveniently divided into "airships" (synonymous with dirigibles) and balloons, the former having a capability for controlled flight; only airships will be considered here. The term "conventional" applies to the class of approximately ellipsoidal-shaped, fully-buoyant airships which have been developed in the past. It is traditional to classify conventional airships according to their structural concept: rigid, non-rigid, or semi-rigid (the semi-rigid differs from the non-rigid only in having a rigid keel). Hybrid airships are classified according to the means by which the aerodynamic or propulsive portion of the lift is generated.

The Feasibility Study was initiated in December of 1974 and completed by the fall of 1976. There were two prime contractors, the Boeing Vertol Company and the Goodyear Aerospace Corporation.

FIGURE 1 - CLASSIFICATION OF AIRCRAFT

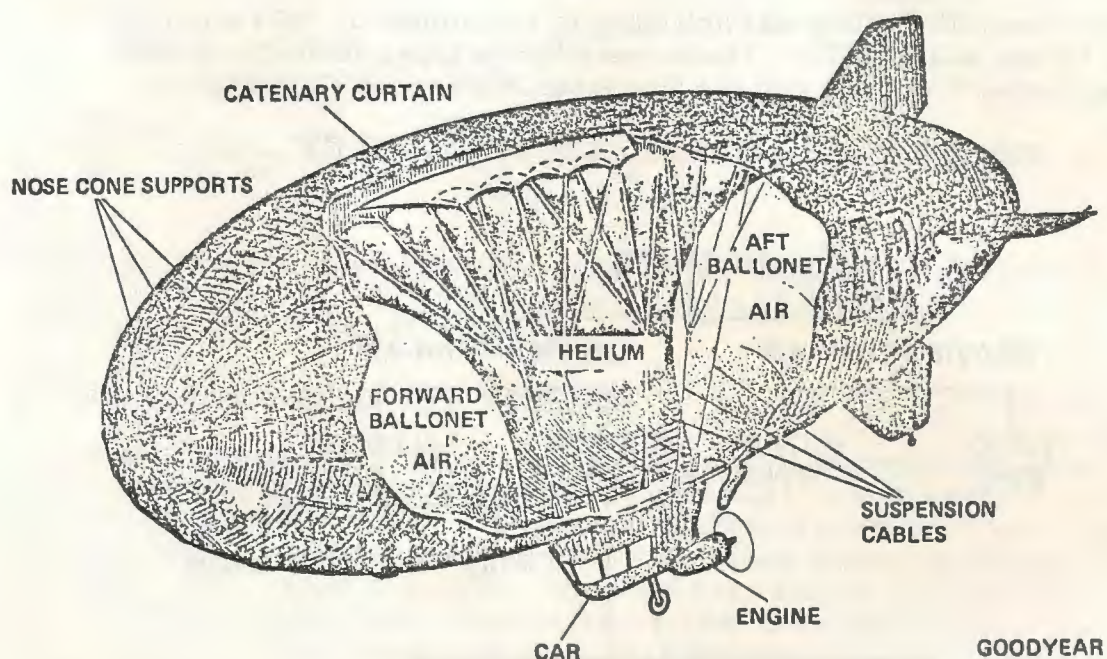


Historical Survey

Past Airship Concepts and Development History. The distinguishing characteristics of the rigid and the non-rigid airship

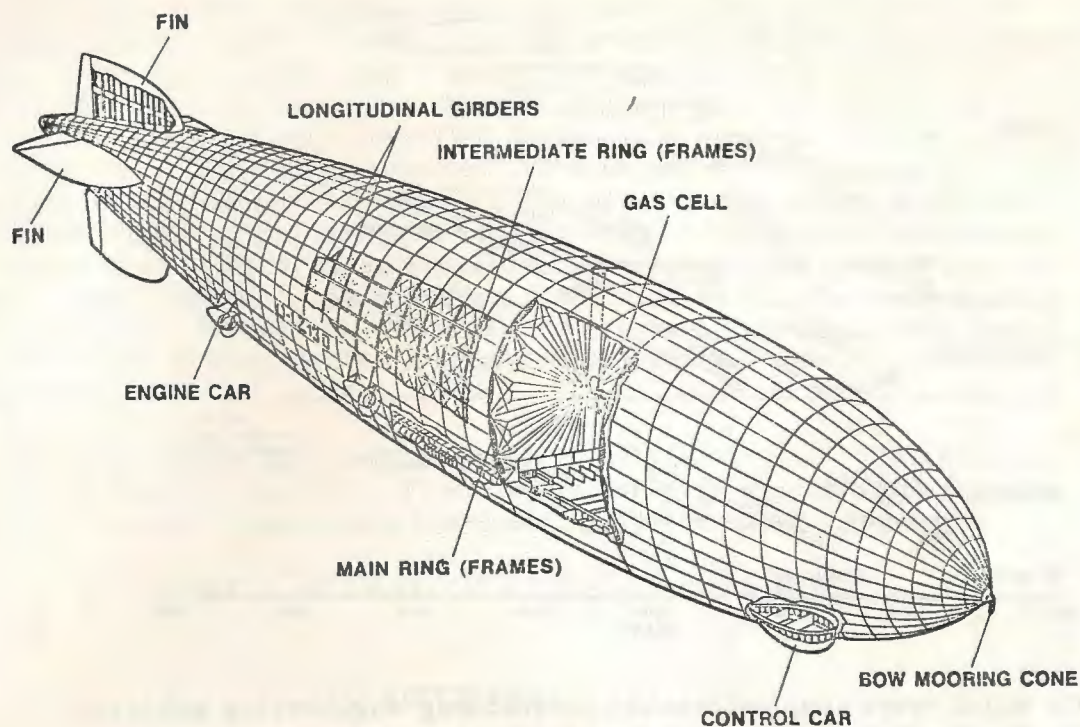
concepts will first be discussed. A typical non-rigid airship is shown in Figure 2. This type of airship consists of a non-rigid envelope, usually fabric, filled with lifting gas and slightly pressurized. Internal air compartments called ballonets expand and contract to maintain the pressure in the envelope as atmospheric pressure and temperature vary. Ballonet volume is controlled by ducting air from the propwash or by electric blowers. The weight of the car structure, propulsion system and other concentrated components is supported by suspension systems attached to the envelope, i. e. by cables running up through the center of the airship to the top of the lift-supported area. (See Fig. 2).

FIGURE 2 - TYPICAL NON-RIGID AIRSHIP



The other major type of airship has a rigid structure (Figure 3). This structure was usually an aluminum ring-and-girder frame. An outer covering was attached to the frame to provide a suitable aerodynamic surface. Several gas cells were arrayed longitudinally within the frame. These cells were free to expand and contract, thereby allowing for pressure and temperature variations. Despite their nearly identical outward appearance, rigid and non-rigid airships have significant differences in their construction and operation.

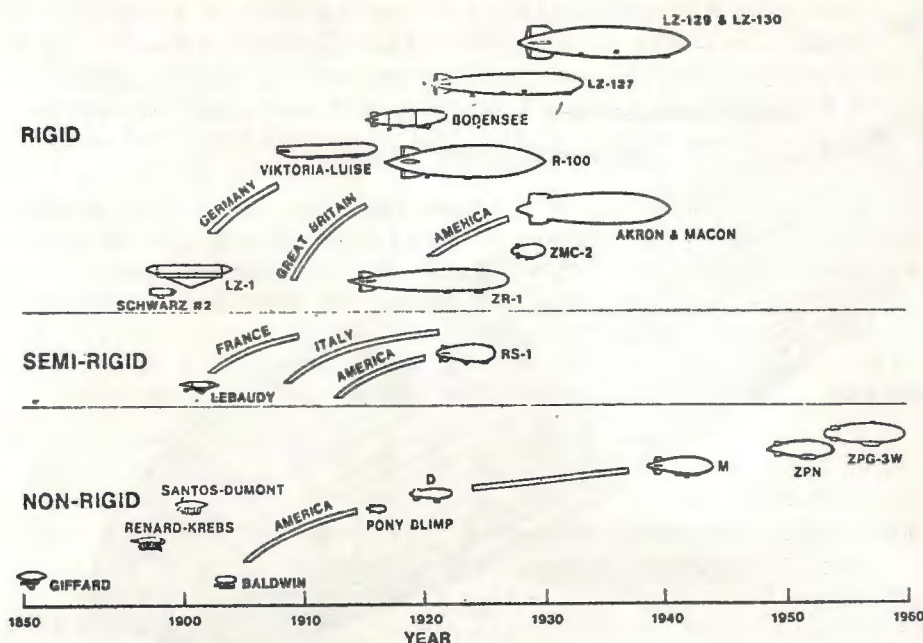
FIGURE 3 - TYPICAL RIGID AIRSHIP



The principal development trends of the three types of conventional airships are depicted on Figure 4. The non-rigids are historically significant for two reasons. First, a non-rigid airship was the first aircraft of any type to achieve controllable flight, nearly 125 years ago. Second, non-rigids were the last type of airship to be used on an extensive operational basis: the U.S. Navy decommissioned the last of its non-rigid airship fleet in the early 1960s. During the many years the Navy operated non-rigids, a high degree of availability and reliability was achieved; most of these were built by the Goodyear Company and a few non-rigids, based on a modified Navy design, are in use today for advertising by that company.

The rigid airship was developed primarily by the Zeppelin Company of Germany, and in fact rigid airships became known as Zeppelins. Even the small percentage of rigids not built by this company were based, for the most part, on Zeppelin designs. The rigid airships of the Zeppelin Company recorded some historic "firsts" in air transportation, including inaugurating the first scheduled passenger air service. The culmination of Zeppelin development was the Graf Zeppelin and Hindenburg airships of the

FIGURE 4 - HISTORY OF AIRSHIP DEVELOPMENT



1930s which were unquestionably outstanding engineering achievements for their day. None of the rigids were in operation by the outbreak of World War II, however.

Technical Qualities and Improvements

Aerodynamics and Design. All three types of conventional airships evolved into a common shape, the familiar "cigar shape" with circular cross sections and nearly elliptical profile. The fineness ratio (length divided by diameter) of the later rigids was typically in the range of 6 to 8. The fineness ratio of the non-rigids, which tended to be smaller and slower than the rigids, was typically in the range of 4 to 5. It is generally acknowledged today that past conventional, fully-buoyant airship designs were very nearly optimum for this class of vehicles in terms of aerodynamic shape and fineness ratio, so that airships could not be expected to show much improvement in this regard. It is estimated that a drag reduction of approximately 10% would be possible with adequate attention to surface smoothness and cleanliness. Use of boundary layer control may give significantly greater drag reduction, but this technology is still relatively undeveloped.

The early airships were designed by primarily empirical methods and the only company to accumulate sufficient experience to design successful rigid airships was the Zeppelin Company.

Two areas in which there was a serious lack of knowledge were aerodynamic loads and design criteria. Work in these areas was continued after the end of the last rigid in the expectation of further rigid developments, and significant progress was made. Improved analytical techniques and better estimates of loads led to improved design criteria which are still useful today.

Structures and Materials. The frames of most of the past rigid airships consisted of built-up rings and longitudinal girders stabilized with wire bracing. The rings and longitudinals were typically made of aluminum alloy and the bracing was steel. This structure was very light and efficient, even by today's standards. However, this construction was highly complex and labor-intensive, and any modern airship of this type would have to have a much simpler construction. Possibilities include the use of metal clad shell, sandwich, or geodesic frame construction. Material would be modern aluminum alloys or, further in the future, filamentary composite materials. A good candidate for wire bracing, if required, is Kevlar rope. It is estimated that use of modern construction and materials would result in a hull weight savings of approximately 25%.

There have been dramatic improvements in soft goods (textiles) with applications for airships in the past two decades. Soft goods are used for gas cells and outer covering for rigids, and for envelopes on non-rigids. The material most often used in past airships for these applications was neoprene-coated cotton; the envelopes of the later non-rigids were made of dacron. Dramatic improvements have been made in the strength of modern soft goods as compared with cotton. Kevlar appears to be the best material, but it has not been fully developed for use in large airships. Use of modern soft goods would result in estimated weight reductions of 40% to 70% as compared with past designs. There has also been a great improvement in coating films, which will result in a tenfold improvement in gas cell and envelope permeability.

The ratio of airship empty weight to gas volume is nearly insensitive to size. This is a reflection of the airship "cube-cube law" (i. e., both the lifting capability and the structural weight increase in proportion to the cube of the length for a constant shape). Since fixed wing heavier-than-air craft follow a "square-cube law," airships will compare more favorably with airplanes as size is increased. Smaller size airships have tended to employ non-rigid or semi-rigid construction, while the larger airships have been rigids. With a few explainable exceptions, past airships have all had about the same efficiency despite differences in design concept, years of development, and lifting gas.

Lifting Gas Selection. A primary consideration for an airship is selection of the lifting gas. The principal factor to be evaluated is lifting capability. It seems clear that the only possible lifting gases are hydrogen, helium, and steam. Other gases which are lighter than air, such as methane, ammonia, and natural gas, have less lifting capability than steam and could probably lift only the empty weight of an airship.

Hydrogen has the greatest lifting capability and is relatively inexpensive with an inexhaustible supply. But its flammability precludes its use, at least at the present time. Because of hydrogen's attributes, development of a fail-safe hydrogen containment system is a worthwhile goal, particularly if helium becomes scarce. The lifting capability of helium is not dramatically less than that of hydrogen, and helium has the great advantage that it is not flammable. The disadvantage with helium is that it is a limited resource. This leads to relatively high prices and possible future availability problems. Although the supply appears adequate for the foreseeable future, large scale use of airships could in time create a serious shortage. All factors considered, helium seems to be the clear choice for lifting gas for airships in the near future, and both contractors assumed its use in their analyses.

The other possibility, steam, has a lifting capability significantly less than hydrogen or helium. The advantages of steam are low cost, unlimited availability, and nonflammability. However, the elevated temperature of the gas requires a containment and temperature control system which is undeveloped at the present time. The elevated temperature also places new demands on structural materials. Because of its relatively poor lifting capability, use of steam will be restricted to airships with low ratios of EW (empty weight) to gross weight (GW). Another gas that is often mentioned is hot air, which has proven to be successful for use in balloons. However, balloons have very low EW/GW ratios because they lack many airship components such as propulsion and control systems. Within the temperature limitations of conventional airship structural materials (about 300°F), hot air would not even be able to lift the empty weight of most airship designs.

Propulsion Systems. Either Otto or Diesel cycle engines were used on the large airships of the 1930s. Modern airships will most likely use turboshaft engines which are highly developed at the present time. Thrustors will be prop/rotors. As compared with engines of the 1930s, these modern engines have about 90% of the specific fuel consumption and as low as 10% of the specific weight and volume. Perhaps more important is the greatly improved reliability and maintainability of modern turboshaft engines. An-

other possibility is a nuclear powerplant, particularly for long endurance missions and large airships, but this would take a long time to develop.

Controls, Avionics and Instrumentation. Flight control systems on past airships were purely mechanical. Commands from the helm (one each for vertical and horizontal surfaces) were transmitted by cable and pulley systems to the control surfaces. There were manual controls for releasing ballast and valving lifting gas. Engine controls of the rigid airships in the 1930s consisted of a telegraph which transmitted engine control commands from the helmsman to an engine mechanic who would then manually make the required engine changes. A modern electronic power management system will eliminate this cumbersome system and greatly increase the responsiveness, accuracy, and reliability of engine and other controls. This system would use many airplane and/or helicopter type components including an autopilot.

There has also been a vast improvement in avionics systems since the 1930s due largely to dramatic changes in electronic communications devices. For example, as compared with 1930 components, modern aviation radio equipment is about one-tenth the size and weight and much more versatile and reliable. Progress in the development of electronic components has also made possible the introduction of many navigation devices not available in the 1930s. Instrumentation on a modern airship would reflect modern airplane instrument technology, chiefly in an increase in accuracy. There will be, of course, a large increase in acquisition cost associated with all these modern systems and components, but this will be offset by lower operating costs due to manpower reductions.

Flight Operations and Ground Handling. The operation of the 1930's airships was as labor-intensive as their construction. In flight, large onboard crews were required to constantly monitor and adjust the trim of the ship and maintain nearly neutral buoyancy. Trim and neutral buoyancy were maintained by one or more of the following procedures: valving lifting gas, dropping ballast, transferring fuel or other materials within the airship, collecting water from the atmosphere and engine exhaust, and moving crew members within the airship. Also, it was not unusual to make repairs to the structure and the engines while in flight. It is obvious that modern structural concepts, engines, avionics, control systems and instrumentation will greatly decrease the workload of the onboard crew.

The experience of the U.S. Navy in the 1940s and 1950s with non-rigids indicates that modern airships can be designed to have all-weather capability at least equivalent to that of modern airplanes. High winds and other inclement weather need not endanger the safety of the airship and its crew, either in flight or on the ground. However, high adverse winds will continue to have a negative impact on the movements of airships due to their low airspeeds.

Extremely large ground crews were needed to handle the early Zeppelins, which were walked in and out of their storage sheds by manpower. Up to 700 men were used to handle the Zeppelin military airships. The Los Angeles needed a 50-man ground crew in ideal weather and 500 men in a 20 mph wind. Subsequent development dramatically reduced the number of men needed for ground handling. The first significant change was the development of the high-mast mooring system by the British. The U.S. Navy then developed the low mast which was more convenient, less expensive, and allowed the airship to be unattended while moored. A "ride-out" car was introduced to allow the ship to "weathervane," i. e., to move around the mast with its nose into the wind. Later, the mobile low mast was employed.

Economics

The flyaway costs per pound of empty weight of the rigid airships of the 1930s were comparable with those of transport airplanes of the same era. Since then, the costs of transport airplanes have steadily risen, even when inflationary effects have been factored out. This is because the steady introduction of new technology has made succeeding generations of airplanes more sophisticated and expensive. This increased cost has paid off in increased safety, reliability, and productivity. As discussed above, a modern airship would have several systems and components which are highly advanced compared with 1930s technology. Thus it seems likely that rigid airship flyaway costs would follow the general trend of fixed wing aircraft, so that a modern rigid airship would cost about the same as an equivalent-size modern airplane. One of the study's contractors, Goodyear, projected that for large airships flyaway costs will be less than for airplanes.

The only significant past commercial airship operations were those of the Zeppelin Company and its subsidiary DELAG. None of these commercial operations can be considered a financial success and most were heavily subsidized by the German government. For the DELAG operation of 1910-1914, for example, when

seven airships offered local pleasure cruises, revenues covered less than half of the operating costs. The LZ-120 operation of 1919 operated at a loss despite a load factor of 100%. The transatlantic service with the Graf Zeppelin in 1933-1937 (590 flights between Germany and Rio de Janeiro) required a breakeven load factor of 93-98%, a value that was seldom achieved. Throughout most of these commercial operations there was little or no competition from heavier-than-aircraft. However, airplane technology was making rapid strides and airplane speed, range, and productivity were rising steadily. By the time of the Hindenburg disaster in 1937, it seems clear that the most advanced airplane, the DC-3, had lower operating costs as well as higher cruising speeds than the most advanced airship, the Hindenburg. Of course, this tended to be offset by the Hindenburg's greater luxury and range.

An extensive design and economic study conducted by Goodyear in the mid-1940s showed that a fleet of advanced, large airships would be competitive with the airplanes of that era for both passenger and cargo applications. But with the vast improvements in transport airplane efficiency and productivity since that study was undertaken, this conclusion would probably not be valid today. Gains in the productivity of conventional airships over the last 30 years would be relatively small because cruise speeds would be essentially unchanged.

Analysis of Possible Vehicles for Future Development

The Feasibility Study included an examination of the engineering relationships that could be applied to a wide range of potential aircraft, including both the conventional fully buoyant airship and a number of possible hybrids depending on both lifting gas plus some kind of aerodynamic or propulsive lift. [Only a few points from this highly technical analysis will be presented here.]

Boeing selected six different types of airship hybrid vehicles for intensive analysis, indicated in Figure 5. Of these the Boeing helipsoid concept proved to have the probability of highest productivity, defined as speed times payload; generally the hybrids had estimated speeds around 150 miles per hour, while airships were plus or minus 100 mph. Boeing focused more on the longer distances (around 2,000 miles) and 50-100 ton payloads. Goodyear, on the other hand, ended its analysis by proposing further study and development of two shorter-range concepts, shown in figures 6 and 7.

FIGURE 5 - CONCEPTS SELECTED FOR PARAMETRIC EVALUATION

FULLY BUOYANT
CONVENTIONAL



RIGID AIRSHIP

PARTIALLY BUOYANT
STOL

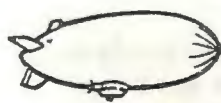


AEREON DYNAIRSHIP
LIFTING BODY CONCEPT

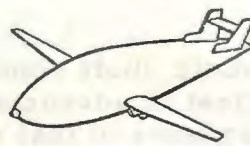
PARTIALLY BUOYANT
VTOL



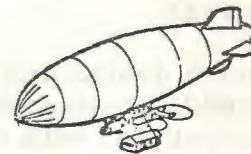
BOEING HELIPSOID
LIFTING BODY CONCEPT



NON-RIGID AIRSHIP



MEGALIFTER
(WITH TURBOPROPS)
FIXED WING CONCEPT



PIASECKI HELI-STAT
ROTARY WING CONCEPT

FIGURE 6 - AIRPORT FEEDER CONCEPT

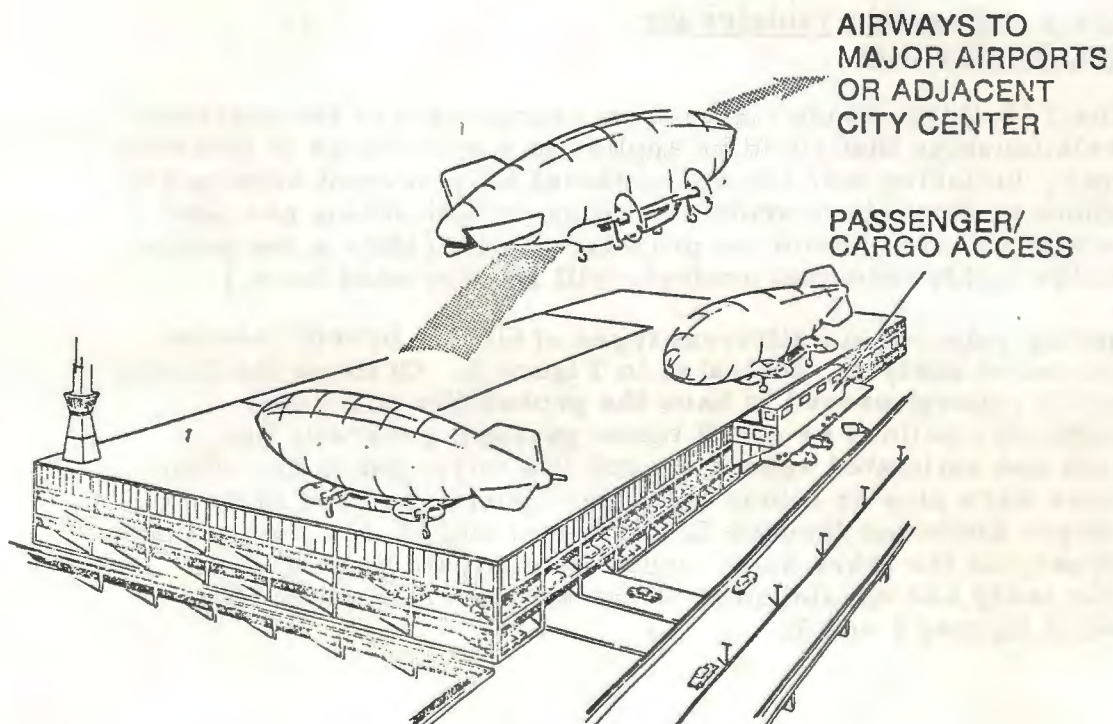
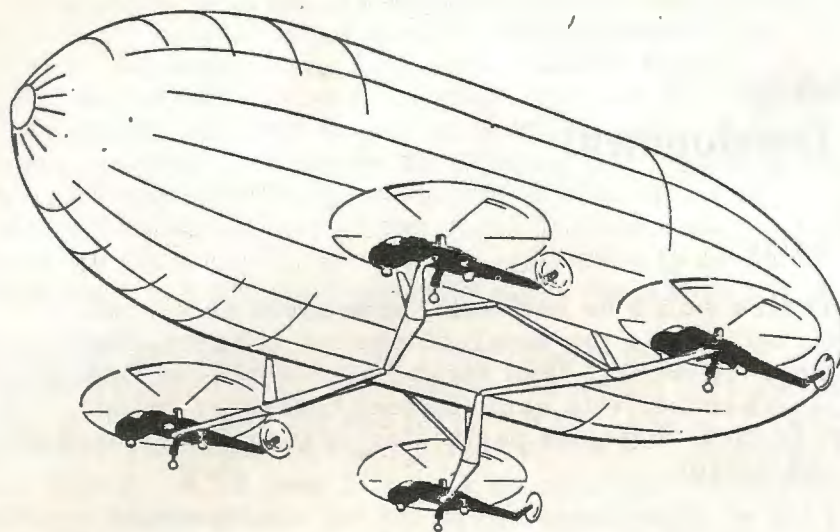


FIGURE 7 - HEAVY LIFT CONCEPT



The first was a relatively small metal-clad airship for use as a feeder of passengers and cargo to and from airports in areas where low-noise and low-pollution requirements would favor the airship in competition with planes or helicopters. The second concept was a "Heli-Stat," an airship assisted by four helicopters intended for lifting very heavy loads, too wide for normal road or rail transport, over relatively short distances. Its weight lifting capabilities would be far in excess of anything in existence today. Some applications for such a vehicle could be: delivery of nuclear and conventional power plants, or delivery of modularized houses and bigger buildings. Other possibilities are the transport of logs from remote timber areas lacking roads, and the loading and unloading of containers from ocean vessels.

[Extracted from a paper presented
to the 9th Scientific Balloon
Symposium of A. F. G. L. at
Portsmouth, New Hampshire,
October 1976.]

Rules for Airships In Economic Development

George J. Beier
Gerardo Cahn Hidalgo

[Where surface routes would be unusually expensive or circuitous, or if the market size is too small to spread infrastructure costs of conventional transport, then airships of tested technology present a workable alternative to conventional transport modes. The paper argues from a series of particular cases; though unusual, these cases are not unique.

Two quite different cases will be analyzed here: the application of large airships of over 100 ton load capacity for long distance transportation; and the utilization of smaller airships to haul small cargoes for relatively short distances.

Cost Characteristics of the Airships

In order to proceed with a cost comparison of the airships against the conventional modes of transport, several assumptions are necessary. For the most part these are embodied in the data in Table 1.

(a) Cost of Construction: We have no recent direct evidence on capital cost for a large airship. Research and development are only counted as very minor cost elements; we are simply attempting to estimate how much the cost of construction has increased over the years since it was actually performed. The basic design and operating

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characteristics are well-known. Dr. Eckener, in 1952, estimated the cost of a new Hindenburg at \$7.7 to \$12.5 million, i. e. from \$68 to \$110 per kg empty weight (i. e. weight without cargo). We have assumed a present (1974) construction cost of \$200 per kg empty weight for the large airship--about three times Dr. Eckener's low estimate. This seems about an adequate allowance for increased cost since 1952. For the smaller airships (2 tons and 15 tons), we assumed a construction cost of \$300 per kg empty weight, in accordance with the average cost estimates given by manufacturers for airships in this size range. Since they are intended for use in more difficult terrain, with many take-off operations, these airships will have to be more maneuverable and need a higher power/weight ratio than the larger ship.

(b) Interest and depreciation: Throughout the paper we assume a 10% interest rate for all alternative transport investments. We assume a 20 year life for the large airship and a 10 year life for the smaller airships, in recognition of the rougher jobs envisioned for the latter. A 20 year life may be near the outer limit of reasonable assumptions for the large ship; but it is not clear that successful airships in this class, e. g., the Graf Zeppelin, were anywhere near the end of their useful life when they were scrapped for want of helium.

(c) Flight time: We assume that the large airship could fly 6,000 hours a year. By way of comparison, the Hindenburg flew 2,810 hours in its first nine months of service, an annual rate of 4,215 hours. The use we are considering is a regular, shuttle type operation and the 6,000 assumption should not be too optimistic in these circumstances. For the smaller airship, in rougher terrain with irregular loadings, we assume a 3,000 hour per year performance--roughly a day-time only schedule.

(d) Locations: We assume that the large airship will be operating under favorable conditions of climate and terrain without interruption. The small airships would operate from small bases at approximately 700 meters altitude.

The large airship is patterned on the Hindenburg, one of the largest airships ever in operation. It was a rigid structured dirigible with a gas volume of 216,000 cubic meters, a static gross lift of 206,400 kg, empty weight of 113,000 kg and useful lift of 93,000 kg. S. L. T. A. Inc. has made a series of estimates on the characteristics of a modernized Hindenburg, which we shall call the "H2". The H2 is similar in design to the Hindenburg, but is increased in length and in diameter by 10%; there is no radical technological change. The enlargement increases the volume of the H2 to 266,000 m³, and the gross lift to 266,000 kg.

Incorporating modern structural materials, lighter engines, and modern advances in gearing, the H2 should be able to achieve a slightly better static efficiency than its predecessor: we have assumed a useful lift equal to empty weight 133,000 kg, using helium as the lifting gas.

On these assumptions, the cost estimates of Table 1 were prepared.

TABLE I
COST CHARACTERISTICS OF THREE AIRSHIPS

Carrying Capacity	H2	smaller ships	
	133 ton airship	15 ton airship	2 ton airship
Airspeed (km hr)	129	130	130
Ground Speed (km hr)	113	110	110
Distance studied (km) ^{a/}	1,290	220	220
Flight duration (hours)	11.4	2	2
Horsepower required	4,937	1,700	1,000
Fuel required ^{b/} (kg per trip)	11,256	680	400
Payload (metric tons)	121.7	11.25 ^{c/}	1.50 ^{c/}
Productivity in ton-km per hour	13,752	1,238	165
Personnel and Maintenance cost (\$/hr)	150	83	43
Personnel and Maintenance cost (¢/ton-km)	1.09	6.7	26.1
Fuel cost (¢/ton-km)	.84 ^{d/}	2.7 ^{e/}	12.1 ^{e/}
Direct operating cost (¢/ton-km)	1.93	9.4	38.2
Yearly capital recovery charge (\$ million)	3.12 ^{f/}	.68 ^{g/}	.31 ^{h/}
Yearly payload (million ton-km)	82.51	3.71	.50
Capital Charge (¢/ton km)	3.78	18.3	62.0
Total Cost (¢/ton-km)	5.71	27.7	100.2

a/ Average distance of trips considered in the main comparison study.

b/ 0.2 kg per hp per hour.

c/ Assumed 75% load factor.

d/ Price per kg, April 1974 price FOB Matadi.

e/ Price per kg \$0.10.

f/ Cost \$26.6 million, depreciated over 20 years at 10% interest.

g/ Cost \$4.20 million, depreciated over 10 years at 10% interest.

h/ Cost \$1.89 million, depreciated over 10 years at 10% interest.

Source: Based on data furnished by Studiengruppe Luftschiffbau und Anwendungs Bereiche.

Use of the H2 in the Zaire Export/Import Trade

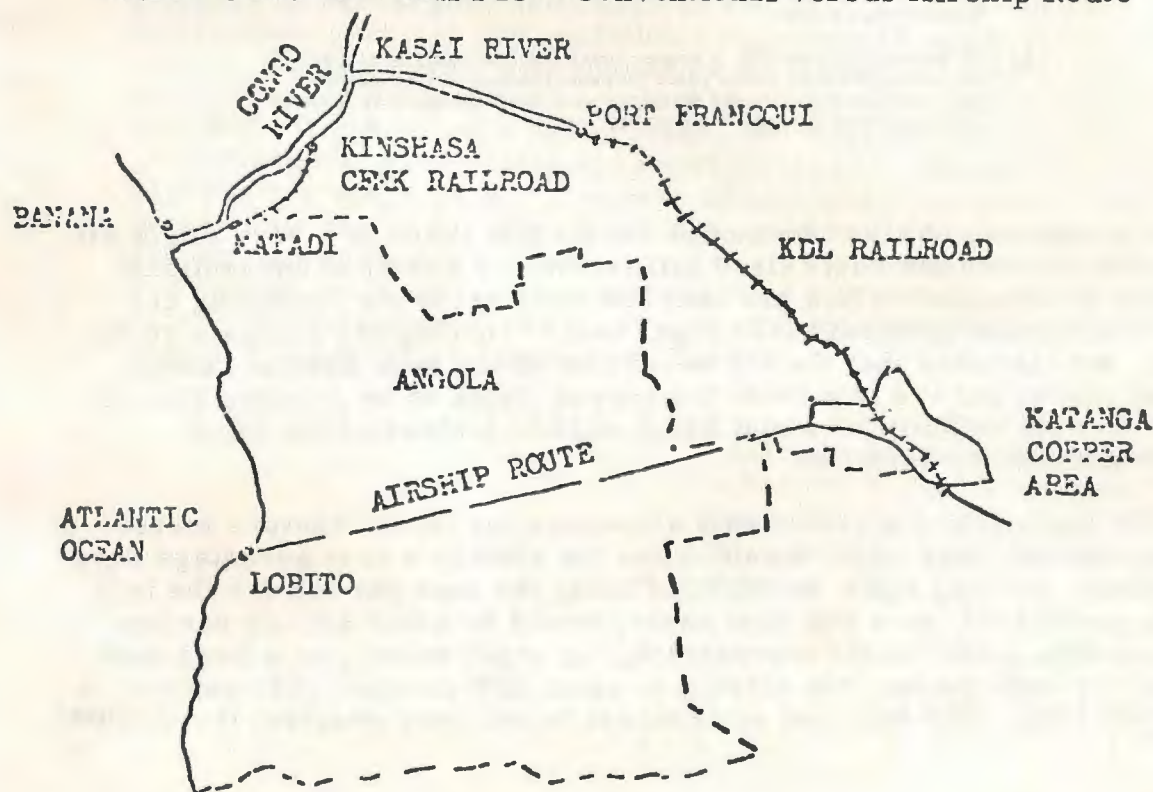
The cost calculation for the H2, shown in the first column of Table 1, was derived to approximate the cost per ton-km of a shuttle service

for moving copper from the Katanga in Zaire to an Angolan Atlantic port, Lobito, and the return of general cargo to Katanga, a stage length of about 1,290 km. Adequate balanced bulk cargo traffic is generated on this route to insure a virtually continuous full load operation. Hence the 100% load factor implied in the Table 1 calculations. The operating conditions on this route are nearly ideal: moderate temperatures and low land elevation.

To compare the cost of the H2 against conventional modes of transport, we calculated the cost per ton via airship over the 1,290 km stage length from Katanga to Lobito: \$73.6 per ton (5.71¢ per ton-km times 1,290 km). The first set of costs against which to evaluate the performance of the H2 are the short run costs of conventional transport modes: the direct operating cost of vehicles (railroad rolling stock and river fleets); the cost of administration, repair and maintenance of infrastructure that vary with use of the infrastructure; the depreciation and interest cost of the vehicle fleet. Specifically excluded are any construction or capital charges for infrastructure, or any charge for fixed administration or maintenance.

The existing transport route we are considering is composed of three parts: the Kinshasa-Dilolo-Lumumbashi Railroad, from the copper areas of the Katanga to Port Francqui (1,430 km); a river barge portion from Port Francqui to the Port of Kinshasa (800 km);

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and a further railroad, the Chemin de fer de Matadi Kinshasa, 366 km from Kinshasa to Matadi, the port on the Congo river with access to the Atlantic. The cost characteristics of the present modes were studied in a major work published in 1971 by the French consulting firm BCEOM. Without updating for the inflation since then, except to take account of the increase in fuel prices, we obtain the following cost estimates (Table II).

TABLE II
OPERATING COSTS OF MATADI-KATANGA TRIP, CONVENTIONAL MODES

	US\$/ton km	KM	\$/ton
Katanga-Port Francqui (rail)	2.86 ^{a/}	1,430	40.89
Port Francqui Trans-shipment			5.95
Port Francqui-Kinshasa (river)	0.92	800	7.36
Kinshasa Trans-shipment			5.95
Kinshasa-Matadi (rail)	1.75 ^{a/}	366	6.40
Total Operating Costs			66.33
Inventory Cost of Goods in Transit ^{b/}			5.04
Total transit cost exclusive of infrastructure investments costs (per ton/trip)			\$71.59

Source: BCEOM, *Etude de Transport de la Voie Nationale*, October 1971.

a/ To update the fuel price changes, the fuel component in marginal cost for the two railways was multiplied by a factor of 3.715, the latter being the ratio of gas oil prices in 1974 (\$117 per metric ton CIF Matadi) and 1971 (estimated at \$31.50 per metric ton CIF West African ports).

b/ An interest rate of 10%, a copper price (FOB Matadi) of \$1,624 per ton, and a bulk goods price (hackhaul cargo) of \$200 per ton, were used to calculate the inventory cost for 20.2 days (the average trip time from Katanga to the port).

A comparison of the two modes shows that there is a very slight difference between the costs (less infrastructure costs) of conventional modes of transport (\$71.6 per ton) and the total costs (including construction costs) of the H2 (\$73.6 per ton). Turning the analysis on its head, we calculate that the H2 would just break even against conventional modes for the trip from the copper fields to an Atlantic Port if the H2 could be built for about \$25.5 million instead of the \$26.6 million which we assumed.

The inclusion of a reasonable allowance for infrastructure investment, on the other hand, would make the airship's cost advantage very striking. Relying again on BCEOM data, the cost per ton for the trip Katanga-Matadi, on a full cost basis, would be about \$20-25 per ton higher than shown in the comparison. In other words, on a total cost basis for both modes, the airship is about 25% cheaper (\$73 per ton vs. \$95 per ton). The full cost comparison is not very precise; the BCEOM

estimate refers to full cost of past investment rather than the full cost of future investment which might be avoided by use of airships. But it is not unreasonable to assume that the BCEOM estimate is less than full future cost. The list of conventional investments required to handle increments to traffic is indeed impressive, totalling from \$148 million to \$266 million, at 1971 prices, for the period to 1990 depending on the assumption concerning use of foreign routes. The bulk of this investment might be avoided or postponed for many years by use of airships.

A few other features of the comparison of costs between conventional modes and the H2 seem worthy of special note. The competitiveness of the airship against conventional modes without infrastructure cost depends on the much longer surface route. This suggests that at the present state of the art the airship will not be generally competitive for bulk loads in cases where surface infrastructure is adequate and the trip is fairly direct, but that the flexibility of movements may tip the scales in favor of the airship when the surface route is indirect. Second, higher fuel prices make airships more competitive rather than less so. Fuel costs are only about 15% of total airship cost; the bulk of the cost is the capital charge. At 1974 prices fuel is in the neighborhood of 35% of operating costs for the competitive modes. Our comparison will hence be more favorable as oil prices increase, less favorable with a decline in oil prices. Third, inventory costs, even for a commodity as expensive as copper, do not turn out to be very important relative to other transport cost items.

We have made this comparison only to, not through, the port because we have no basis for a comparison of ports costs for the H2 and conventional modes. No airship has ever undertaken this type of commercial freight operation. But it is generally believed that port costs could be lower for the H2. Using the airships' ability to operate from a sheltered water base, the H2 might unload onto a special purpose barge, and pick up return cargo, without ever using the normal port facilities. It seems quite clear that this will always give the airship a decided advantage over other air transport because conventional airplanes with a landing site away from the port require at least one more transshipment and a short surface haul. In normal circumstances, transshipment to ships from the H2 would probably be cheaper than transshipment from rail.

There are other examples of sizeable mineral deposits discovered in areas much less well connected to markets than Katanga. For example, a rich deposit of nickel lies very shallow (for open mining) near Rustava in Central Burundi; potential output might be 30-50,000 tons a year. Connecting roads may cost some \$45-50 millions; a rail connection would cost perhaps \$300 million. In such situations the case for airships becomes even stronger.

Use of H2 for Exports of Horticultural Products from Kenya to Europe

An often mentioned possible mission for airships is the intercontinental shipment of fresh produce. For our example, we investigated the possibility of increasing the vegetable and fruit shipments from East Central Africa to Europe--specifically the shipment of such goods from Nairobi to London. At Nairobi-to-London backhaul rates ranging from \$.35 per kg (the most favorable contract rate) to \$.48 per kg (IATA rate), the transportation of produce by air increased from just over one thousand metric tons in 1969 to 6.5 thousand metric tons in the first nine months of 1972. The 1972 traffic experienced shortages of cargo space at backhaul rates, and the growth of this traffic is expected if transport at these rates can be expanded. Sufficient volumes already exist to employ an H2, and traffic can be expected to expand.

The cost per ton-km at backhaul rates (for comparison to Table I) ranges from 7.08¢ (IATA rates) to 5.16¢ (contract rates). As Table I shows, the cost per ton km for the H2 in virtually ideal conditions is 5.71¢. Even after increasing estimated costs by about one-half to compensate for less favorable operating conditions, the H2 could still deliver at rates in the general neighborhood of the 1973 IATA backhaul rates.

The H2 presents a transport alternative, not very much more costly than the backhaul rates which have fostered rapid expansion of the Kenya-London vegetable and fruit trade, and well below the costs of transport at ordinary air freight rates, which at the beginning of 1973 were about 18¢ per ton km from the Nairobi Region to Europe. It would appear therefore that the H2, or eventually a more advanced airship, may be important in breaking the backhaul bottleneck that now impedes further horticulture development in Kenya.

However, the H2 faces some problems not encountered by backhaul traffic. First, the bulking requirements (100 tons) would be much more demanding at the point of origin. Second, the low speed would make the H2 less flexible in meeting the timing requirement at markets than is backhaul traffic. Finally, the airship is barely competitive with conventional airplanes on a cost basis for handling the traffic once volumes are large enough (say 15,000 tons per year) to justify a cargo plane devoted to this use. Costs, calculated on the same basis as those for the H2, ranged from 3.5¢ to 5.5¢ per ton-km for conventional aircraft in 1972. For comparable planes the cost increase has been about 60% since that time, mainly on account of fuel cost increases which have more than doubled. Costs for conventional aircraft would thus be in the 6 to 8 cent range per ton-km, at this point in 1974, roughly competitive with the H2. The

ground cost advantages of the H2 would probably be minimal in this situation because the infrastructure for planes is already highly developed.

Using Small Airships in the Region East of the High Andes in Peru

In the use of airships in the Andean region, the development program is considered in two basic steps: 1) the use of small airships, with useful load capacity of about 2 tons; 2) the use of a larger 15-ton capacity dirigible to replace the small airship in a particular area once the technical aspects of the use of an airship in the area have been proven, experience has been gained with its developmental impact, and crews have received adequate training. Because the crew will generally not have good ground support, they will need skill in maintenance and unassisted landings, as well as for operating in difficult terrain. From the economic point of view, only the larger dirigible will be competitive, as shown below. But to gain experience with maximum safety, the smaller high-powered, easily handled ship will be used. The cost characteristics of both airships were presented in Table I. The general zone that we are considering for use of these airships is east of the Andes mountains in Peru. The region reaches from the mountain side, called "ceja de montana" in Peru, to the Amazon valley. A zone with similar geographic characteristics reaches into Ecuador and Colombia to the north and into Bolivia in the south. The altitude varies from 1,500 m in the mountains to 700 m in the east and goes on into uncharted country, forests, and eventually into tropical jungles through which run the head waters of the Amazon. The valleys are sparsely populated, and the potentially productive area is, for the most part, undeveloped. These areas could potentially support a much larger population if better transportation and communications are supplied and if agriculture production is improved. Peru is now a large importer of foods, over \$230 million per year, in spite of having large unutilized areas for agriculture.

In these regions, roads are costly to construct and hard to maintain, and may be impassable in many periods of the year. Vehicles deteriorate rapidly and have high maintenance requirements. The high freight rates reflect the condition and type of road, the topography, and the irregularity of loads, vehicle circulation, and back-hauls. Transport presents a particular problem in the flow of agricultural products because the arable land is largely found in relatively small valleys separated by rough gorges and ravines. A valley can therefore remain isolated economically, even when it is quite near a road "as the crow flies." The construction of access or penetration roads is extremely costly in the regions under consideration--above \$250,000 per km. Although distances are relatively short, the linking of all of the main valleys with penetration

roads is therefore not justified until and unless a high level of development is reached.

Air transport with conventional aircraft would require a large number of airstrips to provide adequate access, and it is doubtful that they could be constructed at a reasonable cost. Transportation with the prevalent airborne modes has higher direct operating costs as well: for example, the De Havilland twin otter--\$0.56 per ton-km, the Helicopter Sikorski--\$1.49 per ton-km, as compared to the 15-ton airship--\$0.30 per ton-km. Consequently, the VTOL (Vertical Take-Off and Landing) air transport mode is envisioned to fulfill the communication needs.

The transportation needs are for moving small cargos for short distances to road, rail or river heads. The aspects favoring the dirigible, in addition to its relatively reasonable cost of operation, are its flexibility and very low infrastructure cost. It does not require landing strips. An open field a little over twice the length of the vehicle in diameter, with a simple mooring tower placed in its middle around which the airship can weather-vane, will suffice. Thus in regions like those described, the airship could provide the link between the many isolated small communities and the few roads which provide general access to the region.

We may take a specific application for cost calculation: Transportation in the zone linked by the road Huanuco-Tingo Maria-Aguaytia in eastern Peru. Presently the road is semi-completed. It is not paved, and 30 km remain as a five-meter wide earth path. From Huanuco westward, however, the road links up to the coast highway. We may consider the airships as alternatives to road development east of Huanuco.

The cost of completing the construction and the improvement of the 219 km road from Huanuco to Aguaytia was estimated at \$57,597,000, or \$263,000 per km. Depreciation over twenty years with a low estimated maintenance cost of \$650 per km per year results in a total yearly cost of \$31,526 per km for this road. (Costs that have already been incurred for the original road are not included in this estimate.) In 1972, traffic over the 219 km road from Huanuco to Aguaytia varied from 350 vehicles per day between Huanuco and Tingo Maria to 200-250 vehicles per day beyond Tingo Maria. At 300 vehicles per day the annual cost of the road would be \$0.282 per vehicle km or \$.115 per ton-km at the average load of 2.5 tons. The operating cost of the medium trucks that ply this road has been estimated (in 1973) as \$.25 per ton-km.

While the 2-ton airship at \$1.00 per ton-km is not competitive on a commercial basis, the 15-ton airship at \$0.296 per ton-km is highly competitive. In addition, it has inherent advantages over

TABLE III

SUMMARY OF ROAD TRANSPORTATION COSTS HUANUCO-AGUAYTIA

1. Road 219 km	
1. Capital Investment	\$57,597,000
2. Annual Capital Charge plus maintenance per km	31,500
3. Annual Capital Charge per ton/km \$/ton-km	.115
4. Total operating cost for truck \$/ton-km	.255
5. Total cost road transport \$/ton-km	.370

roads. It can stimulate agricultural development in a much broader zone, in regions far from this principal road where the developing stage would not justify the constructions of costly feeder roads for new agricultural development programs. The investment in an airship is minor, and its use is flexible, making it less risky than a high, fixed road investment. The airship can aid the development of potentially rich agricultural zones, such as those considered, almost immediately; it would be necessary to wait a long time before a road network is completed.

We conclude that in this case the airships are competitive with the construction and periodic reconstruction of the main road servicing the area. In addition, the airship can connect regions that are not effectively serviced by the road. Compared to feeder roads, which would also have very high costs but much lower traffic volumes, the airship is far less costly.

We may consider next the question of transportation to an isolated region in the Peru Via area to the southeast of Aguaytia. Except for a few scattered landing strips for light planes, and small fringe areas where dirt roads penetrate, this region is almost inaccessible. It has been amply demonstrated, through unsuccessful colonization experience east of the Andes, that without adequate transportation there is economic stagnation, a lack of progress, and large-scale farm abandonment. Colonization without proper transportation facilities would result in a waste of national resources. Several zones in this area are under active consideration in the country's development plans for the settlement of 37,000 families in the Apurimac-Ene valleys and 20,000 in the Palcaza-Pichi region. The regions are apt for cattle, agricultural, and forest production. More generally, within the radius of 150 km from Atalaya lie regions with an extremely rich potential. It can be expected that the presently existing population will multiply its output once a market for their products is established, and new production technologies can be introduced.

Atalaya is at a projected road distance of 365 km from the west-east road head near San Ramon which provides communication to the coast. A connecting road implies 316 km of mountain road (average construction cost \$/km 250,000) and 49 km of level road (\$/km 150,000). To provide adequate communication, several hundred kilometers of additional feeder roads (estimated construction cost \$/km 30,000) would also be required. The total construction, maintenance, and operating cost of \$0.52 per ton-km (see Table IV) is less than the direct transportation cost of a 2-ton dirigible (\$/ton-km 1.00), but considerably more than on a 15-ton airship (\$/ton-km 0.296) as estimated under present conditions.

TABLE IV

SUMMARY OF ROAD TRANSPORTATION COSTS SAN RAMON-ATALAYA

I. Roads 365 km	
1. Capital Investment	\$86,350,000
2. Annual Capital Charge plus maintenance \$ per ton	28,350
3. Annual Capital and Maintenance Charge \$ per ton-km	.20
4. Truck operation cost \$/ton-km	.32
5. Total cost per \$/ton-km	.52

The present situation is that the produce of this zone does not leave the region due to lack of transport facility, and production remains limited as there are no accessible markets. Thus we are faced with questions such as: (a) To develop or not to develop the zone. (b) To start the agricultural projects practically immediately, or several years hence when the surface communication network can become operational. (c) To risk heavy investment capital to develop surface transport access before the development of the region is proven, or to postpone the projects until the production of the zone is flourishing. We would argue that in this case, where the road infrastructure is not yet in place and the economic risk of such road investments is very large, that the investment in airships is far and away the most conservative approach to linking this isolated area to the market.

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