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CARGO TRANSPORTATION BY AIRSHIPS: A SYSTEMS STUDY

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16. Abstract

A systems engineering study of a lighter-than-air airship transportation system was conducted. This study demonstrated the feasibility of the use of airships in hauling cargo. The economics of the airship are competitive in comparison with airplanes, trucks, and trains. Social, legal, environmental and political factors were considered as well as the technical factors necessary to design an effective airship transportation system. One of the more significant findings of the study resulted from a Congressional survey on the topic of airships. A large majority of those Congressional members responding indicated a favorable attitude concerning airships.

In order to accomplish an effective airship transportation program, the study recommended two phases of implementation. Phase I would involve a fleet of rigid airships of 3.5 million cubic feet displacement capable of carrying 25 tons of cargo internal to the helium-filled gas bag. The Phase I fleet would demonstrate the economic and technical feasibility of modern-day airships while providing a training capability for the construction and operation of larger airships. Implementation of the larger airships would be Phase II. The Phase II portion would be a fleet of rigid airships of 12 million cubic feet displacement capable of carrying a cargo of 100 tons a distance of 2000 miles at a cruising speed of 60 mph. An economic analysis is given for a variety of missions for both Phase I and Phase II airships.

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FOREWORD

This report presents the results of 11 weeks of effort by participants in the 1975 summer program sponsored by the National Aeronautics and Space Administration in cooperation with the American Society for Engineering Education. This program, entitled the NASA/ASEE Engineering Systems Design Institute, is conducted annually at the Johnson Space Center and is jointly administered by the University of Houston.

The systems design team was composed of 20 faculty members representing 16 universities. The team was multidisciplinary and included 16 professors in various fields of engineering, as well as representatives from the fields of political science, economics, and operations analysis. Group composition was designed to enhance the engineering systems concept by incorporating relevant social, legal, political, environmental, economic, and safety factors in the final systems design.

The design team was asked to investigate the feasibility of the use of airships for hauling cargo. The team recommended the implementation of an airship transportation system in two phases--the first to demonstrate the economic and technical feasibility of modern-day airships and to gain ship handling and fleet experience; the second to increase fleet size, range, and cargo-carrying capability.

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1.1 THE STUDY

Lighter than air (LTA) vehicles are attracting renewed interest today (ref. 1-1 and 1-2). Airships are being considered as an alternative to or supplement to current modes of transport for both passengers and cargo.

Transportation is a big, involved business. Twenty percent of the Gross National Product is generated by this industry (ref. 1-3). One out of every twelve workers is employed in moving goods and people from one point to another (ref. 1-4). Activities of this magnitude are obviously energy and resource intensive, and costly.

These facts are sufficient motivation to search for better ways of performing the transport function in our society. Methods are needed which achieve maximum customer satisfaction at a minimum cost in resources.

The LTA vehicle utilizing buoyancy to achieve lift seems to be a likely candidate for detailed investigation. Such airships fill part of the speed gap between current surface and air transport. Cruise speeds are about double the average highway speed for trucks and about triple the average railroad speed (ref. 1-3).

Further evidence of interest in the airship is the recent technical conferences held in Monterey, California, during 1974 (ref. 1-5) and in Snowmass, Colorado during 1975.

Conferences not withstanding, there have been no recent attempts to analyze airships from a total systems viewpoint. This study considers the airship not as an entity in itself but as a vital component of an overall transportation system. Current information from the literature and consultants is synthesized into the design of both missions and airships.

1.2 SYSTEMS APPROACH

This study applies systems analysis to the design of an airship transportation system. Such an analysis considers not only technical and economic aspects but also political, sociological, legal, and environmental factors. Neglect of any one area could result in designs that are unworkable in today's society.

The systems approach is used to answer questions such as:

> Is the concept both technically and psychologically safe?
>
> Does the ship meet both technical and union specifications in the cargo handling system?
>
> If an airship hovers over an area to unload cargo, is the noise level acceptable?
>
> Would past airship disasters keep people from funding or using airships?
>
> What are the real social benefits of an airship transportation system?

Indeed, the interactions between various technical and societal factors must be recognized and accounted for in order to achieve a viable system design.

Before describing the goals of this study, a brief history is given of past experiences upon which this study builds in investigating the modern role of airships.

1.3 HISTORY AND BACKGROUND

This historical introduction is brief and is limited to those data and occurrences that may be of interest to the forward-looking reader. The two primary classifications of airships are rigid, that is, having a structural frame work, and nonrigid, wherein the shape is maintained by the pressure of the lifting gas. Table 1-1 lists the significant characteristics of a spectrum of airships built since World War I. Most of the historical background is taken from Brooks (ref. 1-6).

1.3.1 Rigid Airship Development

The development of lighter-than-air craft before and during World War I was largely limited to the evolution of the zeppelin in Germany. The commercial use of airships, which appeared promising before the war, was converted to military application beginning in 1912. At first the zeppelins were assigned the role of scouting, particularly of England, by long duration, overwater flights. During the last two years of World War I, the zeppelins were used as aircraft to bomb England. Low altitude, night bombing missions were soon countered by British searchlights and anti-aircraft fire. The Germans then undertook high altitude bombing missions above the effective range of anti-aircraft gunnery and British defensive aircraft. The zeppelins were modified to reduce all possible weight to maximize flight altitudes. At the end of World War I, German zeppelins were flying bombing missions over England at altitudes of from 6,000 to 7,000 meters (19,600 to 23,000 feet).

The effectiveness of the German zeppelin operations during World War I is questionable. Probably their greatest contribution was their psychological impact on the civilian population and their preoccupation of British defenses. The bomb loads carried ranged from 2,700 to 5,000 kilograms (5,950 to 11,000 pounds) at a time when aeroplane payloads were a few hundred kilograms. World War I histories show that, of the more than 100 zeppelins used during the war, 39 were lost to enemy action and another 34 were destroyed in accidents, primarily caused by

TABLE 1-1
A HISTORICAL SPECTRUM OF AIRSHIPS
(BASED ON REF. 1-6)

AIRSHIP/ CHARACTERISTIC		LATE WW I MILITARY ZEPPELINS	SHENANDOAH	LOS ANGELES	GRAF ZEPPELIN	AKRON/MACON	HINDENBURG	ZPG-3W	ZWG-1	GOODYEAR COLUMBIA
Year built (type)		1917 (rigid)	1923 (rigid)	1924 (rigid)	1928 (rigid)	1931-33 (rigid)	1936 (rigid)	1959 (nonrigid)	1960 (nonrigid)	1975 (nonrigid)
Length	meter (feet)	226 (743)	207 (680)	200 (656)	237 (776)	239 (785)	245 (803)	123 (403)	141 (464)	58.5 (192)
Diameter	meter (feet)	24 (79)	24 (79)	27.6 (90.6)	34 (113)	40.5 (133)	41.2 (135)	25.9 (85)	33.6 (110)	15.2 (50)
Volume	m^3 (ft^3)	68,500 (2,420,000)	60,900 (2,150,000)	70,000 (2,470,000)	105,000 (3,710,000)	184,000 (6,500,000)	190,000 (6,710,000)	42,500 (1,500,000)	79,300 (2,800,000)	5,740 (202,700)
Useful Static Lift	Newtons (pounds)	484,830 (109,000)	196,600 (44,200)	381,200 (85,700)	475,900 (107,000)	676,000 (152,000)	769,500 (173,000)	120,000 (27,000)	141,400 (31,800)	14,600 (3,281)
Maximum Speed	meter/sec (mph)	28.6 (64)	27 (60)	35 (78)	32 (71)	39 (87)	34.7 (78)	42.2 (94)	37 (83)	22.4 (50)

weather. A German mission that demonstrated the capability of the zeppelins was the flight near the end of the war of the L59. This airship left a base in Bulgaria with 13,870 kilograms (30,300 pounds) of supplies for a beleaguered German force in German East Africa. The airship was recalled by radio near the end of the mission when it was learned that the German force had surrendered. The L59 returned safely to Bulgaria completing a nonstop flight of 95 hours during which 6,700 kilometers (4,200 miles) were covered.

Following World War I, airship technology evolved spasmodically in Germany, England, and France with some early activity in both the United States and Italy. Probably the first postwar accomplishment worth mentioning was the 1919 trans-ocean, round-trip flight of the British R-34 from England to New York. The early airship experience in Germany moved that country to the forefront of airship technology in the mid-1920's.

A war-reparations agreement between the United States and Germany called for the delivery to the United States of an airship. Germany completed the LZ-126, which was delivered to the U.S. Navy at Lakehurst, New Jersey, in 1924, and was renamed the Los Angeles. This airship served the Navy in a scouting, training and experimental role until it was dismantled at Lakehurst in 1939. During this same general period, funds were provided for an American-made airship of about the same size as the Los Angeles. The large hangar at Lakehurst was completed in 1921 and the Shenandoah was constructed in this hangar and flown for the first time in 1923. Two years later, the Shenandoah crashed in Ohio during a storm.

A hangar was completed in Akron, Ohio in 1929 and was used for the fabrication of the Akron and Macon for the U.S. Navy during the early 1930's. The significant feature of these two airships was the provision of an onboard hangar with space for five fighter/dive-bomber aircraft. Launching and retrieval of these aircraft were routinely handled during flight. The Akron was lost off the Atlantic Coast in 1933 and the Macon crashed off California during fleet maneuvers in 1935. Both ships were lost during adverse weather conditions.

Techniques for ground handling and docking of large airships developed rapidly between World Wars I and II. The British perfected a fixed-position, bow-connected mooring mast which was later improved and mobilized by the U.S. Navy. Subsequently, mechanical rail-mounted devices were developed at Lakehurst that reduced the number of men required for ground handling and docking operations by a factor of three.

Following the completion of the LZ-126 which became the Los Angeles, the German Zeppelin Company designed and built the LZ-127, the Graf Zeppelin. In 1929, the Germans gained international recognition with the around-the-world flight of the Graf Zeppelin with intermediate stops in only Japan and the United States. The Graf Zeppelin was engaged in trans-Atlantic passenger service from 1932 until the loss of the Hindenburg at Lakehurst in 1937. During this period, the Graf Zeppelin completed 116 crossings of the Atlantic with passengers and mail. The

German-built Hindenburg, launched in 1936, contained 190,000 m^3 (6.7×10^6 ft^3) of hydrogen. Its promising career was cut short in May 1937, when it was destroyed by fire at Lakehurst with a loss of 35 lives.

The destruction of the Hindenburg essentially ended the rigid airship era, although Germany constructed a sister ship to the Hindenburg and named it the Graf Zeppelin II. This ship was used by the German military for electronic surveillance of British radar during 1938 and 1939. It was finally scrapped and the big hangar at Frankfurt was dismantled in early 1940.

The use of large rigid airships during the 1930 to 1940 era was largely restricted to military operations. Commercial use in Germany before World War I, although promising, was limited to intermittent passenger and pleasure flights patronized by somewhat daring people trying a new and exciting mode of transportation. Commercial revenues during this period did not nearly pay the cost of operations.

Very few data are available about the profitableness of German commercial zeppelin operations during the 1930's. Peter Brooks speculates in his book Historic Airships (ref. 1-6) that the Germans nearly reached a break-even point with their Graf Zeppelin Germany-to-Brazil flights during the 30's. Brooks further estimates that the Hindenburg did conduct profitable operations during 1936 with 15 round trips between Germany and Brazil. The final configuration of the Hindenburg included 72 passenger berths in addition to mail and express cargo areas. Data in Table 1-1 show that the Hindenburg had a useful lift of 769,500 Newtons (173,000 pounds).

1.3.2 Nonrigid Airship Development

The development of nonrigid airships or blimps evolved concurrently with rigid technology. The advancements during and immediately following World War II in support of U.S. Navy problems were significant. Prewar blimp sizes of 5,700 m^3 (2×10^5 ft^3) grew to 21,000 m^3 (740,000 ft^3) during the war and to 42,500 m^3 (1.5×10^6 ft^3) in the 1950's. A significant advancement during the 1950's was the development of mobile constant tension winches for ground handling and docking of airships. The replacement of muscle power with mechanical power reduced ground handling manpower by 75 percent. The antisubmarine warfare missions of World War II were ideally suited to the low altitude, low speed, long duration, all-weather capability of the airship. Following World War II, a fleet of Goodyear-produced U.S. Navy blimps was assigned radar picket duty off the Atlantic coast. The spacious 42,500 m^3 envelope proved to be an ideal location for very large radar antennas. The eleven-day flight of a SPG-2W that circumnavigated the Atlantic Ocean without refueling demonstrated the long duration flight capability of these large nonrigid airships. The Navy airship program was ended in 1961.

The commercial use of nonrigid airships has always revolved around advertising and the gaining of the recognition of trade names and products. The use of airships as airborne television camera platforms and for providing sight-seeing rides has not been profitable and again is justified by the difficult to evaluate advertising value gained by these uses.

1.4 STUDY GOALS

A preliminary analysis of potential mission and airship concepts resulted in the identification of mission specifications for two airship phases. The specifications are given in Table 1-2.

TABLE 1-2

MISSION SPECIFICATIONS

	Phase I	Phase II
Cargo	2.24×10^4 kg (25 tons)	9.07×10^4 kg (100 tons)
Range	966 km (600 miles)	3219 km (2000 miles)
Cruise Speed	36 m/s (80 mph)	27 m/s (60 mph)
Maximum Speed	45 m/s (100 mph)	45 m/s (100 mph)

A Phase III airship having an even larger cargo capacity would be the next step after the Phase I and Phase II airships are developed. The Phase III concept, however, is not considered by the study team. Smaller ships would have to be built first to gain experience.

The Phase I and Phase II airships could be developed simultaneously but a more likely procedure would be to first build a ship of Phase I size to gain both ship handling and fleet experience.

With these mission specifications providing a focus, the major goals to be achieved by this study are:

1. Identify mission scenarios which the airships could perform both uniquely and in competition with current transportation modes.

2. Determine the important economic, technical, social, legal, environmental, and political parameters germane to airship systems.

3. Design the technical configuration of the Phase I and Phase II airships to meet mission specifications.

4. Identify technologies which must be further developed in order to implement a modern airship transportation system.

The following chapters present results related to these goals. Chapters 2 and 3 contain the investigations into economic and social considerations. Chapter 4 discusses the areas of flight and ground operations. The critical problem of loading and unloading cargo is analyzed in Chapter 5. Chapters 6, 7, and 8 present the results of technical investigations into structures, shapes, and performance. Cost estimates and airship configuration summaries are given in Chapter 9. Detailed examples of mission types are presented in Chapter 10. Chapter 11 contains the overall summary and recommendations for implementation.

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CHAPTER 2

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2.1 INTRODUCTION

All of the raw materials necessary for the production of goods and services are seldom found in the same location. Therefore, a process is necessary for the assembly of the raw materials where production can take place. In addition, finished goods need to be distributed to those members of society who desire them. Stated in terms of traditional economic theory, a product or service has form utility, time utility, place utility, and possession utility. Transportation is the process that provides time and place utility. It is the process that brings raw materials from their original location to the place of manufacture and delivers finished goods or services to the location where people want them. A transportation system provides the transport function in a society.

2.2 SYSTEM OUTLINE

A transportation system performs all of the functions necessary to provide a transport service. Implicitly a transportation system must have a vehicle, or some physical means of providing carriage between locations. The carrying function requires some method of loading and unloading. In addition, many support functions are also necessary to perform the carriage function. Often the physical means and the necessary support functions are constrained by society and nature. A general, overall transportation system is shown conceptually in Figure 2-1. It includes the environment within which such a system operates.

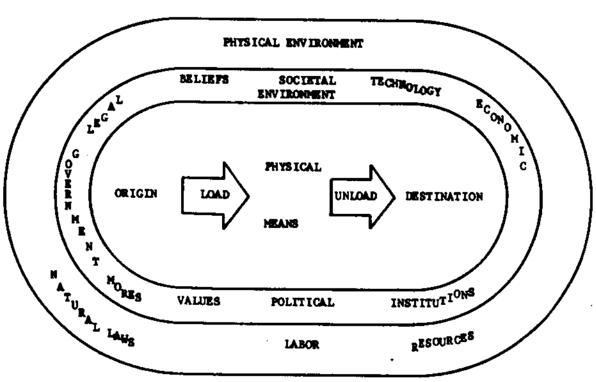

FIGURE 2-1

ENVIRONMENT

An efficient transportation system will optimize the load-carriage-unload functions subject to constraints imposed upon it by its environment.

2.3 SYSTEM ELEMENTS

The primary goal of the NASA-ASEE Design Project is to design an economical airship transportation system utilizing present day technology. That vehicle performing the physical means of transport will be a lighter-than-air vehicle. In this study several parameters are established in order to determine the characteristics of particular systems. A development framework of three phases is established. Each phase is established to serve as a possible base for the succeeding phase. The initial phase, Phase I, will possibly commence commercial operation in 1980 and will be capable of carrying 2.271×10^4 kilograms (25 tons) of revenue producing cargo for 965 kilometers (600 miles) cruising 35.8 meters/second (80 miles/hour). The second vehicle, Phase II, will commence commercial operation possibly in 1990 with the capability of carrying 9.07×10^4 kilograms (100 tons) of revenue-producing cargo for 3,220 kilometers (2,000 miles) cruising at 26.8 meters/second (60 miles an hour). The third phase will develop as needed to meet the conditions of the twenty-first century. It will take advantage of much improved technology. However, needing only some improvement in fabrication techniques, an airship could currently be designed with lift capailities of an order of magnitude greater than Phase II ships.

In addition to a vehicle and service demand, a transportation system requires movement to and from the vehicle as well as loading and unloading methods (See Fig. 2-2).

LTA TRANSPORTATION SYSTEM

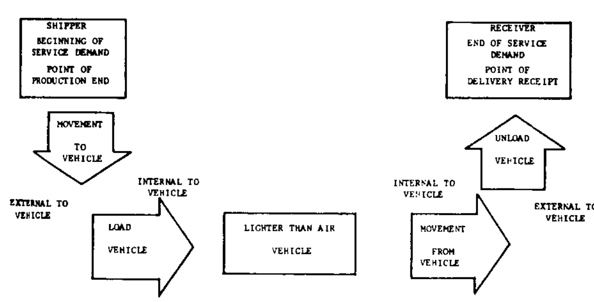

FIGURE 2-2

LTA TRANSPORTATION SYSTEM

The movements to and from the beginning of service may require a mode other than the primary transportation vehicle. An example of this would be an ocean-going vessel. Or the service may be accomplished by the vehicle alone, e.g., by a pick-up truck. Similarly, mechanisms and equipment may be external to the vehicle (fork-lift truck), or internal to the vehicle (hydraulic tail gate). Other elements of a transportation system vary with demand requirements and the specialized needs of the vehicle utilized. Demand elements would include such things as terminals, accounting/billing facilities, customer accommodation facilities, and scheduling facilities. Specialized elements include maintenance facilities and equipment, vehicle staging areas, vehicle storage areas, and crew accommodations.

2.4 MISSION CHARACTERISTICS

For a vehicle to become a viable mode of transportation, it must provide a unique function. This function relates to either an actual activity which cannot be handled by current transport modes or activities handled more economically.

2.4.1 EXISTING MODE CHARACTERISTICS

An examination of general characteristics of established transport modes will indicate specific missions an airship might perform. All of the information utilized in this analysis is for domestic transport only.

2.4.1.1 FREIGHT COST

As can be seen in Table 2-1, average cost per kilogram-kilometer (ton-mile) of cargo moved ranges from a low of 1.7×10^{-4} cent (0.25¢) to a high of 1.7×10^{-2} cent (25¢). Care must be taken in making inferences based only on kilogram-kilometers (ton-miles) in that the distances recorded for each mode are those distances actually traveled; transport routes dictated by physical and societal considerations may not be of the shortest distance. For example, a barge traveling from Chicago to New Orleans cannot travel in a straight line as an airplane can, but must travel many kilometers (miles) east through the Great Lakes, then down around the coast before it finally reaches its destination. The distance actually traveled would be counted in the kilogram-kilometer (ton-mile) figure for water. With this caveat in mind, the numbers are still suitable for analytical purposes. Table 2-1 also indicates an inverse relationship between cost and speed. Of near-future importance may well be the energy utilization directly applied to the production of the transportation. Energy accounting itself will be covered in Section 2.6.

2.4.1.2 FREIGHT LABOR ANALYSIS

Table 2-2 gives an indication of how labor efficient each mode is. The truck is almost half as efficient as the railroad. However, air transport is least efficient. As would be expected, pipelines and inland-coastal water carriers are very labor efficient compared to the other modes.

TABLE 2-2

INDIVIDUAL EMPLOYEE PRODUCTIVITY/YEAR BY MODE (Ref. 2-3)

Mode	Ton-Miles	Kilogram-Kilometer
Truck	0.87×10^6	1.27×10^9
Air	0.10×10^6	0.15×10^9
Rail	1.48×10^6	2.16×10^9
Pipeline	26.89×10^6	39.25×10^9
Water	71.40×10^6	104.22×10^9

TABLE 2-1

AVERAGE CHARACTERISTICS OF FREIGHT MODES

Mode	Cost Per Kilogram-Kilometer / Ton-Mile	Speed Meters/Second / Miles/Hour	Load Kilograms / Tons	Distance Kilometers / Miles	Fuel Consumed Joules/kilogram-kilometer / BTU/Ton-mile
Pipeline	1.7×10^{-4}¢ 0.25¢	0.894 2	1.271×10^6 1,400	965 600	325 450
Water	3.4×10^{-4}¢ 0.50¢	2.235 5	1.632×10^6 1,800	1,239 770	491 680
Rail	1.3×10^{-3}¢ 1.50¢	8.941 20	3.992×10^4 44	797 495	484 670
Highway	5.1×10^{-3}¢ 7.50¢	17,882 40	2.177×10^4 24	418 260	2,024 2,800
Air	1.7×10^{-2}¢ 25.00¢	183.290 410	1.179×10^3 1.3	1,207 750	30,356 42,000
	(ref. 2-1)	(ref. 2-1)	(ref. 2-1)	(ref. 2-1)	(ref. 2-2)

2.4.1.3 FREIGHT COST STRUCTURE

An examination of the cost breakdowns in competing modes can yield information concerning the feasibility of an airship system.

Sales can be made on what is known as a marginal basis. If the sale of a unit produces a revenue equal to the out-of-pocket costs of producing that unit plus some contribution to the overhead, then it is beneficial for the firm to make that sale. Needless to say, total contributions to overhead must at least cover the total overhead and produce some profit or the operation cannot be viable.

Out-of-pocket costs are often referred to as variable costs; that is, they vary directly with production output. The fixed costs are those costs that would continue even though production ceases. Fixed costs are often known as overhead.

In the transportation industry, variable costs will set a floor for rates. The lower variable costs a mode has, the greater flexibility the mode has in setting rates and meeting competition. Table 2-3 indicates the relative relationships of costs for existing modes of transportation excluding pipelines. As can be seen, rail and water have considerable flexibility in setting minimum rates, while the air and motor modes are structurally confined to immediate recovery of costs.

TABLE 2-3

FIXED COSTS VERSUS VARIABLE COSTS BY MODE (ref. 2-1)

Mode	Approximate Percentage of Total Cost	
	Fixed	Variable
Rail	67	33
Water	50	50
Air	20	80
Truck	15	85

2.4.1.4 PASSENGER MODE ANALYSIS

Table 2-4 shows the use characteristics of relevant passenger modes. Interestingly, passengers appear to purchase more units of transportation [kilometers (miles) traveled] as the cost per unit increases. People apparently consider in their purchase of transport service more than distance and price.

TABLE 2-4

CHARACTERISTICS OF PASSENGER MODES (averages from ref. 2-3)

Mode	Distance		Fare	
	Kilometers	Miles	Kilometer	Mile
Bus (Intercity)	148	92	2.4¢	3.9¢
Rail	338	210	3.0¢	4.8¢
Air	1094	680	4.0¢	6.4¢

2.4.1.5 SUMMARY

Table 2-5 summarizes the operational characteristics of existing modes of carriage in a subjective manner as might be determined by a consumer. The convenience category refers to both directness of shipment from point to point and the need for utilizing another mode of carriage to provide complete door-to-door service.

2.4.2 AIRSHIP CHARACTERISTICS

Historically, the airship was a relatively slow vehicle although considerably faster than even current water vehicles. Indications are that 58 meters/second (13 miles/hour) is practical maximum speed for a fully buoyant vehicle (see Chapter 6). In the past, airship operations required large amounts of labor both for flight and ground handling. Navy experience during the 1950's and 1960's indicates that much labor can be replaced with mechanical and electronic devices. Navy experience during World War II indicates that airships have capabilities of operating at remote sites without great amounts of preparation. Experience has also indicated operational capability during most weather conditions. Ballast and buoyant gas management has limited airship operations because of pressure-height restrictions. Also, in the past, the airship has been restricted structurally to a limited cargo capacity.

TABLE 2-5

OPERATIONAL CHARACTERISTICS OF FREIGHT CARRIAGE MODES

Mode	Speed			Cost			Convenience			Cargo Size			Cargo Weight		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Air			x			x		x		x				x	
Motor		x			x				x		x			x	
Pipeline	x			x			x			x				N/A	
Rail		x		x				x			x			x	
Water	x			x			x					x			x

No airship moving the state of art forward has been built since the 1950's. However, modern technology can be utilized to build the large size airship needed to carry economic size loads.

Considering the gap between the older airship and modern technology, it would be advisable to develop an airship transportation system in steps or phases.

Phase I would be a learning stage that modernizes the state of the art particularly in manufacturing and operations. In order to establish the airship as a commercial vehicle, it may be necessary to operate with mission and weight characteristics "between" those of a truck and an airplane. The Phase I ship would carry 2.3×10^4 kilograms (25 tons), about the capacity of a current intermodal container. Its speed at 36 meters/second (80 miles/hour) is double the average truck speed of 18 meters/second (40 miles/hour)--see Table 2-1. It also has the ability to load and unload without special facilities, i.e., it can perform door-to-door service.

Phase II would increase carrying capacity considerably, enlarging the potential market and technically stretching the state of the art. Phase II increases the cargo capacity to 9.072×10^4 kilograms (100 tons) with some sacrifice in speed at 27 meters/second (60 miles/hour). But this is still faster than the average truck speed.

2.5 ECONOMIC MODEL

2.5.1 GENERAL

Any economic analysis has to consider the long run effects of costs and revenues upon the rate of return on investment. Because direct operating costs generally do not reflect long run profitability, an economic analysis must consider a full internalization of all identifiable costs. Moreover, the long run viability of a competitive airship system requires a "reasonable" rate of return on invested capital, regardless of whether private or public capital is considered.

The economic model developed for the airship system is a natural outcome of the project's requirements and is based upon the following excerpt:

> Because there is little faith in current LTA cost estimates, a different approach was suggested. The most useful studies should be directed toward examining potential markets for LTA in the existing transportation world. By analyzing the existing competition for potential LTA markets, cost and performance requirements can be derived at which LTA's would be economically feasible. By "working backwards" in this way, one can try to design an airship which will not exceed these costs (ref. 2-4, p. 22).

In addition to the foregoing, the economic analysis in this study was influenced by the following:

> The type of analysis that must be conducted to determine the marketability of the concept (airship) is clear, however. It must address both supply and demand elements. It should start from a marketing concept to define the performance specifications for the system as a whole including terminal organization and operation. From this a detailed set of equipment costs and costs per ton-mile must be developed and translated into a rate structure. . . . (ref. 2-5 p. 110).

At the outset of the project, the decision was made to incorporate state-of-the-art technology into the airship design(s). Consequently, it became increasingly clear that cost estimates of these technological innovations would be completed only towards the end of the project. Moreover, a priori decisions to specify absolute tonnage capacities for the airships fixed many operational cost parameters. Thus, a natural outcome was the development of an economic model that would leave the construction costs of an airship fleet as the only variable to be determined. Interestingly, this is just the "working backwards" approach suggested above.

2.5.2 MECHANICS OF THE MODEL

Although its principal aim is to determine the cost parameters of the system, the model is general enough to permit some parametric analysis. From a definitional point of view, the net productivity of an investment may be determined by setting the present value of costs equal to the present value of expected revenues. The following definitions comprise the components of the model:

$(S_1/r)[1-(1+r)^{-t}]$ = Present value of a sum of money S_1 that is paid out (or received) once a year, at the end of each year, for t number of years.

$S_2\int_0^t e^{-rv}dv = (S_2/r)[1-e^{-rt}]$ = Present value of a sum of money S_2 that is paid out (or received) at a constant, continuous rate per year for t number of years.

$S_3[1+r]^{-t}$ = Present value of a sum of money S_3 paid out (or received) at the end of t years.

The general model is:

$$\Sigma A+(\Sigma B/r)[1-(1+r)^{-(t-1)}]+\Sigma C\int_0^t e^{-rv}dv = R\int_0^t e^{-av}dv + \Sigma S(1+r)^{-t} \quad (3\text{-}1)$$

where:

ΣA = Total dollar amount spent initially,
ΣB = Annual costs of items paid once a year,
ΣC = Annual costs incurred at a continuous rate,

ΣS = Salvage value of all physical items,
R = Annual expected revenue,
t = Project life in years,
r = Cost of capital,
a = Internal rate of return.

After integration (assuming that cargo insurance is one percent of revenue) and identification of specific costs, the model becomes:

$$\sum_{0}^{4} A_i + (1/r) \sum_{0}^{1} B_i [1-(1+r)^{-(t-1)}] + \sum_{0}^{8} C_i (1-3^{-rt}) - \sum_{0}^{3} S_i (1+r)^{-t} = (.99R/a)[1-e^{-at}] \quad (3\text{-}2)$$

where:

A_0 = fleet cost,
A_1 = cost of helium,
A_2 = cost of terminals,
A_3 = cost of hangar operations equipment,
A_4 = initial insurance payment,
B_0 = annual insurance payment,
B_1 = annual helium cost,
C_0 = annual cost of hangar rent,
C_1 = annual cost of terminal personnel,
C_2 = annual cost of flight personnel,
C_3 = annual cost of hangar personnel,
C_4 = administrative annual cost,
C_5 = annual cost of terminal operations,
C_6 = annual cost of hangar operations,
C_7 = annual cost of fuel and oil,
C_8 = annual cost of spare parts,
S_0 = salvage value of airship fleet,
S_1 = salvage value of terminals, less land,
S_2 = salvage value of land (=initial value),
S_3 = salvage value of helium (=(1.2) x initial value).

2.5.2.1 INTERPRETATION OF THE MODEL

In equations (3-1) and (3-2), the value of the constant "a" is the net productivity of the investment, or, alternatively, the internal rate of return. The value for R was estimated from census data. The cost of capital, r, is taken to be eight percent for all computations. Project lifetime is estimated to be 20 years, (any of these could be varied in the model for a parametric analysis).

Given the foregoing, A_0 is determined by fixing the value of "a." The particular values chosen for analysis are 3%, 8%, and 12%. Thus, for any particular system, the fleet cost (A_0) corresponding to a given set of revenue, project life, and rate of return can be determined. This model was used to analyze some of the missions in Chapter 10. Results are presented in that chapter.

2.5.2.2 LIMITATIONS OF THE MODEL

Because of the decision to fix the cargo capacity of the airships (see Chapter 1), the model developed is not used for optimization. Ideally, technical and economic information should be integrated from a project's inception and hence provide the framework for designing an optimum size airship. In order to accomplish this task, economists must be thoroughly familiar wi existing technical relations so that cost and performance tradeoffs can be identif and incorporated into the model. Likewise, technical decision-making should be constrained, wherever possible, by cost considerations.

In summary, an ideal economic model would be a thoroughly integrated set of economic and technical relations, and would probably be a set of simultaneous equations. These relations would characterize the entire design schema, and would permit the designing of an optimum-size airship.

2.6 ENERGY ACCOUNTING

Society as a whole has a major stake in the utilization of energy by any segment of society. As any product or service bids for its place in society it must show not only evidence of beneficial service but also must be energy efficient.

2.6.1 INPUT-OUTPUT MODEL

The cost of energy related to any product or service must account for all the energy expended in the production and assembly components as well as that expended in putting it in position to be utilized. The total energy (Fig. 2-3) includes such things as the energy expended in the production or extraction of raw materials, including energy utilized in producing the tools utilized; the energy expended in converting the raw materials to usable form; the energy expended in moving materials; the energy expended in building and maintaining facilities; the energy expended in heating, cooling, and lighting facilities; and of course all of the energy expended by people not only in direct labor involved but in management, sales, etc.

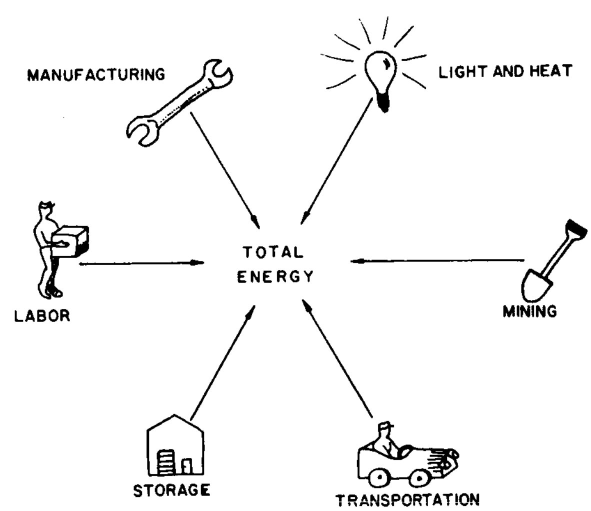

FIGURE 2-3
TOTAL ENERGY

The collection and assembly of each component of energy utilized in a portion of the total system is conceptually possible, but because of the magnitude of the number of components involved the task is forebod-

TABLE 2-6

OPERATING COSTS OF TRANSPORTATION MODES

Mode	Cost in Cents Per Kg-km	Per* Ton-Mile	Per Kg-km $(\frac{km}{hr})$	Per Ton-Mile $(\frac{mile}{hr})$
Pipeline	1.7×10^{-4}	0.25	5.4×10^{-5}	0.125
Water	3.4×10^{-4}	0.50	4.3×10^{-5}	0.100
Rail	1.3×10^{-3}	1.50	3.2×10^{-5}	0.075
Truck	5.1×10^{-3}	7.50	8.1×10^{-5}	0.188
Airplane	1.7×10^{-2}	25.00	2.6×10^{-5}	0.061
Airship				
Phase I	1.0×10^{-2}	14.96	6.6×10^{-8}	0.217
Phase II	5.6×10^{-3}	8.23	4.3×10^{-8}	0.141
*ref. 2-5				

ing. An input-output matrix of this magnitude may be beyond current digital computer capacity.

Just because the input-output matrix is not practical at this point, energy consumption cannot be ignored. A practical approach to the problem can be an approach similar to the approach taken in National Income Accounting, that is, using indirect methods of arriving at the desired result.

2.6.2 Operating Cost Model

Operating costs of any mode of transportation are an expression of all the costs that go into the production of a unit of carriage, direct and indirect. Cost reflects the quantities of energy expended and the length of time incurred in the use of that energy in the production of a good or service. Therefore, an indirect method of measuring the relative total energy consumption of various modes of transportation is to compare the operating costs of the modes (see Table 2-6). Kilogram-kilometer (ton-mile) costs are normally utilized in measuring the unit of carriage production. It is the cost of carrying one kilogram (ton), one kilometer (mile). Money also has time value, and in addition, the longer a product is enroute, the larger the inven-

TABLE 2-7

FUEL CONSUMPTION OF TRANSPORTATION MODES

MODE	JOULES Per kg-km	Per kg-km $(\frac{km}{hr})$	BTU's Per* ton-mile	Per ton-mile $(\frac{mi}{hr})$
Pipeline	325	102.2	450	225.0
Water	491	61.8	680	136.0
Rail	484	15.2	670	33.5
Truck	2,024	31.8	2,800	70.0
Airplane	30,356	46.5	42,000	102.4
Airship				
Phase I	6,252	49.1	8,650	108.1
Phase II	1,749	18.3	2,420	40.3
*ref. 2-6				

tory of the product is; hence, more energy is utilized in maintaining the proper flow of product from producer to consumer. One must then consider the cost paid for higher speeds and resultant reduced time. A parameter which simply indicates this is found by dividing the cost/mass-distance by the average speed of each mode (see Table 2-1). This parameter is also shown in Table 2-6.

While existing transport mode characteristics are historically determined averages, projected airship characteristics are based on operations under optimum design conditions.

2.6.3 FUEL CONSUMPTION

Consideration of energy consumed by the carriage function is important in light of possible near-term fossil fuel shortages. Table 2-7 illustrates the relative energy efficiencies of the various modes. Once again, in addition to the standard kilogram-kilometer (ton-mile) units, these data are divided by speed and the results presented.

Table 2-8 indicates the effect of speed on energy consumption for the Phase II airship. The effect of stops is also shown in Table 2-8. The indication seems to be that long, slow flights consume lesser amounts of energy. However, market conditions will determine the airship's speed and the duration of flights.

Point-to-point energy consumption, it must be remembered, is only a satisfactory method of comparison for short term purposes, and even then when all facets of "out-of-pocket" energy costs are directly compared. For example, more than one mode may be required for total movement, and one mode may travel more miles than another to move goods between the same points.

2.6.4 SUMMARY

Three conclusions may be drawn concerning energy consumption of airships:

1. The airship on an energy/mass-distance basis can be expected to fall in the area between the truck and the airplane (see Table 2-6).

2. As airship capacity increases, it operates more economically and is more energy efficient (see Tables 2-6 and 2-7).

3. As the speed of the airship increases, it operates less economically (see Table 2-8).

4. If time utility is considered, the energy and cost factors look very favorable, particularly for the Phase II airship (see Tables 2-6 and 2-7).

2.7 SUMMARY

Society requires transportation to effectively satisfy its wants and needs. The airship transportation system must find its niche in the current environment of transport modes by performing uniquely. The airship can perform uniquely if it gives, for example, service equal to that given by a truck but at a greater speed.

TABLE 2-8
PHASE II AIRSHIP
FUEL USAGE AT VARIOUS SPEEDS
FOR 3200 KILOMETER (2,000 MILE) TRIP

SPEED		FUEL CONSUMPTION							
		Joules/kilogram-kilometer		$\frac{\text{Joules}}{\text{kg-km}\left(\frac{\text{km}}{\text{m}}\right)}$		BTU/ton-mile		ton-mile $\left(\frac{\text{mile}}{\text{m}}\right)$	
km/m	Miles/Hour	Non Stop	Stop each 800 kilometers	Non Stop	Stop each 800 kilometers	Non Stop	Stop each 500 miles	Non Stop	Stop each 500 miles
80.6	50	1,361	1,466	17.3	18.6	1,883	2,028	38	41
96.5	60	1,749	1,861	18.2	19.5	2,421	2,575	40	43
112.7	70	2,235	2,340	20.0	20.9	3,092	3,238	44	46
128.9	80	2,967	3,072	23.2	24.1	4,105	4,251	51	53
144.7	90	3,535	3,641	24.5	25.4	4,891	5,037	54	56
160.9	100	4,281	4,386	26.8	27.7	5,923	6,069	59	61

The economic model discussed in this Chapter is a general model, used to compute a permissible airship construction cost based on a specific rate of return on the investment.

The airship is very competitive with the airplane on an energy/mass-distance basis. The Phase II airship is competitive with all modes of transportation on a time utility basis.

SELECTED REFERENCES

2-1 Fair, M. L., and Williams, E. W.: Economics of Transportation and Logistics. Business Publications, Inc., 1975.

2-2 American Railways Association Bulletin, Washington, D.C., 1974.

2-3 Summary of National Transportation Statistics. U.S. Department of Transportation, June, 1974.

2-4 An Assessment of Lighter Than Air Technology, the Report of the Multi-Agency Workshop on LTA. Monterey, California, Sept. 9-13, 1974.

CHAPTER 3

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3.1 INTRODUCTION

This design study is a feasibility study concerning the reutilization of the airship as a major component of the transportation system. Two major areas of concern were designated: 1) to provide a new technical design, and 2) to determine an economic basis for the LTA that will promote an effective, efficient, and profitable operation.

For the system to be effective environmental concerns must be included in the technical analysis (ref. 3-1). To achieve this aim, technology must be assessed and evaluated in relation to the other systems with which it interacts. It is important that environmental and various social systems be examined to determine if changes caused by a new system will be constructive or degrading, high or low in costs, desirable or undesirable in both quality and quantity of service provided, and to determine the patterns or effects that will be produced within each of the various systems. Technology assessment properly utilized in the form of systems analysis will determine constructive policy and decision making.

A study of how the structure, function and processes of each system interact with the LTA transportation system technology gives information about effects that may be expected from various actions. The areas of concern are many and varied; to discuss these areas in a methodical systematic manner allows the exploration of the full range of possibilities that could have effect upon the new form of the technology.

3.2 TECHNOLOGY ASSESSMENT

3.2.1 INTRODUCTION AND SCOPE

The airship will perform within the framework of society. Society encompasses all the human needs and endeavors; it is here that the airship technology must sustain itself as a part of the transportation system.

Technology assessment deals with the question of the impact of LTA transportation systems on the total environment. These impacts relate to air and water quality, noise, and land use.

The legal subsystem is examined as to the regulatory agency constraints and other legal restrictions which could influence the airship design and operation.

The socio-political system furnishes information regarding socio-political interest group support, congressional support, possible funding areas, and the political-labor factors that could contribute to the success or failure of the new system.

A sociological analysis evaluates the attitudes and perceptions of the various social groups (publics) relative to the airship concept. Attitudinal survey results will furnish evaluation data.

The design of the LTA Transportation System represents an attempt to reestablish the LTA concept in a new configuration that will provide a set of unique services permitting the system to be come a viable technology in the total sphere of transportation.

Figures 3-2 and 3-3 portray the airship technology of the past. Technology assessment was not utilized in the introduction of past airship transportation systems. The operational factors were limited to military use and to provide national prestige. These non-economical functions presaged the demise of the technology over time as the airplane became a faster and more efficient form of air transport.

The lapse of the LTA vehicle as an effective form of transportation was brought about by a narrowness of assigned missions and the unsafe use of hydrogen as a lifting gas. Proper "assessment" of the airship capabilities could possibly have shown economic viability and further advanced the effectiveness of an LTA vehicle.

Technology forecasting is the attempt to relate airship technology with a set of possible situations, strategies, or policies that may help or hinder the system in providing new capabilities. Technology assessment can predict useful actions to insure efficient and effective utility.

Technology assessment is not necessary to determine a capability to build, construct or fabricate the LTA vehicle, but it is necessary in order to forecast probabilities of creating a market-efficient mission

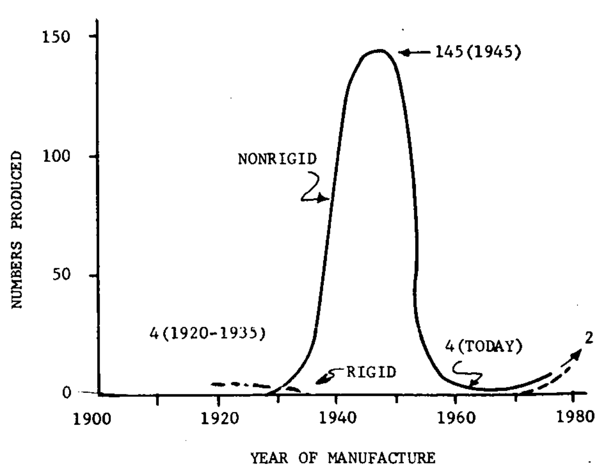

FIGURE 3-1
USA-LTA AIRSHIPS OVER TIME

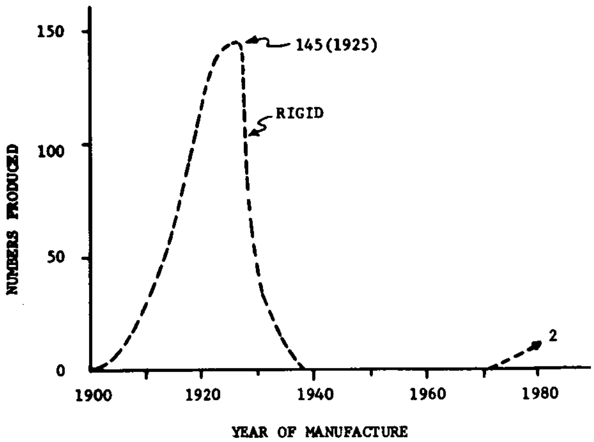

FIGURE 3-2

NON USA-LTA AIRSHIPS OVER TIME

capability, i.e., a need that can be efficiently performed. It will be the social acceptance, economic needs of the society, and the effect on the environment in which the airship will operate that determine success or failure.

Past LTA technology has not demonstrated persistance. The renewal and rehabilitation of that technology into some new configuration with new mission formats could provide a means for its re-introduction.

Forecasting that is beneficial and effective should:

1. determine what trends are operative;
2. determine alternative trends;
3. determine what is involved in each of the positions and alternatives as to actions and reactions and determine what acts must be introduced to make them come true;
4. determine which occurence is most likely to occur.

3.2.2 Political Facts

An air transportation system must obtain from Federal regulatory agencies permission for routes, operating areas, carrying capacities, and rates. Licenses must also be obtained from these agencies. These factors, related to both markets and technology, will operate to benefit or constrain the ability of the LTA vehicle to be built efficiently and perform economically.

Survival of LTA technology also depends upon economic factors that are profit motivated and incentive oriented. The economic system will be the prime determinant of survival. Combined with the economic system are the political institutional arrangements arrived at through legal requirements set forth by government.

Competing interest groups in transportation will exert influence to deny the entry of the new system into their spheres of the transportation systems network. The sharing of the carrier market will not come easy. The policies that are created for or against the LTA system will be influenced by lobby groups.

Part of the air freight sector will be a competitive area for the airship. Additionally, the land-freight, short-haul trucking industry should also provide a competition for the LTA vehicle.

Figures 3-3, 3-4, and 3-5 show some useful data related to the different modes of transportation. The cost of shipment per mass-distance and the speed of shipment both have importance to the new technology. There is an area between the average airship revenue per kilogram-kilometer (ton-mile) and the truck system within which the LTA could compete. It is noted that Fig. 3-3 shows an upper speed of about 89 meters/second (200 miles/hour). This speed may be attained by semi-buoyant vehicles but the most efficient maximum speed for fully buoyant vehicles is 45 meters/second (100 miles/hour)--see Chapter 6.

Both the truck carrier sector and the air freight sectors will perceive threats to their rates and profits. Figure 3-3 indicates that the LTA vehicle could seek its freight rate in the range 0.007 to 0.014¢/kilogram-kilometer (10 to 20¢/ton-mile).

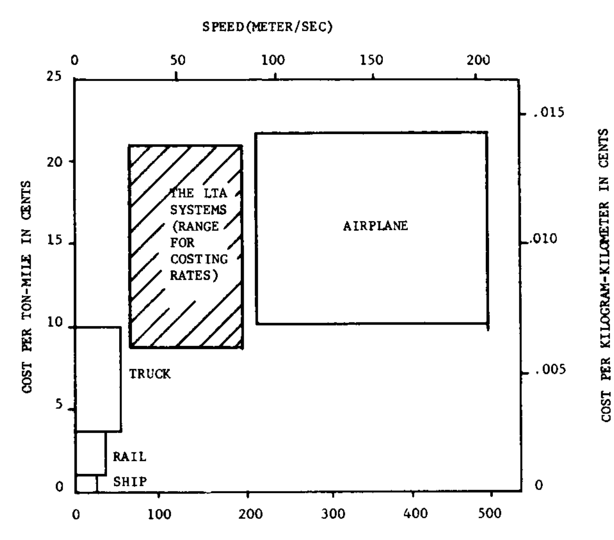

FIGURE 3-3

FREIGHT RATES
(adapted from ref. 3-2)

	1962	1972
AIR CARRIER, CERTIFIED DOMESTIC OPERATIONS, SCHEDULED SERVICE	0.0145¢ (21.31¢)	0.0156¢ (22.75¢)
CLASS 1 RAIL	0.0009¢ (1.35¢)	0.0011¢ (1.62¢)
CLASS 1 INTERCITY MOTOR CARRIERS OF PROPERTY		
COMMON	0.0044¢ (6.41¢)	0.0055¢ (8.00¢)
CONTRACT	0.0049¢ (7.29¢)	0.0048 (7.02¢)

FIGURE 3-4

TOTAL AVERAGE FREIGHT REVENUE PER KILOGRAM-KILOMETER (TON-MILE) (adapted from ref. 3-3)

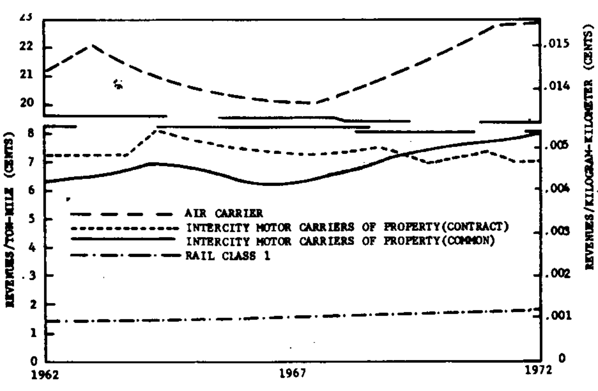

FIGURE 3-5

AVERAGE FREIGHT REVENUE PER KILOGRAM-KILOMETER (TON-MILE) (adapted from ref. 3-3)

These rate limits still border on truck and air transportation rates as seen in Figures 3-4 and 3-5. Neither of these two modes of freight transportation will be desirous of sharing their carrying capacities.

The airline freight carriers at the present time receive subsidy for profit maintenance. In order to assist the airline industry both airmail and first class mail are transported by airplanes. While it can be assumed that this is to ensure speedy delivery, it must also be understood that the carrying rates for the transportation of the mail is structured as an airline subsidy to assist the ailing air transport system. Postal freight plays an important part in maintaining the profitability of the airlines.

Some airlines, currently operating at a deficit have had their government mail subsidy increased as a means of financial aid. Further, the route structures of airlines are expanded or dropped to create or assist in attaining profitability for the airline industry as a whole.

Given this example of support by the regulatory arm of the government, preferential relationships can be subsumed from these actions on the part of the regulatory agency toward their current clients. These relationships could have an inhibiting effect on a new transportation mode.

Labor politics might also be of importance. In the transportation system the Teamsters' Union is a dominant force. Since the majority of the Teamster membership is drawn from the truck transportation sector of the union, threat perceptions on the part of that faction can be anticipated. This large and militant sector of the union could threaten the airship by lobbying for regulatory legislation which could prevent the growth of LTA vehicle systems.

There are also more general ways that labor unions can affect the new industry. Two methods are suggested. First, control can be obtained over the LTA labor group forcing the members to enter one of these unions in order to work. This is within the capability of the large national and international unions as has been demonstrated in the past.

The second manner of constraint would be the imposition of a wage structure so high that a new industry would be forced to operate at a loss and be unable to compete with the other more mature and established carrier lines.

3.2.2.1 CONGRESSIONAL ATTITUDE SURVEY

The legislative arm of the political system will be crucial to the LTA transportation system. This system with its component subsystems of political parties and interest groups will have primary decision making power which will affect the amount of support in the public domain for the airship.

The Congressional-Legislative group will, in all probability, be one of the initial and primary decision makers relative to the creation and re-establishment of the LTA system. Since decisions regarding appropriations and funding as well as regulations and laws lie with this branch of government, it would be beneficial to know what sort of support action would be forthcoming.

An attitudinal survey (see Appendix A) was mailed to each member of the two houses of the United States 94th Congress--total membership 535; 100 in the Senate and 435 in the House of Representatives.

The Congressional survey elicited a 34.4% aggregate response, providing a usable sample return numbering 184. (The total response was 201; some members answered "did not reply to surveys," or only a partial response was returned.)

Within the survey were two prime questions relating to "support perceptions." These were questions number 6 and 9. Question number 6 asked for a response as to support of R&D Funds relative to LTA technology: "Research and development funds to update airships for transportation purposes would be a good investment." Answers permitted were: strongly agree, agree, do not know, disagree, and strongly disagree. In answer to this question there was a majority support for providing R&D funding for the LTA technology: 57% agree, 87% strongly so. Also 8.2% are opposed, 2.2% strongly so, while 33% are neutral. (See Fig. 3-6.)

Question 9 asked for support or nonsupport for the statement, "If modern technology can make the airship feasible, would you support Federal funding to make it a reality?" In answer, 58.6% are in support of funding the technology: 8.6% definitely would, 50.0% probably would. This can be viewed as strong support by the Congress. Also, 15% were not favorable to funding. On this question 26.4% were neutral. (See Fig. 3-6.)

It should be noted that if both the neutral and negative responses were combined into a nonsupport group, there is still a majority support for the LTA concept.

3.2.2.1.1 CONGRESSIONAL RESPONSE BY DESIGNATED COMMITTEES

Since the Congress of the United States operates through its committee system, it is important to determine which of the survey respondents are on the committees which could affect the successful re-introduction of the airship system. Seven committees in the House and four in the Senate were chosen. Respondents were asked to designate membership on any committees listed below and support percentages were then determined and given in Table 3-1.

<u>Support Within the House of Representatives Committee System</u>

In general, a relatively high response percentage coupled with an overall positive

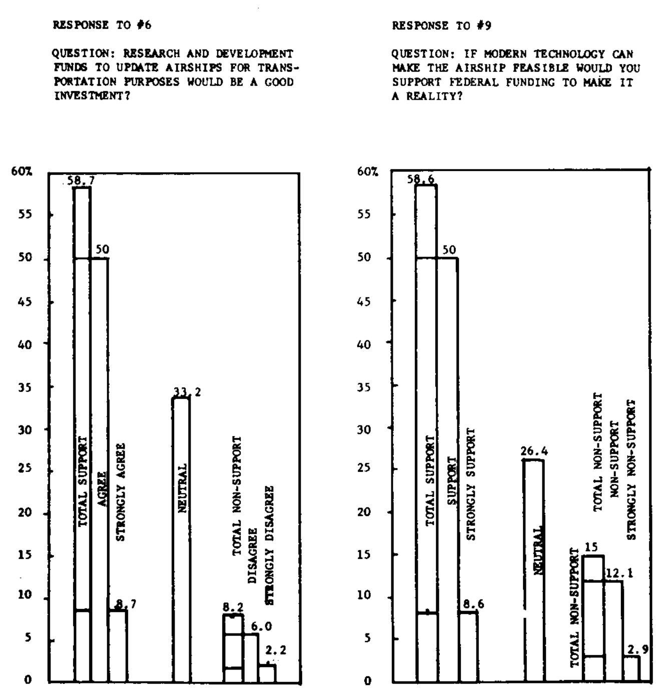

FIGURE 3-6
OVERALL CONGRESSIONAL RESPONSE TO ATTITUDINAL SUPPORT SURVEY
(94TH CONGRESS 1ST SESSION)

attitude would be an indication of support. Hence, the survey response indicates a favorable committee environment in the Ways and Means Committee (the revenue raising committee), the Science and Technology Committee, and the Armed Services Committee (military usage) within the House of Representatives.

Support Within the Senate Committee System

By the same reasoning, the Senate committee system showed support strength in three of the four committee areas selected: Aeronautical and Space, Armed Services, and Commerce. The small return from the Appropriations Committee cannot be considered favorable to the program; however, this response is not considered significant enough to forecast any adverse decisions from this particular committee. In summary, the committees of both houses are perceived to be favorable to LTA technology.

3.2.2.1.2 CONGRESSIONAL RESPONSE BY GEOGRAPHIC REGION

The survey questionnaire also asked each congressional respondent to designate his particular region: West North Central; East South Central; Middle Atlantic; Mountain; New England; Pacific; South Atlantic; West North Central; West South Central; and Alaska-Hawaii.

Again, a high response percentage coupled with the overall positive attitude would indicate support. A low percentage response might then indicate the reverse, i.e., little interest.

The strongest support was demonstrated by the Pacific and the East South Central regions followed by West North Central, South Atlantic, and the Middle Atlantic regions. The least support by region came from the New England States and Alaska-Hawaii. The low regional support in the New England region might be due to lack of an expansive geographic area. The two noncontiguous state locations seem to preclude LTA vehicle systems because of distances and, perhaps on the part of Alaska, climate. What is interesting is the median support provided by the Mountain States, fifth in order of ten, suggesting the area's desire for LTA system availability. It will be important to retain this particular regional support. The LTA capability will be such that altitude limitation does not preclude its usage within the Mountain States area. Naturally, if this mountainous area perceives no benefits from this technology, its congressional support could be withdrawn. The potential to operate LTA vehicles at high altitudes is included in the design concept.

The regions and Congressional response by region are shown in Fig. 3-7 and Table 3-2 respectively.

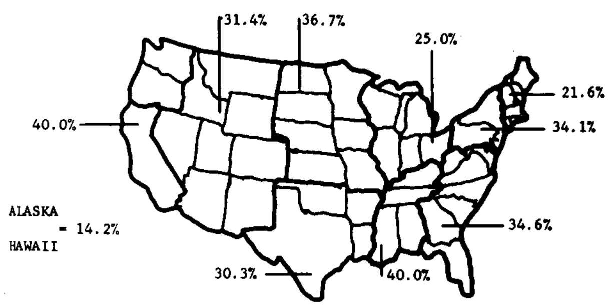

FIGURE 3-7

CONGRESSIONAL RESPONSE, BY REGION, FOR LTA TECHNOLOGY-FEASIBILITY SURVEY

TABLE 3-1

PERCENTAGE OF CONGRESSIONAL RESPONDENTS BY COMMITTEE

	Members	Respondents	Percent
U.S. House of Representatives Committees			
Appropriations	55	11	20
Armed Services	40	11	40
Education and Labor	40	10	25
Foreign Affairs	32	9	26.4
Interstate and Foreign Commerce	42	8	19
Science and Technology	37	15	40.5
Ways and Means	36	16	44.4
U.S. Senate Committees			
Aeronautical and Space Sciences	10	4	40
Appropriations	26	4	15.4
Armed Services	18	8	44.4
Commerce	18	7	38.9

TABLE 3-2

CONGRESSIONAL RANKING IN REGIONAL RESPONSE

Rank	Region	Respondent percentage
1st	East South Central	40.0
1st	Pacific	40.0
2nd	West North Central	36.7
3rd	South Atlantic	34.6
4th	Middle Atlantic	34.1
5th	Mountain States	31.4
6th	West South Central	30.3
7th	East North Central	25.0
8th	New England	21.6
9th	Alaska-Hawaii (non contigious)	14.2

3.2.2.1.3 SURVEY SUMMARY

The 58% congressional support for the LTA system indicates political-governmental support to the LTA technology. The low 15% nonsupport figure shows minimum antagonism to the airship concept. If the neutral respondents are added, it appears that majority support could still be anticipated. The neutral or "don't know" group represented at the maximum 33%. Logically, the neutral block might tend to provide support along the same general percentages of "for and against" as shown in the survey. The probability of a strong negative vote from this group is small. General support from this group should be anticipated.

3.2.2.2 FUNDING

There are several funding methods that appear feasible for the construction and operation of LTA technology. Both governmental and business sectors have the capability to generate sufficient funds for the airship industry.

However, neither of these sources is funding a comprehensive LTA transport system. This may be due to several negative factors. One such factor is that there has not been a demonstrated need for a new system of air transportation. No profitable use has yet been investigated thoroughly. Also, there is no past record of economic viability for any LTA vehicle system. The German Zeppelins and the British R-101 were semi-productive economically, but ultimately did not produce a return on investment. The past provides no information regarding fleet operations.

However, the previously cited survey of Congress has established a possible source of support. There appears to be majority support to generate initial funds for further development. While the Government appears to offer the best source of funding, the private sector also appears promising. Private funds would, however, only become available after a demonstration of the feasibility of the concept.

Table 3-3 indicates several funding methods. Two methods are from the Governmental sector, two involve the Government and private sectors jointly, and two are from the private sector alone.

Government Funding

The primary source of funds could well be the line item in an agency's budget. This line item would be for research and development funds to build and operate a series of LTA vehicle prototypes to obtain information useful for extending the technology into the private sector.

A secondary source of funds would be a multi-agency effort. Prototypes would be adapted to meet specific missions related to each agency. In this manner usage factors and costs can be obtained. Prototypes could be leased to the private sector area to generate economic utility data relative to effectiveness and efficiency.

Joint Funding

Another funding method would be to combine government and private sector efforts. This would entail research funding by the Government and construction funding by the

TABLE 3-3

FUNDING METHODS

Government	Joint	Private
1. Line Item in Agency such as NASA.	1. Government developed airship used by a consortium of private industries.	1. Industry provides all funds and operates a consortium.
2. Joint Agency Funding - DOD, DOT, NASA, and ERDA.	2. Government developed airship used by individual industries.	2. Current air carriers develop airship and lease or operate system.

private sector. An example of this would be the Postal Service providing research funds so that an industrial consortium could develop a mail carrying fleet of airships. (See Chapter 10).

Another joint government-private sector funding method would be the involvement of only one industrial firm with the Government. For example, companies such as duPont could develop materials for an airship developed by government agencies.

Private Sector Funding

The private sector can generate funds through a consortium formed by manufacturing companies. This entails the joint usage of the LTA vehicle fleet on an internal schedule with point to point pickup-delivery determined by the user group. Operational costs and any profits could be prorated.

Funds would be jointly contributed by general manufacturing industries. The operating structure would be a subsidiary company, or a new autonomous corporation, jointly controlled by the groups involved. Operational periods would provide utility factors and cost of operation factors which in turn are used to predict economic feasibility.

An alternative in the private sector could be the use of the LTA concept by the aerospace and the airline industries. This could also be a consortium arrangement. The aircraft industry would design and construct a given number of LTA prototypes. These would be utilized by the airlines within their present route structures. This funding and operation technique could be used to develop a viable LTA vehicle system without harming the current air transport industry.

3.2.3 LEGAL CONSIDERATIONS

3.2.3.1 LEGAL DEFINITIONS

According to the Federal Aviation Administration (FAA), an airship is defined as an engine-driven, lighter-than-air aircraft that can be steered. Similarly, the agency defines a lighter-than-air vehicle as an aircraft that can rise and remain suspended by using contained gas weighing less than the air that is displaced by the gas.

3.2.3.2 BACKGROUND

Certain legal obligations have been placed upon transportation businesses due to the dependence of society upon their services. These special obligations may take four different, yet interrrelated forms: to serve; to deliver; to charge reasonable rates; and to avoid discrimination. The legal nature of airships functioning in existing transportation networks would be analogous to other basic forms of aircraft transportation. Origins of the four obligations listed above have filtered down through the ages and are now referred to as common law, i.e., based on tradition and the law of precedents. According to Sampson and Farris, the word "common" can be translated to mean "public in the sense of being available to all" (ref. 3-6, p. 105).

With the passage of the Federal Aviation Act of 1958, the Government was given complete and exclusive national sovereignty in the airspace over this country. In essence, any citizen of the United States is granted a public right of freedom in transit via air commerce through the navigable airspace. Navigable airspace is defined as airspace above the minimum safe altitudes of flight.

Other legal concerns are determined by court cases cited under the following general headings:

Airports and Liability
Damages and Injuries on the Ground
Liability to Passengers and Others
Tariffs--Limitation of Liability
Workmen's Compensation
Limitation of Liability
Liability of Manufacturers and Repairers (ref. 3-7).

3.2.3.3 AIRCRAFT RESTRICTIONS--COURT CASES

Since the passage of the Federal Aviation Act, federal law grants extensive authority for the FAA to control airspace and to regulate air traffic. Therefore, cities are unable to exercise much control over aircraft noise, clearly one of the most controversial of all noise sources. Any attempts by local governments to curb aircraft noise by local ordinance have been overturned by the courts when the ordinance was found to create an unconstitutional burden on interstate commerce (ref. 3-8). However, local ordinances regulating some aspects of airport operations presumably would be allowed when they do not jeopardize aircraft operational safety or burden interstate commerce. For example, a municipality might order engine maintenance activities moved to another location when noise levels exceed those permitted by state or local law. In addition, airport owners can exercise direct control over some portions of airport noise (ref. 3-9). Restrictions on the permissible noise level of aircraft using the airport can be established. They can also specify the location for engine runup procedures.

Aircraft noise has created legal problems in such places as Grand Canyon National Park. During a telephone conversation, the park superintendent noted that the primary problem with commercial aircraft tours over the canyon was the noise factor; there have been numerous complaints about noise from helicopters and small aircraft. As a result, on January 3, 1975, Public Law 9362 was passed. In short, the law gives the Park Service the authority to take action against excessive noise in the Canyon by complaining to the FAA.

3.2.3.4 REGULATING AGENCIES

3.2.3.4.1 THE FEDERAL AVIATION ADMINISTRATION

As mentioned, the FAA was created by the Federal Aviation Act of 1958, as an independent board and given comprehensive authority over air safety and the control of airspace. An additional function was for the organization to give broad planning and research assistance in connection with the nation's airports and air transportation planning. Policy guidance in the Federal Aviation Act is broad and primarily aimed at the development of a safe and economically sound air network. Because of the nature of flight, it is impossible to have state or local regulation. For this reason, Federal Aviation Regulations (FAR's) have been issued through the FAA in the interest of air safety. The most important of these FAR's include Part 61 (Certification: Pilots and Flight Instructors), and Part 91 (General Operating and Flight Rules). Part 61 prescribes the requirements for issuing pilot and instructor certificates and ratings, the conditions under which those certificates and ratings are necessary, and general rules applicable to them. Part 91 presents the regulations governing the operation of aircraft within the United States (ref. 3-10). Table 3-4 notes those regulations most applicable to airships.

3.2.3.4.2 THE CIVIL AERONAUTICS BOARD

If utilized for freight or as a common carrier, the airship would be subject to CAB regulation. These regulatory functions commenced in 1938. This agency has a unique dual mission of both regulation and promotion of air transportation. CAB regulates the routes to be flown as well as the airports that make up the stages in the route structure. At present, the CAB has no specific regulations which cover airships.

3.2.3.4.3 OTHER REGULATORY AGENCIES

Other agencies which have some influence upon the development and operation of the airship are listed in the following paragraphs. Only the most relevant organizations were chosen for discussion.

National Transportation Safety Board. The NTSB is responsible for matters of safety in the aircraft industry. One of the most important responsibilities is to investigate crashes and report the findings to the FAA and others. After each crash, the NTSB goes to the site of the accident and retrieves the flight recorder (the tape recordings of the cockpit area conversation). The other device retrieved is the Digital Flight Data Recorder, which retains

TABLE 3-4

FEDERAL AVIATION REGULATIONS APPLICABLE TO AIRSHIPS AND CREWMEMBERS*

FAR Number	Title
1	Definitions and Abbreviations
23	Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes
25	Airworthiness Standards: Transport Category
33	Airworthiness Standards: Aircraft Engines
36	Noise Standards: Aircraft Type Certification
61	Certification: Pilots and Flight Instructors
63	Certification: Flight Crewmembers Other Than Pilots
65	Certification: Airmen Other Than Flight Crewmembers
91	General Operating and Flight Rules
103	Transportation of Dangerous Articles and Magnetized Materials
121	Certification and Operations: Domestic and Supplemental Air Carriers and Commercial Operators of Large Aircraft

*FAR's may be purchased from: Superintendent of Documents
Government Printing Office
Washington, D.C. 20402

a record of technical data during flight. These data include such items as:

1. engine thrust,
2. air speed,
3. altitude and heading,
4. vertical acceleration,
5. roll and pitch, and
6. angle of attack.

Based on all the crash findings, the NTSB publishes a public document which includes graphs, photos, and recommendations for improvements which would help prevent future tragedies.

Air Transport Association. This group is the aircraft industry's trade association. Membership of the organization constitutes one of the larger lobby groups in Washington. In 1938, their efforts helped establish the Civil Aeronautics Board. The ATA consists of 24 active members representing major airlines in this country. There are two associate members representing the Canadian Airlines.

3.2.3.5 PROFESSIONAL ORGANIZATIONS

Of all the specialized organizations in the aircraft industry, two seem to be the most significant for this study. They are the Air Line Pilots Association (ALPA) and the Aircraft Mechanics Fraternal Association (AMFA).

Air Line Pilots Association. ALPA represents about 37,000 commercial pilots of all classifications in the United States. There are 35 airlines represented; other pilots' associations exist which are not as large in terms of total membership. This association, like the ATA, is active in legislative affairs. Passage of anti-hijacking legislation is attributed to this pilots' organization. When new aircraft are introduced, ALPA committees are formed to test the design and safety features. For example, a "747" committee was established when it was introduced in the market. Similarly, if an airship were to be designed and introduced, an ALPA committee could contribute significantly to any refinements in design and safety features.

Aircraft Mechanics Fraternal Association. AMFA is an organization composed of about 8,000 aircraft mechanics. The group is also concerned with aircraft safety; their latest concern is promotion of air-carrier maintenance procedures with the FAA.

3.2.3.6 AIRSHIP INSURANCE

Two types of insurance must be considered before any airship can be operated on a commercial basis--hull insurance and liability insurance. Little information was available from insurance firms about rates for a proposed airship plan. Airships owned by the Goodyear Tire & Rubber Company are insured by the Aviation Underwriters Association for the value of the hull. This rate, 4.5¢/$1,000/year of hull value, was established based on experience over 25 years of safe operation. For liability, there is a $10,000,000 policy in effect wherever the airship operates.

Air carrier liability is changing with the complexity and nature of services provided. Limitations of liability are numerous and have been established by precedent court cases. For example, the carrier is generally held responsible except under five classifications:

1. War-hostile acts or acts of God, such as floods, tornadoes;
2. acts of public authority, seizure or quarantines;
3. acts of the shipper, goods not marked or packed efficiently;
4. inherent dangers in goods (livestock fighting, molasses fermenting);
5. riots or strikes. (Ref. 3-6, pp. 108-110.)

3.2.3.7 AIRSHIP CERTIFICATION REQUIREMENTS

Procedures for certifying any aircraft are prescribed by the FAA. Airship certification procedures would be similar to those applied to any aircraft. First, all design and manufacturing data would be submitted to the engineering section of the FAA. After reviewing all documentation, preliminary approval would be given to construct the vehicle. Since the FAA has standard aircraft specifications pertaining to such things as types of rivets, dope, layers of fabric, etc., care must be taken to assure conformity. After the airship is finished, the FAA would again inspect the vehicle to determine conformity to submitted specifications. Finally, the airworthiness, safety, and operating procedures for the vehicle would be agreed upon and finalized.

3.2.3.8 CERTIFICATION FOR PILOTS

Part 61 of the FAR's includes certification for pilots and flight instructors. Part 61.117 describes the lighter-than-air rating with regard to necessary experience.

3.2.3.8.1 PRIVATE PILOT CERTIFICATE

An applicant for a private pilot certificate with a lighter-than-air category rating must have at least the aeronautical experience appropriate to the rating sought prescribed in paragraph (a) or (b) of this section. For airships, a total of 50 hours of pilot flight time is required. At least 25 hours in airships including five hours of solo or an equivalent amount of time performing the functions of airship command pilot are required.

3.2.3.8.2 COMMERCIAL PILOT CERTIFICATE

An applicant for a commercial pilot certificate with an airship rating must have a total of at least 200 hours of flight time as pilot, including:

1. 50 hours of flight time as pilot in airships;
2. 30 hours of flight time, performing the duties of pilot in command in airships, to include:
   a. 10 hours of cross-country flight,
   b. 10 hours of night flight;
3. 40 hours of instrument time, of which at least 20 hours must be in flight with 10 hours of that time in airships.

3.2.3.9 LEGAL IMPLICATIONS

There seem to be few legal problems which would hinder airship development alongside other existing modes of transportation. The only possible problem seems to be in the area of noise. If airships are to operate successfully, especially over suburban areas and national parks (see Chapter 10), they should have very low noise levels.

Once plans are formulated for an airship or fleet of airships, the engineering section of the FAA would have to approve airworthiness and other engineering standards for the industry. Once in operation, the CAB would approve routes and rate structures to be utilized for scheduled and non-scheduled cargo missions.

The role of rules and regulations in the development of airship systems is indicated by a flow diagram in Fig. 3-8.

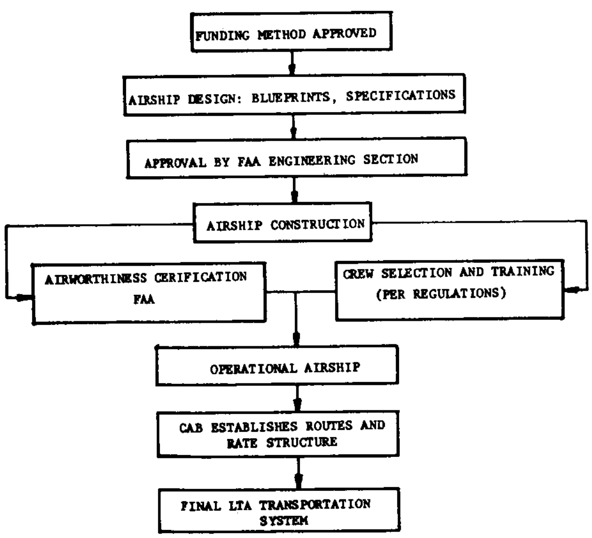

FIGURE 3-8

LEGAL ROLE IN AIRSHIP DEVELOPMENT

3.2.4 ENVIRONMENTAL CONCERNS

3.2.4.1 INTRODUCTION

The quality of our environment in the urban areas of the nation is deteriorating with the continued use of present transportation systems. The Environmental Protection Agency, acting under the authority granted the agency by the "National Environmental Policy Act of 1969," has developed air pollution levels to be attained in each urban area by 1977. These proposed levels require significant reductions in motor vehicles and industrial emissions in these areas. In Los Angeles, one of the critical areas, it has been estimated that to meet the 1977 criteria, an 80 percent reduction in vehicle miles traveled must be attained. This level of reduction in the given time frame is considered by many people to be unreasonable. However, there is no question that our future transportation system must be designed with such reductions as top priority.

All transportation systems today are plagued with environmental problems that are of serious concern to the public. In our endeavors to provide safe, economical transportation of people and goods, we have created systems that are noisy, air polluting, and wasteful of energy.

Present air transportation requires substantial amounts of urban land for airports. The newer, larger planes are requiring airport extensions or construction of complete new airports at new locations. The operation of aircraft in landings and takeoffs at older airports over populated urban areas has caused many problems in recent years due to increased traffic volumes and noise.

The advent of new high-powered jet aircraft has increased operational noises in the vicinity of our airports to the extent that many cities are abandoning old airports that are now surrounded by residential neighborhoods and moving to new locations many miles from the urban population. Notable examples are Washington, D.C.; Houston, Texas; Louisville, Kentucky; Kansas City, Kansas; and others. Another approach open to cities when the noise level reaches critical levels is the condemnation and purchase of housing falling within the recommended "clear zones" at the end of runways and, in some cases, housing in adjacent residential areas parallel to the runways. This is the only way some airport operations can be modified to meet EPA noise restrictions.

Moving the airport may be more economical with respect to land purchase or damages paid to land owners adversely affected; however, the overall economic cost may be tremendously expensive to the public, due to land removed from tax rolls, etc. Cargo handled by aircraft must be trucked from the airport to city destinations in most cases. Moving the airport to remote areas obviously increases these trucking distances. This additional ground transportation is costly from pollution, energy, and dollar standpoints.

Not moving may leave the airport in the most attractive location with respect to ground transportation; however, the concentration of all air cargo traffic in one location will continue to concentrate the truck traffic and accompanying air pollution in one area of the city.

The airship has the potential to offset many of the above adverse consequences of present transportation systems. Airships can operate at smaller airports in urban areas and can operate possibly without the noise problems associated with regular aircraft. The air pollution factors, both from the airship and necessary ground transportation would be substantially reduced.

An attempt at solving transportation problems without considering the total trip involved would be an unfortunate attempt indeed. Design of any transportation system must include an evaluation of the entire origin to destination or "portal to portal" trip. Too often only the "line haul" portion of a trip is examined, omitting concern for the collection, distribution, and terminal system. When considering the airship potential, the apparent ability to either eliminate or substantially reduce the collection and distribution systems by use of smaller, decentralized airports or pickup and delivery at the factory is an obvious plus factor. The accrual of the total benefits to be gained from this advantage, including the social, environmental, and economic benefits, must be considered.

Utilization of small airports that now exist in many urban areas as terminals for airships would permit an economy of scale. The large truck-tractor combinations now used at major airports, harbors, and truck terminals could in many cases be replaced by the delivery truck. Commodity delivery would be more efficient. This type of operation would also permit decentralized employment, with accompanying dispersement of work trips, etc.

The economics of environmental protection have been the subject of considerable debate. One reference states the following:

> Our national income accounting does not explicitly recognize the cost of pollution damages to health, materials, and aesthetics in the computation of our economic well-being. Many goods and services fail to bear the full costs of damages they cause from pollution and hence are underpriced. (Ref. 3-9.)

This statement identifies one of our major problems when considering the feasibility of any project. Project justification has historically been on the basis of economics, revenue versus income relationships, utilizing current dollar value. In our present society this approach is not adequate. It fails to recognize our changing value systems, especially in the areas of redistribution of income and environment. There are those who feel that the only way to evaluate any variable is to reduce it to a dollar value. However, air pollution, water pollution, destruction of plants and animals costs cannot easily be expressed in dollars. When they are, the costs usually relate to an estimate of cleanup in order to comply with Environmental Protection Act (EPA) regulations. Presently this agency assumes total cost to consist of the following:

1. costs of pollution that has already occurred,
2. costs incurred to meet new regulations,
3. costs of providing control for new regulations.

The federal report entitled Environmental Quality (ref. 3-9) further discusses environmental economics as follows:

> Expenditures to improve environmental quality are an investment in the quality of life. As with similar investments in education, the results are not immediately available as profits or growth in the Gross National Product. Nevertheless these investments can reap great dividends.
>
> Like any reallocation of resources, the investment to achieve environmental quality will bring about short-run adverse impacts, i.e., higher prices, temporary unemployment, and plant dislocations. Matched against these negative results are the investments dividends, such as decreased health bills, increased recreational opportunities, diminished damage to materials, and better maintenance of the ecological balance necessary for human survival.

This same report also addresses such problems as the pollution in our national parks.

> Man's increasing impact on the beauty, primitiveness, and tranquility of the National Parks has brought the country face to face with the need to protect the ideal born 100 years ago around the campfire at Yellowstone. The goal to make the parks available to all--to enrich and educate an urban society on its natural heritage--conflicts with the goal of preserving the parks in a pristine state. The solution to this dilemma will demand a high level of creative management. To do less may result in unnecessarily roping off the parks to many Americans or to see them further deteriorated from overuse.

Another statement from the same source states:

> In many parks, visitors' use can be expanded without damaging the environment by using buses or other forms of mass public transit.

In Grand Teton and Yellowstone, fringe area parking and mass transportation are being used to reduce environmental damage to the parks (ref. 3-9).

3.2.4.2 SPECIFIC ENVIRONMENTAL REQUIREMENTS

Specific regulations with respect to environmental subsystems are outlined below.

3.2.4.2.1 NOISE

The FAA is granted extensive authority by Federal law to control use of aircraft and airspace. This limits municipal control over such items as noise. The limits of municipal authority involving noise levels at airports are still being argued in court.

The noise levels involved with our transportation systems are becoming more and more of concern to the people living and/or working near these noise sources. A Department of Transportation publication (ref. 3-10) provides the following information on noise measurement. Sound levels are measured by a meter in units called decibels (dB). The human ear is such that this doesn't always correspond to relative loudness or annoyance. Different scales have been developed for specific noise sources for better evaluation. A unit designated EPNdB which weighs the sound pressure of the various frequencies of a noise, adds corrections for annoying tones and sound durations. The unit dB(A) is a scale similar to EPNdB developed specifically for surface transportation. The difference between them is approximately a constant 13 dB, i.e., (EPNdB - dB(A) ≈ 13 dB). Fig. 3-9 illustrates the comparisons between several noise sources using the two scales. In the vicinity of major airports the noise problem has reached a point where to reduce the noise level to an acceptable level during night hours, controversial measures such as simultaneous takeoffs and landings in the same direction on parallel runways have been implemented.

New aircraft must meet strict FAA regulations concerning noise. As a result of the attention to the problem and application of advanced technology to aircraft design, the newest jumbo aircraft, the DC10 and L1011, have noise levels at takeoff and approach significantly reduced from older aircraft (see Fig. 3-9, 3-10, 3-11, and 3-12).

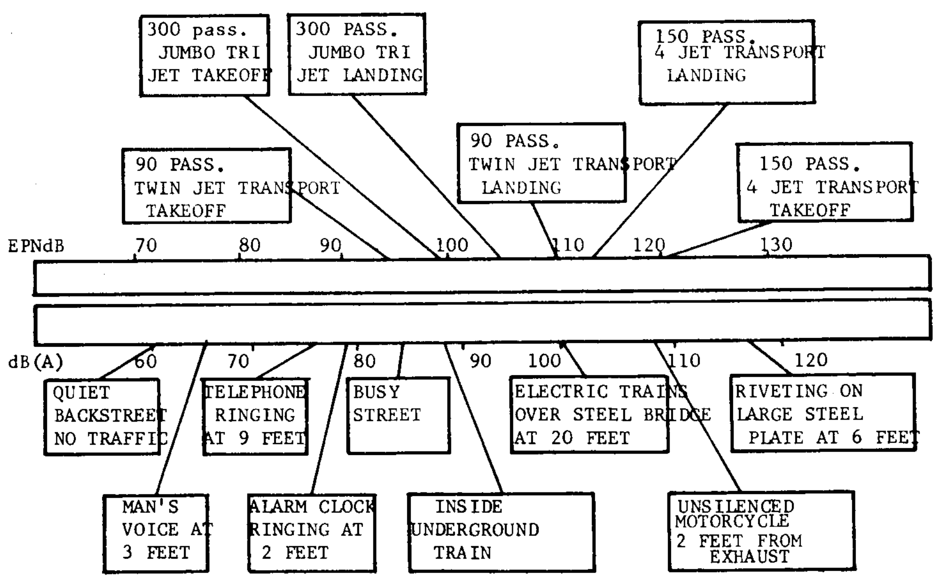

FIGURE 3-9

TYPICAL NOISE LEVELS
(ref. 3-11)

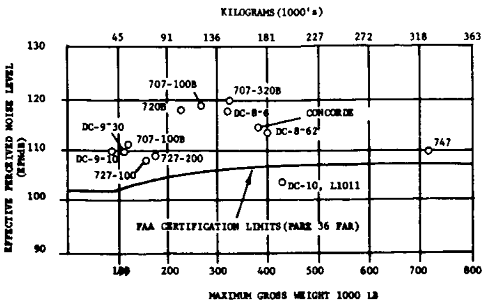

FIGURE 3-10

AIRCRAFT APPROACH NOISE LEVELS 1.9 KM (1 NM) FROM THRESHOLD (adapted from ref. 3-11)

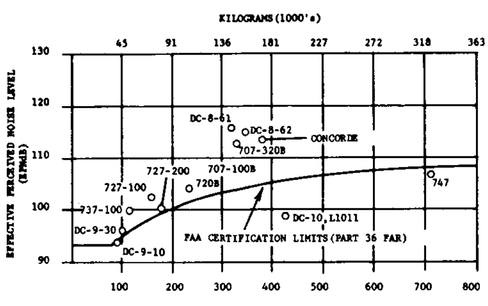

FIGURE 3-11

AIRCRAFT TAKEOFF NOISE LEVELS 6.5 KN (3.5 NM) FROM BRAKE RELEASE (adapted from ref. 3-11)

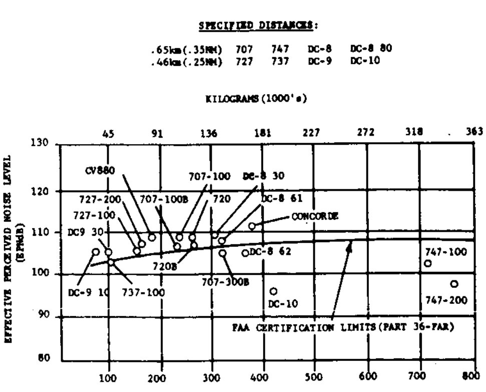

FIGURE 3-12

AIRCRAFT SIDELINE NOISE AT SPECIFIED DISTANCES (adapted from ref. 3-11)

3.2.4.2.2 AIR QUALITY

The Federal Clear Air Act establishes air quality standards for six of the most prevalent air pollutants: particulate matter, sulfur dioxide, carbon monoxide, hydrocarbons, nitrogen dioxide, and photochemical oxidants.

3.2.4.2.3 WATER AND SOLID WASTE

Solid waste disposal control is primarily left to local authorities under state laws.

Water quality is being strictly controlled in most states. Discharges into streams as well as activities near streams that could cause silt or foreign material flow in case of rain are controlled. Wash water, oil, and fuel are types of waste that cannot be discharged into streams or ponds without treatment.

3.2.4.3 ENVIRONMENTAL IMPACT OF AN AIRSHIP SYSTEM

3.2.4.3.1 INTRODUCTION

The proposed airship fleet impact on various environmental subsystems analyzed used a matrix with the subsystems on one axis and the individual airship operations on the other axis.

This matrix is given in Fig. 3-13. It identifies the broad areas of potential airship impact, both positive and negative, on numerous subsystems that constitute our total environment. This is not intended to be a design impact statement for a specific location but a more general planning impact statement; therefore, specific information concerning species of wildlife, types of vegetation and particular types of streams or bodies of water are not addressed. The following material discusses the concerns and benefits indicated in the matrix.

3.2.4.3.2 AIR QUALITY

The propulsion and thrustor units of the proposed airships must be designed to meet emission requirements of the Environmental Protection Act. The emissions to be controlled are particulate matter, nitrous oxides, hydrocarbons, and carbon monoxide.

Engines in the Phase I and Phase II airships are turboprops. These operate on the Brayton cycle. Boeing Vertol (ref. 3-12) presents data indicating that this cycle has lower emissions than current Diesel and gasoline engines. The reference also shows that the Rankine and Stirling cycles do better on emissions. However, Rankine cycle engines (steam) are too heavy for airship application and Stirling engines are not well developed. The thrustors utilized eject air only and therefore do not contribute to air pollution.

AIRSHIP FUNCTION

GROUND OPERATIONS / AIR OPERATIONS

ENVIRONMENT FACTORS	GENERAL	WASTE DISPOSAL	VTOL	FUELING	CARGO HANDLING	TERMINALS	ELECTRICAL POWER	BALLAST	TRAFFIC	EMISSIONS	GAS LEAKAGE	TYPE OF CARGO	ENERGY CONSUMPTION	MAINTENANCE	WASTE DISPOSAL	EMISSIONS	ROUTES	BALLAST MGT	AIR CONTROL
AIR QUALITY	+	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WATER QUALITY	0	X		X	X	X		X		X		X		X	X			X	
LAND USE	+		X			X			X								X		
STREET USE	+					X			X			X							
VISUAL IMPACT	-		X			X			X									X	X
AIR SPACE	-		X														X		X
LOCAL GROWTH	+					X											X		
VEGETATION	+		X		X	X			X	X	X	X	X			X	X	X	
WILDLIFE	+		X		X	X			X	X	X	X	X			X	X	X	
NOISE	+		X		X	X			X					X			X		

X INDICATES IMPACT
\+ POSITIVE IMPACT
\- NEGATIVE IMPACT
0 NO IMPACT

FIGURE 3-13

ENVIRONMENTAL IMPACT MATRIX

Airship operations are proposed for several types of areas: existing airports, new facilities designed specifically for airship operations near urban areas, or airship terminals in industrial areas. In the latter two cases the existing zoning and air quality regulations will influence if not determine the location of the facility.

The fuel storage and refueling operations at terminals must be properly controlled to reduce hydrocarbon emissions.

Fueling and storage of fuels will be conducted in a manner to meet current safety regulations. Cargo handling, cleanup, and maintenance procedures for the airship operations must be designed to meet all current air quality regulations.

Trucks and auto traffic into the airship operations area will directly affect the amount of pollutants in the air; however, because of the size of the operations it is not anticipated that these additional vehicle operations will be detrimental.

Helium leaks from airships at an extremely slow rate and is an inert, colorless, odorless, lighter-than-air gas. No resultant adverse air quality affects are expected either at terminals or during air operations.

3.2.4.3.3 WATER QUALITY

Airship operations will affect water quality during cargo handling, fueling at terminals, and waste disposal. Sewer facilities for liquid waste and treatment facilities for fuel and grease lost during maintenance will be provided as a part of terminal construction.

Minor effects of engine emissions on natural bodied water along routes of air operations are anticipated. Emissions will be dissipated over a wide area before actual contact with water when the airship is at its operational altitude.

3.2.4.3.4 LAND USE

Airship landing and takeoff, terminal locations, truck and auto traffic serving the airship will have effects on land use.

The vertical takeoff and landing feature of the LTA airship reduces land required for air terminals.

In areas where new LTA operations sites are to be established, the quality of local life will be protected by zoning and other land use controls. Buffer zones will be developed between the LTA operation and adjacent land.

Surface transportation serving LTA operations must be an integral part of transportation planning to ensure acceptable levels and locations of service roads and railroads in a given area. The dispersal of terminal locations could reduce traffic densities compared to those around current air transport terminals.

3.2.4.3.5 STREET USE

Street use will be affected by terminal location, type and magnitude of cargo, and truck size. Street use should be a part of land use planning. The use of airships will provide a means of reducing street loads, i.e., the use of several fringe terminals instead of concentrating all activity at a single heavier-than-air airport will decrease localized high traffic densities.

3.2.4.3.6 VISUAL IMPACT

Due to the extremely large size of the LTA vehicle, there will be a visual impact during takeoffs, landings, and terminal operations. The reaction to this impact by wildlife, residents in the area, and those along the air routes is not completely known. The experience of the past indicates some domestic animals, specifically turkeys, (See section 3.2.5.3.9) affected by airships passing overhead. The operation of the Goodyear airships has not created any known problems for other wildlife. Any potential adverse effects can be eliminated by proper planning of flight altitudes and routes.

3.2.4.3.7 AIRSPACE

Operations of airships will require that airspace be regulated in the vicinity of LTA terminals. This would be true especially if existing airports are used. Airship operations will require a careful review of existing flight regulations. Modifications may be needed to reduce potential conflicts between regular aircraft and LTA vehicles. Takeoff and landing techniques are entirely different for each mode. The airship can develop VTOL capability whereas most aircraft cannot. Careful route planning will be needed for an LTA carrying heavy loads external to the ship (See Appendix D).

3.2.4.3.8 LOCAL GROWTH

Growth on a localized basis would result from LTA vehicle operations. Where new terminals or use of existing airports are proposed, growth could be induced in the immediate area to support the operation. This produces higher employement but also increases the burden on the local environment due to population increases.

3.2.4.3.9 ECOLOGY

LTA operations could affect wildlife and vegetation in the areas near terminals and maintenance facilities. Operations at existing airports should not increase this problem. However, when a new LTA terminal is constructed, there will be an adverse impact on wildlife and vegetation in the immediate area.

Airship operation will affect the ecology in the vicinity of the routes through engine emissions and noise. Visual impact also seems to be a concern. Conversations with Goodyear blimp pilot indicate that the sight of an airship "drives turkeys wild."

3.2.4.3.10 NOISE

Noise has been discussed previously (See section 3.2.4.2.1). The airship, because of its inherent buoyancy, operates differently from a regular aircraft. Except when hovering to transfer cargo, very little noise producing engine power is necessary. Noise during hovering may be a major problem. The airship and the load-unload system must be designed to alleviate this potential difficulty.

3.2.5 SOCIOLOGICAL IMPACT

3.2.5.1 INTRODUCTION

Airship missions have numerous consequences for the socioeconomic system. In this section, these consequences will be discussed in general; the specific impacts of the various missions are detailed in Chapter 10. History is examined when necessary to shed light on these problems. These difficulties are set in a sociological context, i.e., the solutions affect groups in society.

3.2.5.2 PERSPECTIVE ON AIRSHIP SAFETY

3.2.5.2.1 HINDENBURG SYNDROME

No extensive civilian use has been made of the airship since the late 1930's. During the first four decades of this century, a number of spectacular airship crashes caused loss of public faith in the airship as a safe vehicle. The most dramatic of these crashes was, of course, the Hindenburg crash at Lakehurst, New Jersey, in 1937. As a result, members of the Design Team felt that there still might exist a negative attitude toward airships.

As a part of technology assessment it was necessary to attempt a determination of the degree to which a Hindenburg syndrome exists. If a negative image of the airship really remains in the mind of the public and Congress, it would be impossible to generate Federal funding for research and development or to gain public acceptance of the airship as a viable means of transportation.

A review of the major causes of airship crashes indicates that the Hindenburg crash was an atypical crash. While the Hindenburg disaster was the result of using hydrogen as a lifting gas, most other aircraft crashes were associated with wind and weather conditions. As Table 3-5 indicates, most nonrigid airship losses were related to violent weather or landing problems.

TABLE 3-5

CIVILIAN AND NONHOSTILE MILITARY RIGID AIRSHIP ACCIDENTS
(ref. 3-15)

ACCIDENT CAUSE	SHIPS LOST
Burned in shed	13
Handling and flying accidents:	
Coming out of shed	3
Burned on the ground	3
Landing	15
Burned in flight	7
Failed structurally in flight	3
Lost in storms	16
TOTAL	60

These data for both airship types indicate that structural failure was not a major problem. Ground handling and landing problems presented a far greater threat to the destruction of the airship.

Airships of the configurations proposed in this report would have the advantages of computerized avionics and the capability of thrust vector control. This would give the airship ability to take off, land, and dock with a degree of control previously impossible. Most of the problems encountered by previous airships could be solved by the application of modern technology related to structures, control, and operation.

While rational analysis suggests that a safe airship transportation system is technically possible, there is no assurance that the public and Congress agree. In an effort to assess the degree to which Congress and the general public regard the airship as unsafe, an opinion survey was conducted among members of Congress and an available sample of college students.

3.2.5.2.2 CONGRESSIONAL SURVEY

Three questions in the survey described in section 3.2.2.1 were related to airship safety. Congressional responses to these three questions are presented in Figure 3-14. The overwhelming majority of the respondents to these questions feel that the airship is safe. Even though many of these respondents

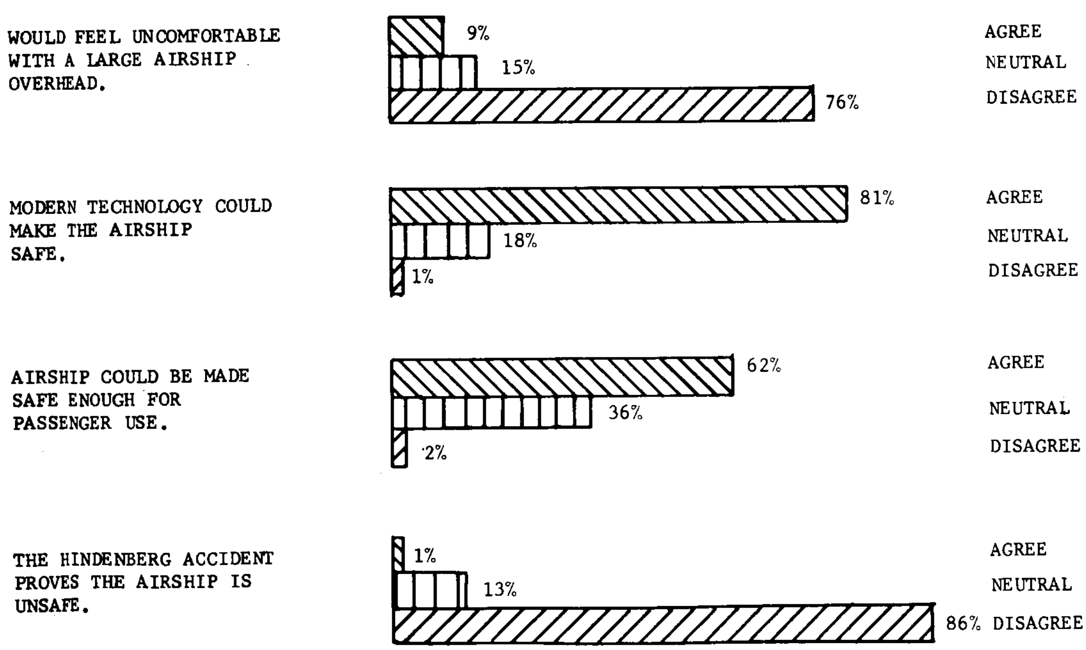

FIGURE 3-14

CONGRESSIONAL ATTITUDES: AIRSHIP SAFETY

are old enough to remember the Hindenburg crash, they do not think that the Hindenburg accident is indicative of the safety of the airship per se. There appears to be confidence among the Congressional respondents that modern technology can devise an airship safe enough for commercial use.

3.2.5.2.3 STUDENT SURVEY

The airship attitude survey was also administered to 318 students attending two large southwestern universities. Students were told that the survey was related to a systems engineering feasibility study. They were not provided with any information about past, present, or proposed airships. Responses to questions related to airship safety are presented in Fig. 3-15. Somewhat surprisingly, students are less confident about the safety of airships than are Congressional respondents. However, a decisive majority of the student respondents are in agreement that the airship is safe enough for civilian passenger service and that the Hindenburg accident is not proof that the airship per se is unsafe. Apparently, the relatively large undecided response resulted from the fact that many students had never heard of the Hindenburg airship.

Taken together, the student and Congressional surveys indicate that there is very little concern about the safety of airships among those surveyed. This suggests that a Hindenburg Syndrome which could inhibit the modernization of airship technology does not exist.

3.2.5.3 IMPACT ON INDUSTRIAL AND EMPLOYMENT TRENDS

A major socioeconomic problem in employment is that new technologies such as the airship can create or decrease employment and/or cause employment shifts. The airship transportation system would compete mainly with trucks and trains, but the amount of business which can be realistically projected for the airship would not reduce overall employment in either the truck transporation industry or the railroad industry. The amount of cargo (commodities and mail) that the airship transportation system would account for would be less than one percent of the total cargo moved by truck and rail. Such a small share of the market will cause little or no displacement of employed workers.

Unscheduled missions envisioned for the Phase I and Phase II airships would have a small impact on existing employment. Many of the tasks suggested are either not being handled currently or are being handled less than adequately by present transportation systems.

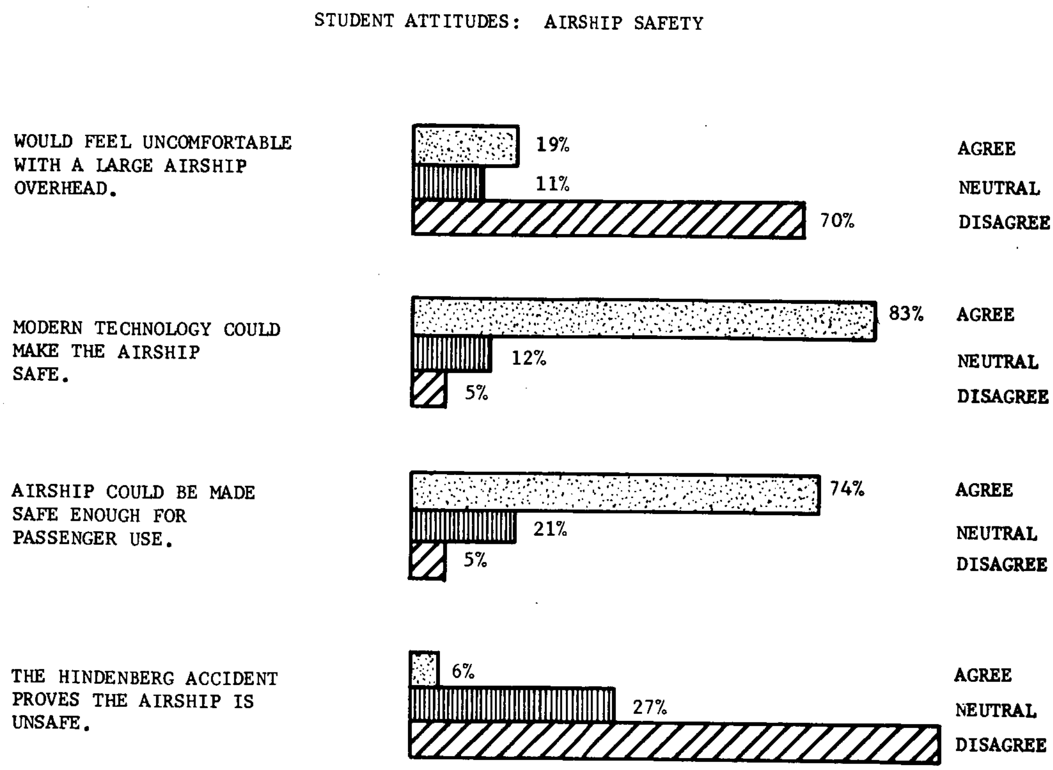

FIGURE 3-15

STUDENT ATTITUDES: AIRSHIP SAFETY

The airship would generate almost no displacement in the economy and would add several hundred jobs. It appears that the overall economic impact of the airship transportation system would be positive. Little, if any, unemployment would result from reintroducing the airship.

If there is a relatively small economic impact on existing modes of transportation, one would not expect vigorous resistance from existing modes of transportation or related vested interests such as equipment manufacturers and unions. It is possible that these companies and unions would co-opt the emerging industry. In other words, one might expect the major transportation companies to become airship owners of the future.

3.2.5.4 ENHANCED TECHNICAL CAPABILITIES

Another sociological concern is the technical capability of society.

The use of airships to move heavy and outsized loads would enhance industrial design capabilities in several areas. Utilizing airships to move centrally constructed modular housing units would have a major impact on modernizing the housing industry. Utilizing airships to move petrochemical plant components, electrical generators, and other extremely heavy or outsized industrial equipment would give the designers of such equipment greater design flexibility. Since such equipment is now moved primarily by truck or rail, designers are constrained by the width of the roadbed and height of overpasses and other overhead obstructions.

3.2.5.5 CONCLUSION

Numerous benefits would accrue to society if an airship transportation system were to be integrated into the transportation system of the country. There is apparently less resistance to the modernization and the development of an airship transportation system than was initially assumed by researchers. There would be almost no displacement of workers or capital in the established transportation industries, an important factor for the successful implementation of any new system which might require Federal funding to become a reality. Not only is the airship a beneficial concept in that it does not displace a substantial amount of employment, it also offers tangible social benefits without entailing significant social costs.

3.3 SUMMARY

Support for the airship can be expected from the Congress. The Civil Aeronautics Board and the Federal Aeronautics Administration must develop necessary routes and operational regulations.

Large national and international corportation unions will take steps to ensure their involvement in governmental policy making related to the airship systems.

Environmental factors are not expected to inhibit the development of an LTA transportation system. The system itself offers the potential for eliminating large concentrations of cargo at central terminals by bringing the freight carried by air closer to its final destination. This would reduce concentrations of truck traffic, noise, and air pollution where large central terminals now exist. From an energy viewpoint, the airship would be better than airplanes; for the Phase II airship, better than trucks, but not as good as rail, water or pipeline transport.

It appears that the development of an airship transportation system would generate substantial social benefits at minimal costs. Contrary to initial assumptions, neither the Congress nor the general public has a negative attitude concerning the airship per se. The socioeconomic impact of developing an airship transportation system would be positive. There would not be any significant socioeconomic dislocation within existing industries and several hundred permanent jobs would be created. When airships are utilized to move outsized industrial equipment, industrial designers would have a significantly greater degree of design flexibility--a benefit to society related to economy of scale.

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CHAPTER 4

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4.1 INTRODUCTION

The airship operations experience of the past, both military and commercial, will be the base upon which future operational procedures will be built. In order to have a viable airship transportation system, particular attention must be given to cost sensitive areas such as flight crew size and ground handling crew size. Ground equipment development for any aircraft system is costly. Any system which does not provide adequate ground equipment, however, will fail.

Full advantage must be taken of state of the art in avionics, materials, and weather forecasting systems. Since there will be little possibility of using flight crews with past airship experience, it will be necessary to train new flight crews using simulators. Training of maintenance technicians will not present a problem.

4.2 GROUND OPERATIONS

4.2.1 HISTORICAL

For the purposes of this study, the historical review of ground handling equipment developed for airship operations will be limited to that developed and in use for rigid airship operations in the 1920-1940 period and for nonrigid operations in the 1940-1962 period.

The British developed the first high mast, 36.6 meters (120 feet), for mooring rigid airships at Pulham in 1919, ref. 4-1. Flying moors to the mast were made as well as static takeoffs directly from the mast. The U. S. Navy operated from high masts on the U.S.S. Patoka, airship tender, as well as at NAS Lakehurst.

In 1927, the U. S. Navy first operated the U.S.S. Los Angeles from a low mast 18.3 meters (60 feet). A wheel was clamped to the aft power car of the Los Angeles to serve as a "riding out" wheel while at the low mast. The Los Angeles was operated from low masts erected at Parris Island, South Carolina; Guantanamo Bay, Cuba; and Panama.

In 1929, a telescopic mast with a triangular base mounted at the corners of three crawler treads was put into service for docking and undocking the Los Angeles. Docking rails and trolleys together with manpower tended the stern of the airship while the mobile mast handled the bow.

In 1931, a railroad type mobile mast was completed at naval air station Lakehurst for use with the Akron and Macon. The railroad type mobile mast was used in conjunction with a stern beam mounted on a railroad riding out circle. This mast was also used with docking rails and trolleys for undocking and docking operations.

Prior to World War II, mobile masts, mounted on rubber tires and towed by tractors, were developed for nonrigid airship operations. Mobile masts as well as air transportable "stick" masts were used extensively in advance base operations through World War II.

Expeditionary type stick masts were used where the upper section of a mast, approximately 2.5 meters (8 feet), was flown into an advance base and available materials (guywires, anchors, poles, etc.) were used to erect the mast.

Mechanized ground handling vehicles became available for U. S. Navy nonrigid airship operations in 1957. Two types were developed--a heavy duty vehicle designated as MC-3 and a light duty vehicle designated as MC-4. The vehicles became known popularly as ground handling "mules". Constant tension winches were mounted on the mules. The maximum cable tensions for the MC-3 Mule and MC-4 Mule were 35,580 newtons (8000 pounds) and 16,900 newtons (3800 pounds) respectively, ref. 4-1.

During World War II portable helium purification units were developed for use at advance bases. The purification process was accomplished while the airship was "riding out" on a mast.

In the 1950's, inflight refueling and reballasting techniques were developed. Methods and pumping equipment were developed to refuel from surface ships as well as from the ground while airborne.

4.2.2 MOORING PROCEDURES

Both Phase I and Phase II systems should be designed so that hangaring of the airships will only be during periods of major overhaul or when major emergency hull repairs are required. All regular operations would be from a low mast or stick mast as it is popularly called. Ideally, a hydraulically retractable stick mast should be used. The mast and supports should be flush with the ground when in the retracted position. Fig. 4-1 is a sketch of the suggested retractable hydraulic mast.

Mobile masts developed for Phase I airships should be so designed that they may be used as "riding out" masts. Railroad type mobile masts developed for docking of Phase II airships should not be designed for use as a "riding out" mast.

4.2.3 UNDOCKING AND DOCKING PROCEDURES

Docking of airships should be only

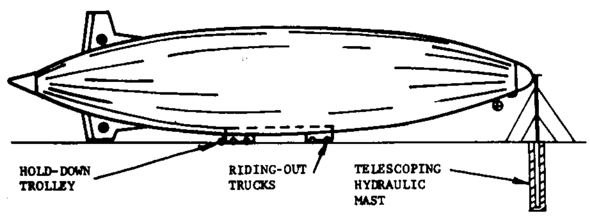

FIGURE 4-1

MASTING AND RIDING OUT CONFIGURATION OF PHASE I AND PHASE II

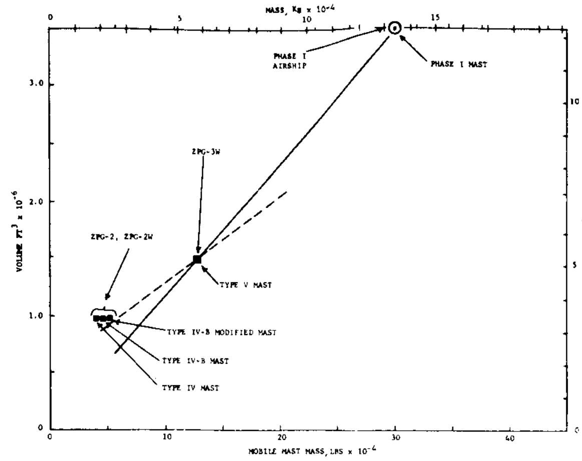

FIGURE 4-2

AIRSHIP VOLUME VS. MOBILE MAST MASS FOR PHASE I

for purposes of conducting maintenance or inspections requiring hangar facilities.

4.2.3.1 PHASE I AIRSHIP DOCKING

The Phase I airship will require design and development of a tire mounted mobile mast. The Type V U.S. Navy mobile mast developed for the ZPG-3W nonrigid airship is not large enough for the Phase I airship, according to information received from Mr. Jack Waldman of Goodyear Aerospace Corporation in a telephone conversation on July 27, 1975. The overturning moment on the mast when a masted airship is struck by a side gust can be shown as approximately directly proportional to the displacement volume. Assuming an ellipsoid of revolution the side gust forces will be directly proportional to longitudinal cross-section area.

The ratio of overturning moments for two airships will be approximately

$$\text{area}_1\ b_1/\text{area}_2\ b_2 = a_1\ b_1^2/a_2\ b_2^2 \qquad (4\text{-}1)$$

where b is maximum radius of the airship, and a is airship length/2.

Since the volume of an ellipsoid of revolution is $(4/3)\ \pi ab^2$, the ratio of moments can be written as being proportional to the volumes.

$$\text{moment}_1/\text{moment}_2 = \text{volume}_1/\text{volume}_2. \qquad (4\text{-}2)$$

Figure 4-2 shows the ZPG-2, ZPG-2W and ZPG-3W airship displacement volumes plotted versus mass of mobile masts designed specifically for these models.

From Figure 4-2 it can be seen that a mobile mast designed for use of the Phase I airship would have a mass of about 136,078 kilograms.

Mobile masts for Phase I airships will be used primarily for docking and undocking. They will therefore be located only at hangar bases. Docking and undocking of Phase I airships should be done using the mobile mast together with trolleys and docking rails, as shown in Fig. 4-1.

4.2.3.2 UNDOCKING AND DOCKING PHASE II AIRSHIPS

A railroad type mobile mast must be used for docking and undocking Phase II airships. The mast would be parked beside the hangar. When an airship is to be docked, the mast would run on rails to a position in front of hangar doors. All movement of the mast must be done on rails. The airship to be docked must be "walked" from a nearby landing site or transferred from a stick mast using ground handling mules.

The docking sequence is shown in Fig. 4-3. The landing is accomplished into the wind, where mules would probably be used for lateral movement. In sequence number two, the airship is rotated such that its centerline is aligned with the hangar. Finally, in sequence number three, the airship is moved into the hangar. The Phase II railroad type mobile mast would not normally be used as a "riding out" mast.

4.2.4 REFUELING

Refueling of airships is done in hangars, at the mast, or airborne. Airborne refueling would be done routinely for ballasting to static equilibrium just prior to a landing or a load/unload maneuver. Airborne refueling would also include enroute refueling for purposes of extending the range or for managing the airship equilibrium condition. An airship encountering low fuel state because of adverse wind or

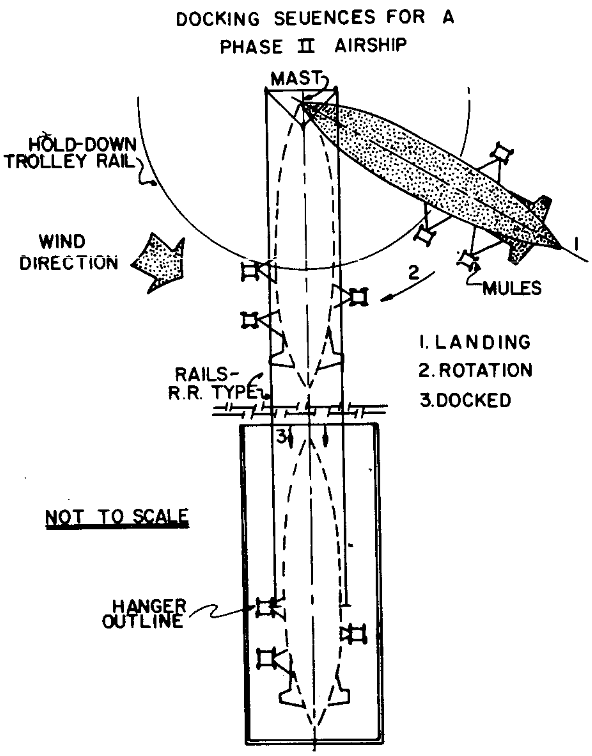

FIGURE 4-3

DOCKING SEQUENCE FOR A PHASE II AIRSHIP

weather conditions could be refuled while airborne over land or water.

4.2.4.1 REFUELING ON GROUND

Refueling in hangars or on masts would be accomplished using standard fuel trucks. Fueling with a truck at a mooring circle requires three men. The driver must man the truck at all times and be prepared to move with the airship as it vanes. One man tends the hose at all times and performs the hose connect and disconnect operations. One man in the airship regulates fuel distribution as fueling progresses.

4.2.4.2 AIRBORNE REFUELING

Through the 1940's and 1950's, equipment and methods were developed to refuel airborne airships from the ground or from sea-going vessels. The system developed involved a fuel pump on the surface along with a free hose which was picked up by the airship while airborne (ref. 4-2). The fueling was controlled electronically from the airship. Procedures were also developed for picking up fuel bags.

Emergency refueling of an airship that is at low fuel state can be done with available refueling equipment near the airship's position. If transoceanic flights are regularly scheduled, then it would be advisable to develop a system of airborne refueling using an airship as a tanker.

4.2.5 BALLASTING OPERATIONS

Ballast requirements can be divided into two general groups, namely, flight management and payload management. Whenever the payload carried is less than design payload, then ballasting will be required. This ballast could be water, fuel, or sand and could be loaded either on the load platform or in the airship tetrahedron structure. (See Chapter 5 for a more detailed discussion of the load/unload system.) Ballast for flight management will be either fuel or water. It will be for the purpose of fixing the heaviness or lightness at takeoff and landing for the particular mission being flown.

4.2.6 MAINTENANCE

The concept of "progressive" maintenance would be used for regularly scheduled inspections and preventive maintenance. This system of maintenance avoids long periods of planned airship "down" time.

4.2.6.1 INSPECTIONS

Routine inspections will be performed on engines, structures and equipment whenever the airship is masted between flight operations. Consideration should be given to flying maintenance personnel when time on the mast is not sufficient to permit completion of inspections and preventive maintenance. Some of the routine maintenance could be performed while the airship is in flight.

4.2.6.2 ENGINE CHANGES AND INSPECTIONS

Engines will be mounted with quick change couplings. They will be accessible using a wheeled dolly attached to the midship structure so that it will vane with airship (see Fig. 4-4). The dolly will carry a hydraulic lift mounted with an engine work platform. Access to a stern mounted engine installation would have to be with a mobile "cherry picker" lift.

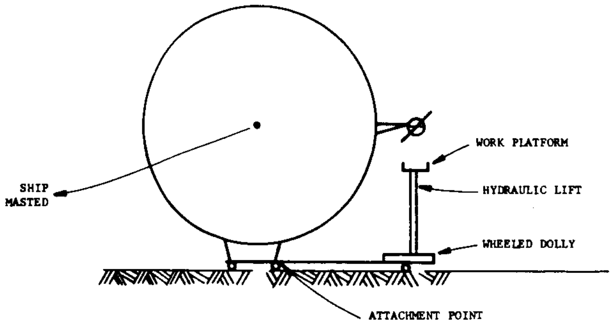

FIGURE 4-4
ENGINE WORK PLATFORM

4.2.6.3 HYDRAULIC SYSTEM

The hydraulic subsystems for control surface actuation, engine gimballing, winch operation, etc., will be provided with electric motor driven pumps located at the site of each subsystem. Pump operation and control of the subsystem will be done remotely using electrical means. Access to the control surface hydraulic subsystem will be through the upper cover of horizontal stabilizers. Maintenance personnel will be able to get to horizontal control surfaces by using the mobile cherry picker. Safety lines running from the leading edge of the upper vertical stabilizer to the horizontal stabilizers would then permit access to the hydraulic subsystem.

4.2.6.4 ELECTRONICS AND ELECTRICAL

The electronics and electrical systems will be designed so that components may be replaced as "plug-in" units. Field repair of components will be performed only on an emergency basis. The systems will be designed so that check out of all components can be done from the airship car.

4.2.6.5 TOPSIDE INSPECTION

Safety lines running from the bow of the airship can be used to get men topside for emergency inspections of the hull and upper control surfaces. Rope ladders over the hull as well as anchored (hull centerline) boatswain's chairs will permit close inspection of sections of the upper half of the hull. Provisions should be made to view the inner surface of the upper part of the gas containment regions from the underneath side of the hull. Very small holes can be found in this manner when the airship is in bright sunlight. The primary purpose of topside inspection of the hull while at the mast will be to locate helium leaks. Topside inspection of tail surfaces and controls will be required on a routine basis while masted. Most of the discrepancies calling for topside inspection could not be found without close inspection by maintenance personnel. The use of helicopters for topside inspections is not considered to be helpful.

4.2.6.6 INTERIM OVERHAUL

Interim overhauls will be performed in airship hangars. Airships will be scheduled into hangars approximately once each year. Total flight hours of operation will regulate the period between interim overhauls although calendar time will play some part in the scheduling.

4.2.7 AIRSHIP GROUND WATCH

During the operational life of an airship there must be a continual "watch" of certain changes in the airship's environment while it is masted or in a hangar. Changes in atmospheric pressure, temperature, and humidity as well as ice and snow accumulation can require changes in ballasting of the airship.

4.2.7.1 PRESSURE WATCH

A pressure airship will require pumping or valving of air to maintain the design pressure as temperatures drop or rise. Depending upon the fullness of lifting gas space, both pressure and nonpressure airships may go to the pressure height condition where gas fills entire available volume on the ground when temperatures rise. Once pressure height is reached, valving or removal of lifting gas is necessary in order to avoid overpressure.

4.2.7.2 SUPERHEAT

The difference between lifting gas temperature and ambient air temperature, positive or negative superheat, can require changes in the ballasting of the airship. When high positive superheat is experienced while riding out on a mast, pressure height may be reached, requiring the valving or removal of lifting gas.

4.2.7.3 BALLASTING

The loading (ballasting) of a moored airship must be continually monitored to make certain it has the proper "heaviness" for riding out. The "heaviness" can change with changes in pressure, temperature, and superheat.

4.2.7.4 ICE AND SNOW REMOVAL

Ice and snow accumulation on a moored airship presents a problem. Accumulation of ice on top of the hull causes the airship to "heel" over on its side if the accumulation is too great. Snow will accumulate on the horizontal stabilizers under certain wind conditions. Removal of both ice and snow from airships has been accomplished historically using fire hoses. Equipment developed for ice and snow removal for large airplanes should be adapted for use on airships.

4.2.7.5 WEATHER WATCH

When airships are moored during extreme wind conditions, experience has shown that it is advisable to "fly" at the mast using engines and elevator controls. The "heaviness" of the airship is particularly important during high winds and must be continually monitored.

4.2.8 GROUND EQUIPMENT DEVELOPMENT

Much of the ground equipment developed for earlier airship operations will be directly adaptable to Phase I and Phase II airship operations. Some new equipment must be developed, however, as discussed in the following paragraphs.

4.2.8.1 MOBILE MASTS

A tire-mounted mobile mast will have to be developed for the Phase I airship. It would be an adaptation of the Mark V mast built for the U.S. Navy ZPG-3W airships. One such mast will be required at each base where there will be docking and undocking of Phase I airships. For Phase II airships railroad type masts similar to those used with the Akron and Macon will be required. (See Fig. 4-3.) One each will be required at bases where Phase II airships are to be docked and undocked.

4.2.8.2 STICK MASTS

A hydraulically operated stick mast must be developed. The design should be such that it can be used for either Phase I or Phase II airships. When retracted, the mast, as well as the guy wires, must be stored flush with the ground. Expeditionary type masts developed for advance base operations can be adapted for Phase I and Phase II airships.

4.2.8.3 GROUND HANDLING MULES

Initially, it would be advisable to develop methods of handling the prototype Phase I and II airships with ground handling mules developed for the U.S. Navy ZPG-3W. It would be necessary, however, to use more mules than were used on the -3W because of the increased size of both the Phase I and Phase II airships. For fleet operations of the Phase II airship particularly, larger mules would have to be developed. The use of the smaller mules would be a manpower intensive effort and could not be justified on an economic basis for a fleet of airships.

4.2.8.4 HELIUM PURIFICATION UNITS

Air and water vapor tend to diffuse into the helium areas after long periods of time, thus reducing the purity of the helium. As the helium becomes contaminated, its lifting capacity is reduced. Traditionally, this has been a greater problem with nonrigid airships than with rigid airships.

Portable helium purification units were developed for advance base use during World War II. Larger capacity units should be developed for the Phase I and Phase II airships. The contamination problem should certainly be minimized with improved materials and a metal skin.

4.2.8.5 ENGINE WORK PLATFORM

A dolly configured to vane with the airship at its mooring site will be required for engine work. A hydraulic lift mounting an engine work platform will be installed on the dolly. An engine work platform mounted on a mobile "cherry picker" will be required for servicing any tail-mounted engine (see Fig. 4-4).

4.3 AIR OPERATIONS

The flight operations of both Phase I and Phase II Airships will be the same. Any differences in operating procedures will be specifically noted.

4.3.1 LAUNCHING

Launchings will always be from a mast. The airship will normally be vaned into the wind. If the airship is not headed in the desired direction at launch time, it will be necessary for the pilot to rotate the airship around the mast using his aft lateral thrustors.

The airship will always be heavy while riding at the mast. If necessary, water ballast will be pumped aboard to compensate for superheat. It will ride on four, multi-wheeled pneumatic trucks. These trucks will have full castoring wheels to accommodate the side to side motion of the airship as it vanes into the wind on the mast. The trucks will be attached near the four corners of the main airship load frame. They will be unlatched during launch preparations so that they will pull out of the airship structure and will remain on the ground at lift off.

Load cells at the mast and at the hold-down trolley will indicate the trim of the airship as it rides at the mast. (Trim is indicated by the relative heaviness of bow to tail). These load cells are also used during the launching sequence to determine when upward thrust is sufficient to release the airship.

The launching sequence is relatively simple. A ground supervisor communicates with the pilot via portable radio. When they agree on launch readiness, the pilot applies upward thrust and when the upward force, as measured at the fore and aft hold-down load cells reaches a predetermined value, the airship is released. The pilot depends on longitudinal load cells on the bow structure to apply a sufficient forward thrust vector to overcome the wind load.

Ideally, the ground supervisor could launch the airship with the aid of two men. One man would be at the mast to read the forward hold-down load cell and to release and lower the mast when directed. The second man, equipped with a portable radio, would be at the track-mounted hold-down trolley. This second man would inform the supervisor of the aft load cell readings and would release the hold-down when directed.

The ground supervisor may choose to have from two to five additional men standing by during a launch depending on the wind and weather conditions. One or two mobile winches might be advisable in the event that lateral holding or movement of the airship should be required. An additional man might be assigned to the riding out trucks to insure that they drop away properly at lift off.

After rising vertically to perhaps 305 meters (thousand feet), the pilot will make the transition to forward flight by the rotation of his engines.

4.3.2 FLIGHT

Both Phase I and Phase II airships will carry a crew of four for each eight hours of flight, identified as pilot, co-pilot and navigator, mechanic, and loading supervisor. Flight stations assigned to each crewman will be occupied during launchings, landings and hovering maneuvers. During normal flight under good weather conditions, the airship will be flown by an autopilot. When flown under manual control, the pilot will have computer assistance in sensing and responding to motion stimuli. Normally, the pilot will control the airship by fingertip movement of a small "joystick". During launchings, landings, and hovering maneuvers, the pilot will require the assistance of the navigator acting as a copilot to perform secondary control actions and to communicate with other members of the crew and with ground personnel.

The pilot should also be trained in meteorology and in the operation of all electronics associated with airship control, navigation and communication. The mechanic will be a specialist in the field of rotating machinery, particularly relating to the main propulsion engines, the auxiliary power supply and the thrustor system. His job will be to monitor the controls and indicators that pertain to the above-mentioned systems. The loading supervisor is a specialist in the operation and maintenance of the cargo hoisting and stowing system. During loading and unloading this man will operate the cargo hoisting system and will coordinate closely with the pilot and the ground loadmaster.

The airships will have all normal cockpit instrumentation and will, of course, meet all FAA requirements for navigation, communication and emergency avionics. In addition, the airships will have controls and instrumentation associated with the helium and ballonet pressurization system and those related to control of the engines and the fore and aft thrustors. Both Phase I and Phase II airships will be instrumented with a network of strain gages attached to critical structures. Particular attention will be given to tail surfaces, bow structure, and the main loading frame. The strain gage readings could be in the form of indicator lights in the pilot's compartment. The pilot will monitor this light array during rough weather and during cargo loading operations to insure that critical airship structures are not being overstressed. This display may, for example, influence the pilot's decision to switch from auto-pilot operation to manual control during rough weather.

In contrast to high speed airplanes, airships respond to control direction very slowly. Instead of being concerned with response times of fractional parts of a second, the airship pilot must wait for seconds or even tens of seconds before the airship responds to applied aerodynamic surface movements or thrustor actuation. The inclusion of a computer in the sensor/response control loop will provide faster response to motion-induced stimuli.

During flight the lightness or heaviness of the airship is compensated for with dynamic lift, flying with the bow of the airship inclined upward or downward. Usually this inclination will not exceed five degrees. The angle of inclination can be maintained without the deflection of aerodynamic control surfaces or the application of vectored thrust by changing the longitudinal static trim of the airship. This can be accomplished by adjusting the relative amounts of air in the fore and aft ballonets.

When preparing for and during launchings, landings, and special operations, the airship crew will dilligently follow check sheets to insure that all systems are operable and that nothing has been omitted in an operations sequence. During flight the pilot must maintain a continuous awareness of the static equilibrium of the airship. The consumption of fuel is monitored periodically; however, there are other factors that are even more important to static equilibrium than fuel consumption. These factors in general relate to the density of the air or the relative density of the air with respect to the density of the lifting gas. The four most significant are altitude (or field elevation), air temperature, gas purity, and superheat. Other density-related elements of lesser importance that influence static equilibrium are atmospheric barometric pressure and relative humidity.

Rain can cause a sudden heaviness of the airship and because of the large tail surfaces, can cause a shift of longitudinal trim. Snow and sleet are not as serious a hazard to airship flight operations as once thought. If the Phase I and Phase II designs both have metal hulls, as discussed in Chapter 7, then snow and ice will be shed much more readily than the fabric covered airships of the 1930's. A two-year program carried out by the U.S. Navy during the late 1950's found that accumulation of snow is not a serious flight hazard and that icing can generally be avoided with changes in flight altitude. It may be necessary, however, to remove accumulations of snow or freezing rain from a masted airship. A stream of water has proven effective for this purpose.

Airships operate at low altitudes; therefore, they fly in and not above bad weather. As a result of this exposure to weather, both the pilot and the navigator must be weather-conscious and weather-wise. At night, radar is particularly helpful in avoiding thunderstorms and in finding areas of light intensity when traversing weather fronts. During long flights in adverse weather, an on-board computer terminal will display weather data and hourly cloud pattern photographs from weather satellites. Winds circulate clockwise around areas of high barometric pressure and counterclockwise around low pressure areas. The pilot can often find more favorable winds in flying long missions by applying his knowledge of pressure patterns as indicated on weather maps and satellite photographs.

Another hazard of low-altitude flight is collision with small airplanes. Collision precautions include radar detection or an alarm from the onboard Proximity Warning Indicator (PWI) instrumentation. Special airship operating corridors assigned by the FAA are recommended for airship scheduled flight operations. In addition, sufficient anticollision strobe lights should be installed to outline the shape and size of the airship.

4.3.3 CARGO HANDLING, FUELING AND BALLASTING

Cargo loading/unloading, fueling and ballasting all can be accomplished in a flight hovering mode (the cargo loading system is described in detail in Chapter 5). In order to accomplish inflight loading, fueling, or ballasting, the airship must be within 61 to 91 meters (200 to 300 feet) of the ground and winds must be favorable. Fueling or ballasting with water can be successfully carried out in winds of 18 to 22 meter/sec (40 to 50 miles/hour), since once the fuel or water line is retrieved and quick-connected to the airship plumbing, a considerable amount of airship motion can be tolerated. The loading/unloading operation requires much better hovering control of the airship; therefore, loading or unloading should be restricted to wind conditions of from 4.5 to 9.0 meter/sec (10 to 20 mile/hour) maximum. A range of wind conditions is specified since the gustiness or the shifting of the wind is also a factor. There may also be some types of cargo-handling operations that are more sensitive to airship motion than others. All hovering operations will be with the airship headed into the wind. Wind directional shifts will be with the airship headed into the wind. Wind directional shifts will be compensated for by thrustor-induced rotation to maintain airship/wind alignment.

In preparation for a loading or unloading operation the pilot will perform a simulated hover to determine the static equilibrium and trim of the airship. This practice hover will give the pilot a feel for the engine settings that will be required and also for the way in which the airship responds to the application of thrust vector forces. Check sheets will be used by the pilot and load supervisor in planning and coordinating the sequence of steps that will be followed in the loading operation. Radio communication between the airship crew and ground personnel will probably be necessary in advance of the final hovering approach to insure mutual understanding of the sequence of steps that will be followed.

The last 30.5 meters (100 feet) or more of the final hovering approach for loading or unloading will be at .9 to 1.3 meter/second (2 to 3 mile/hour) during which time final adjustments will be made in altitude. Primary airship control will be by adjustments to the thrust magnitude and direction of the main engines. Secondary or fine control adjustments will be made by the fore and aft thrustors. The effectiveness of the aerodynamic control surfaces during hover will depend solely on the wind speed. As the loading site is approached, the airborne load supervisor will lower the loading frame and will communicate with the ground via two-way radio. It may be desirable to have provisions for the ground control supervisor to be able to control the fine adjustment of the ship via the thrustors. This may be required for precise airship positioning. This transfer of control may not always be necessary, and in any event, the pilot would always have the capability to override ground control As explained in Chapter 5, loading and unloading cargo always involves an exchange of approximately equal weights--ballast for payload or payload for ballast. Of course, it may be desirable to pick up a few thousand kilograms more of weight to compensate for fuel consumption.

4.3.4 Fueling and Ballasting

Fueling or ballasting with water can be carried out either while masted or while in a hovering mode. When the airship returns to base after a long flight, it will normally be light because of fuel consumption. Before landing, the airship will hover over the landing area (mooring mast retracted to ground level) and a line will be dropped from the fueling/ballasting hatch to pull up either a fuel or water hose. The hose will be quick-connected to the airship plumbing, and fuel or water will be pumped aboard until a preselected heaviness is attained. This method is preferable to maintaining station with engines and/or thrustors, because of increased fuel consumption. Since refueling will be required anyway, it can be accomplished prior to the landing operation.

4.3.5 Landing

Landing and masting will be accomplished from the hovering mode. Two handling cables will be dropped from the bow and will be attached to mobile constant tension winches. The winch drivers will position themselves on both sides of the airship to control the lateral motion of the bow. The bow cable or pendant will be lowered and will be connected to the mast winching-in line, and when good control is assured, the mast will be raised. The airship will be in a somewhat tail-high attitude as the airship is winched to the mast and locked in place. Once the airship is secured to the mast, the pilot will adjust vertical thrust to bring the tail down. The four riding out trucks will be attached to the main structural frame as the airship settles to the ground. Finally, the hold-down trolley which ties the airship to the circular rail will be attached.

The ground handling supervisor will require a maximum of nine men for landing either Phase I or Phase II airships, as follows: one man to connect the airship pendant to the mast, to raise the mast, and to winch the airship to the mast; two men, each driving mobile winch vehicles; four men to connect the four riding out trucks; one man to assist the loading supervisor in attaching the hold-down trolley; and one man equipped with a portable radio to move to the assistance of anyone as directed by the ground handling supervisor. As experience is gained, and under favorable wind conditions, it may be possible to dispense with the use of mobile winches and to land directly to the mast.

While an airship is riding at the mast, a water pump system mounted on castering wheels could be attached to the rear of the main loading frame. This piece of ground support equipment could automatically pump water on or off the airship to compensate for changes in static lift which may be caused by temperature changes, superheat or even a passing rain storm. The readings from the hold-down trolley strain gage could control the pump.

4.3.6 Mission Planning

A factor that must be considered in planning airship missions is that of maintaining an approximate static equilibrium throughout the flight, particularly during launching and landing. The gross elements that must be balanced are the buoyancy of the lifting gas and the total weight of the airship including the fuel and the payload. Small deviations from static equilibrium can be compensated for by the upward or downward thrust of the engines or by dynamic lift during flight resulting from a positive or negative angle of attack.

In addition to the above major upward and downward factors, there are other elements that affect static equilibrium that must be taken into consideration during mission planning. They are as follows:

1. Ambient air temperature
2. Altitude of flight or field elevation
3. Humidity of the ambient air
4. Atmospheric pressure (barometric)
5. Superheat (difference in temperature between the ambient air and the lifting gas)
6. Purity of the lifting gas
7. Percentage of lifting gas fullness

The first four of the above factors relate to the density of the air. The fifth concerns the relative density of the lifting gas with respect to the ambient air.

The last two relate to the amount of lifting gas in the airship.

A lift equation used in planning airship flights takes into consideration all of the above factors. This equation is a modification of the lift equation contained in the U.S. Navy Bureau of Aeronautics Rigid Airship Manual (ref. 4-3).

$$L = FV/R\ (P-.378e)(T_G-ST_A)/(T_A - T_G) \quad (4-3)$$

where

L = airship lift in newtons
F = lifting gas fullness factor, decimal fraction of unity
V = volume of lifting gas in m^3 when the airship is 100% full
R = universal gas constant for air
P = air pressure in Newton/m^2 corrected for atmospheric pressure and elevation
e = pressure of water vapor in the air in Newton/m^2
T_G= temperature of the lifting gas in °K
S = specific gravity of the lifting gas, helium, relative to air and corrected for helium purity
T_A= temperature of the ambient air in °K

A Worst Case Mission

The purpose of this section is to consider missions with a Phase II airship that introduce worst case situations from the viewpoint of static equilibrium.

Each of the seven factors introduced in the last section will be considered in a mission so that these effects are additive. First, a flight will be planned to produce a very light airship. The latter case is the more critical since the consumption of fuel adds to rather than subtracts from the static equilibrium related factors.

The "Heavy" Case

The factors selected to produce maximum heaviness at landing would be as follows:

1. Air temperature - a higher air temperature upon landing than at launching
2. The landing field at a higher elevation than the launching field
3. Humidity higher at landing than at launching
4. Atmospheric barometric pressure higher at launching than at landing
5. Less superheat at landing than at launching.

The gas purity can be assumed the same throughout the mission. For this particular case, the ballonets are assumed full at takeoff, and the helium will be allowed to expand freely as the ambient pressure decreases.

A typical worst case mission might be a takeoff on a cold day at or near sea level and then landing at a higher elevation in a warmer temperature. Consider taking off from Chicago, elevation 183 meters (600 feet), on a -6.7°C (20°F) day with a gas temperature of 4.4°C (40°F). Assume the landing would be at Denver, elevation 1524 meters (5000 feet), with ambient air temperature of 15.5°C (60°F), and no superheat. An evaluation of the parameters in the lift equation shows that changes in humidity and atmospheric barometric pressure are less important than temperature, elevation, and superheat. For the temperature, pressure, and elevation changes, the ballonets are full at launch and are empty at landing. This makes the gas volume at takeoff equal to $2.72 \times 10^5\ m^3$ ($9.6 \times 10^6\ ft^3$) and the volume at landing equal to $3.29 \times 10^5\ m^3$ ($11.6 \times 10^6\ ft^3$). Helium purity was assumed to be 95 percent. Applying the lift equation (as modified by the assumptions),

Gross Lift at Launch (Chicago) = 2.92×10^6 Newtons (326 tons)

Gross Lift at Landing (Denver) = 2.77×10^6 Newtons (309 tons),

a difference of 1.5×10^5 Newtons (17 tons). Perhaps 2727 to 3936 kilograms (6000 to 8000 pounds) of fuel would be consumed in the flight, but the airship would still arrive at its destination several thousand kilograms (pounds) heavy.

The problem then is how can a mission planner accommodate a flight of cargo from Chicago to Denver under these adverse conditions? The following would probably be considered:

1. Launch and land at times during the day when there would be superheat in Denver but not in Chicago.
2. Delay the mission until the low temperature in Chicago moderated and/or the temperature in Denver was lower.
3. Launch as light as practical using downward thrust of engines to compensate for static lightness.
4. Land as heavy as practical using upward thrust of engines to compensate for static heaviness.
5. Reduce the weight of the payload and carry water ballast that could be dumped before landing or during the flight.

The "Light" Case

The factors selected to produce maximum lightness at landing would essentially be the reverse of the previous case:

1. Air temperature - A lower air tempera-

ture upon landing than at launching.

2. The landing field at a lower elevation than the launching field.
3. Humidity higher at launching than at landing.
4. Atmospheric barometric pressure higher at landing than at launching.
5. More superheat at landing than at launching.

Launching in Denver on a warm day and landing in Boston on a cooler day, for instance, would produce about the same lift difference as before, except the fuel usage would be additive. For this case, the lightness could be as much as 1.8×10^5 Newtons (20 tons).

The mission planner would consider the following to minimize this very light condition:

1. Time the mission to depart Denver at the coldest time of the day and to arrive in Boston during the warmest time of the day.
2. Using vertical thrust, launch as heavy as practical and land as light as practical.
3. Consider refueling while in a hovering mode.

In many military missions during and following World War II, airships would often remain on station for long periods of time, thus consuming a great deal of fuel. The nonrigids thus were often launched heavy and were returned to base near equilibrium conditions. Mission planning usually just amounted to takeoffs and landings at nearly the same temperature conditions. For scheduled cargo or passengers, the airships would have to operate under a wider range of temperatures, elevations, etc., and would require a great deal more mission planning than has gone into previous U. S. airship experience.

Fortunately, the three most important factors of temperature, altitude and superheat are generally not found in additive combinations. For example, it is generally cold at high altitudes or elevations. Also, if the temperature is high, there is generally superheat. Finally, most of the missions foreseen for the airship will be at low field elevations and flown at low altitudes.

4.4 FLIGHT AND GROUND CREW TRAINING

4.4.1 Flight Crew Training

As an introduction to this section it would be well to review the various tasks that must be performed by the airship flight crew. As discussed previously, there are four stations that are manned: pilot, copilot and navigator, mechanic, and load supervisor. Each of these four assignments will be described in some detail before discussing the training needed to acquire the necessary level of skills.

4.4.1.1 CREW RESPONSIBILITIES

Pilot

The chief pilot is the airship captain. Depending on the length of the flight, two or three additional pilots may be required; however, as discussed below, the navigator is a trained pilot and is available to serve as a pilot during long flights. The pilot controls the airship by combining the effects of a number of actions or conditions as follows:

1. Static condition--relates to the lightness or heaviness of the airship (with no forward motion).
2. Trim--relates to the attitude of the airship (whether the bow is up or down with respect to the tail). Trim is determined in an absolute sense when there is no relative motion with respect to the surrounding air.
3. Dynamic control--relates to controlling the airship by applying forces, such as those from aerodynamic surfaces, lateral thrustors or axial thrust from the main propulsion. The dynamic forces needed to produce the desired control of the airship depend upon the combined effects of trim, attitude, static condition, velocity and influences of weather.

Copilot and Navigator

As mentioned above, the navigator will be a trained pilot as well as being a specialist in the field of navigation. The task of the navigator is that of designing and following the course that the airship will fly during the mission. There are at least two reasons why weather is more critical to the operation of an airship as compared to the operation of an airplane: first, the airship generally flies in, not above, the weather; and second, winds are of much more relative importance to airship ground speed.

Mechanic

The mechanic will be located at a console of controls and indicators related to the main propulsion, auxiliary power, reaction control, hydraulic, fuel systems and related subsystems and components. The primary responsibility will be as a propulsion specialist with secondary expertise in electrical generation and hydraulics. The mechanic will have the tools, spare parts and know-how to make emergency repairs while in flight.

Loading Supervisor

The responsibility of this crew member is in the loading, stowing, and unloading of cargo. The problem of ballast exchange during the loading/unloading mode of operation is a crucial one, and warrants the full attention of a crew member.

Minor structural repairs during flight could also be accomplished by the loading supervisor.

4.4.1.2 CREW TRAINING

In some respects airship flight crew training would appear to be a formidable task since there are no existing skills in flying large airships. There exists, however, some flight experience with small nonrigids, and some pilot training could be accomplished in nonrigids of comparable size to existing Goodyear blimps, i.e., 6000 m^3 (200,000 ft^3).

The flight training could also benefit tremendously from airship flight simulators. These simulators would have to be developed, but the degree of complexity would be much less than that required for jet aircraft simulators or those designed and used by NASA in the manned space program (ref. 4-4).

4.4.1.2.1 INDIVIDUAL CREW TRAINING

Pilot and Navigator Training

Pilot training should start at least fourteen months before the flight of the first operational airship. The physical and mental selection criteria for pilots should be similar to the qualifications required for military and airline pilots. A bachelor-level college degree and a private pilot's license would be the suggested minimum requirements.

Extensive training would be required on the complete operation of the airship systems including flight control, propulsion, auxiliary power, hydraulics, structures, gas management, load handling and ground handling. Some flight training in a smaller airship is recommended. Classroom work would also include navigation training and instruction in the use of weather satellite data.

The final phase of training could be accomplished in a flight simulator. A flight simulator for airships was built by Goodyear for the U. S. Navy in the 1950's. Some of the sophistication developed by NASA in the manned space programs could be incorporated into the airship simulator, but special environments of vibration, vacuum, rapid acceleration, noise, heat, etc., would not be required. Most maneuvers can be realistically simulated by "out-the-window" visual displays. Airship flight configuration hardware would be used in the simulator.

Mechanic Training

The mechanic must be trained to understand and operate the systems he is responsible for in the airship. Much of this training can be accomplished in the classroom, but this job is hardware oriented, and the initial trainees should also be involved with the qualification and performance testing of the airship components. Some airship flight experience on a small nonrigid is also desirable.

A great deal of system training for the mechanic can also be done in a simulator. Routine, as well as emergency situations can be simulated.

Loading Supervisor

This particular position cannot be easily simulated. Familarization with the airship's load/unload system, structure, and ballasting requirements will be a necessary part of the training, with the bulk of the learning coming from the actual operation of the airship's system.

4.4.1.2.2 CREW SIMULATOR TRAINING

Final crew training should take place in a completely integrated airship simulator. Routine maneuvers should be performed, using flight check sheets. All crew members should be at their assigned crew stations. Particular attention should be given to the crucial areas of launching, landing, hovering, and the masting/unmasting operations. Emergency situations should also be simulated.

4.4.1.3 FLIGHT TRAINING

A crew flight training course will have to be developed during the early flights of the first operational airship. Documentation and check sheets will be written and flight proven for all routine airship operational events and maneuvers as well as for all conceivable emergency situations. This training syllabus will be used during the flight training of follow-on airship flight crews.

4.4.2 GROUND CREW TRAINING

Ground crews will be composed of both personnel with specialized training and semi-skilled personnel. Three areas of training will be involved. Much of the training for utility personnel, such as ground handlers, will be on-the-job training. Some personnel, such as engine mechanics, hydraulic technicians, and electrical/electronics technicians would require training in ground schools of their speciality. Their skills, learned in any similar aircraft system, would be readily transferable.

4.4.2.1 MAINTENANCE PERSONNEL

Most maintenance personnel will receive on-the-job indoctrination into airship operations. Some, such as structural technicians, will require basic airship ground school. If a technician is to train for flight duties, it will be necessary to complete air crew training. Some on-the-job training in airship operations will be required for all technicians. Normally technicians will have received their specialty training before coming to lighter-than-air.

4.4.2.2 UTILITY PERSONNEL

Airship handling will be taught on the job. Technicians, as well as utility personnel, will be trained in ground-handling operations. Mobile winch operators, fuel and ballast truck drivers, and cargo handlers will be trained on the job.

4.5 SAFETY

Design of an airship requires the same attention to safety as the design of any aircraft. However, operational characteristics and size of airships introduce safety problems which are not inherent in other aircraft.

4.5.1 Airship Corridors

It will probably be necessary to establish airship corridors which are as clear as possible from airways. Airships will normally operate at low altitudes and at slow speeds. If they are then to fly IFR operationally it will be necessary to provide paths or "corridors" clear of the airways.

4.5.2 Sudden Loss of Payload

If the external cable-supported heavy load, such as a reaction vessel, should suddenly be dropped while in flight, some structural failure would probably occur, and the airship would be subjected to very high acceleration upward. If allowed to rise unchecked the airship would go through pressure height experiencing lifting gas overpressures which could not be relieved by design valve action. Rupture of gas containment would then cause further structural damage.

If the crew abandoned the airship immediately after complete loss of payload, the airship would become an airborne derelict, or if the lifting gas loss was too great, it would be involved in an uncontrolled crash. The design of airships should provide a means of emergency release of enough lifting gas to counter the loss of payload. Rip panels in lifting gas containment volumes which provide the approximate lift of the payload weight would be one means of providing a necessary safety feature. Countering the loss of payload by emergency release of gas would give the crew an alternative to abandonment. An emergency landing or a controlled crash could be made by the crew.

4.5.3 Hull Protection From Rotor Failure

In using turbomachinery for the airship, safety dictates that provisions be made to protect the hull against occasional highspeed rotor failure. Protection of the hull from rotor-failure damage will also provide protection against hailstones and ice thrown by the propellers. A region of the hull surface in the vicinity of the propellers would require additional structural protection.

4.5.4 Lightning Hazards

The design of an airship electrical and avionics systems should include protection against lightning hazards. Use should be made of experimental information such as that obtained by NASA Lewis Research Center, ref. 4-5. The avionics system should include equipment for detection of thunderstorms. Lightning protection of the moored airship will be provided through grounding of the masts.

4.5.5 Structural Fatigue

Fatigue failures cannot be totally eliminated through design. Fatigue testing of structures can usually discover errors in design; however, defects introduced in manufacture and operation are difficult to detect. The structural inspection intervals are normally based on manufacturer's recommendations, FAA directives, and past inspection experiences. Use should be made of strain counters, (ref. 4-5). The counters would be used with strain-gages located at carefully chosen positions in the airship structure. The counters will record the number of times strain at some point in the structure exceeds preset levels. The counter information would be used to establish inspection intervals.

4.5.6 Personnel Fatigue and Crew Quarters

Intensive training with respect to possible emergency procedures and the design of redundant and safe equipment will eliminate most crew concerns with safety. There is one aspect of flight operations, however, which provides some measure of concern for airship crews. The flying of small aircraft has been described as "hours of boredom interspersed with moments of stark terror". This phrase points to the tendency toward crew boredom and resulting fatigue during operations of such aircraft. The airship is such an aircraft. It also points to a lack of readiness for emergency situations encouraged by the boredom.

The pilot and crew quarters should be designed not only with a concern for comfort, but also with a concern for spaciousness. Standard operations in calm weather will include much use of the autopilot so that the crew can move about and relieve the boredom. Instrument placement should be made so that the eyes are encouraged to move about. Galley facilities will be standard so that hot meals and beverages are readily available. Toilet facilities should be of a chemical-type similar to present passenger airliner installations. At their normal stations, each member of the crew should have easy visual contact with every other member of the crew.

The Phase II ship involves multiple crews on longer flights. Space will be provided for bunks and lounge facilities. In addition, shower facilities should be provided.

Access to the loading area would be provided by an enclosed walkway just above the bottom surface of the hull. The loading supervisor would have a station just forward of the loading area, from which to control loading operations with full visual contact of the load/unload system. This station too should be designed with concern for comfort and adequacy of space.

The placement of the engines away from the crew quarters on these airships will relieve the tendency toward fatigue engendered by engine noise and vibration.

4.6 WEATHER

Airships normally fly at low altitudes and slow speeds. It is therefore imperative that the planning of all airship operations be carefully integrated with weather patterns and localized weather conditions. Knowledge of prevailing wind patterns such as shown in Fig. 4-5, taken from the Goodyear Aerospace Corporation's space shuttle presentation to NASA in October, 1973, would be a typical pattern utilized in overall mission planning. Localized weather patterns would be used for detailed routing of missions.

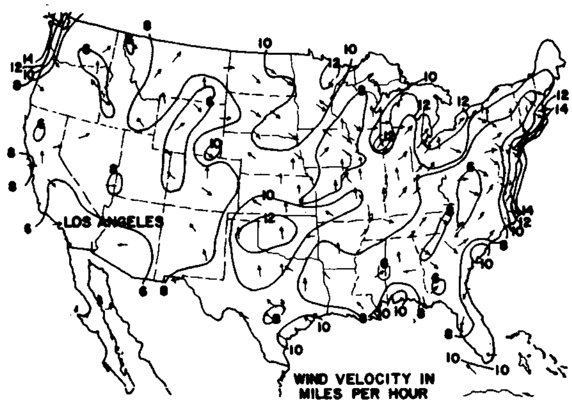

FIGURE 4-5
PREVAILING SURFACE WINDS OVER THE UNITED STATES FROM GOODYEAR AEROSPACE CORPORATION'S PRESENTATION TO NASA ON SPACE SHUTTLE STUDY, 1973

4.6.1 Flight Limitations

While airborne, airships must avoid any highly turbulent air such as that encountered in or near cold front activity. Unexpected high headwinds can bring on a low fuel state requiring abort of a mission. Aside from increased fuel usage, high steady winds present no other major problem to an airborne airship.

4.6.2 Landing Limitations

Although airships have been landed in zero-zero weather in military operations using limited navigational aids, current aircraft minimums will be adhered to in all operations. Winds can be a limiting factor in a safe landing operation. Airship landings would probably not be made when winds are above 10.3 meter/second (20 knots). Under certain conditions of gusting, shifting winds, this limit could be lower.

4.6.3 Load/Unload Limitations

The design of the vectoring system will determine the upper limits of the load/unload operation. The system is designed to allow safe operations up to 7.7 meter/second (15 knots) of wind. Visibility minimums required for landing should be a limiting factor for the load/unload operation.

4.6.4 Takeoff Limitations

Although airship takeoffs, historically, were made in zero-zero weather, current aircraft minimums for visibility will be used. Takeoffs from hydraulic stick masts will probably be limited to winds of 12.9 to 15.4 meters/second (25 to 30 knots). This limit could be lower for gusting, shifting winds.

4.6.5 THUNDERSTORMS

Airships should avoid thunderstorms at all times. If it is necessary for an airship to penetrate a squall line of a cold front, radar must be used to avoid thunderstorm cells. Penetration of a squall line or a cold front is usually less hazardous at sea. Typical weather maps such as shown in Fig. 4-6, can be used for long

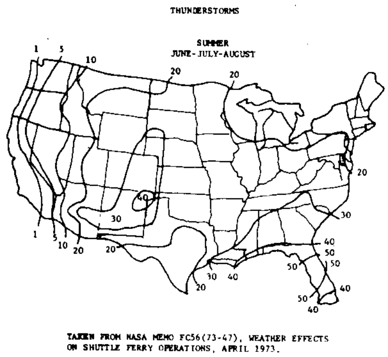

FIGURE 4-6

AVERAGE NUMBER OF SUMMER DAYS WITH THUNDERSTORMS

range mission planning. Of course, any particular flight will have to use current weather data and onboard radar to avoid thunderstorms.

4.6.6 EVACUATION CONDITIONS

It should be planned to evacuate masted airships from any area where winds are predicted to be greater than 20.6 meters/second (40 knots). Military airships have withstood winds greater than 36 meters/second (70 knots) while masted; however, evacuation procedures are recommended when the winds are excessive.

4.7 SUMMARY

There are five areas which are critical to the operation of an airship transportation system. Briefly stated, they are as follows:

1. Use of main engine vertical lift to compensate for fuel weight changes and other lift changes occurring during flight.
2. Use of thrust vectoring for close control in load/unload operations and for VTOL operations.
3. Use of a computer-operated flight control system to minimize size of flight crew required.
4. Use of mechanical ground handling equipment and hydraulic stick masts to minimize ground crew size.
5. Use of advance base maintenance techniques developed with military and commercial airships to minimize hangar time.

With proper selection of engines and use of gimballing, the necessary vertical thrust is available. Some extremes of engine vertical lift requirements are as shown in flight plans as described in paragraph 4.3.6.

The use of computer-controlled flight mode and vector mode will minimize crew sizes. In addition to thrust vector control, mechanical groundhandling equipment and hydraulic stick masts must be used in order to achieve the minimum ground crew sizes.

Airships can be operated from stick masts and under advance operating base conditions for long periods of time as was demonstrated by the U.S. Navy in its World War II operations. The success of such operations is dependent upon specially designed ground equipment for use in maintenance and a satisfactory procedure for riding out of the airship under a wide range of weather conditions.

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CHAPTER 5

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5.1 INTRODUCTION

Both the containerized cargo missions and the large bulky single-item missions can conceivably require the discharge of the total useful cargo at one time. Any unloading of significant weight from an airship must be accompanied by the exchange of an equal weight of ballast if the same buoyant stability is desired. Vertical vectored thrust might account for part of the differential but only if the vertical thrust can be transformed to aerodynamic lift as the ship gains forward flight.

Airship safety requires that the ship be secured to the ballast before the load is released and vice-versa. If the load is lost, the airship will ascend very rapidly, endangering the safety of the crew and ship. One major principal in the design of the load/unload system has, therefore, been safety in the ballast operation.

There are other ramifications due to the large differential of gross lift being exchanged at one time. The influence of the load/unload operation on the basic structure of the ship increases with the differential. To avoid a multiplicity of hull designs and yet have a ship applicable to a variety of missions, a load/unload system must be devised that is adaptable to many missions, yet distributes approximately the same loads to the hull under all task loadings. A single hull configuration for a multiplicity of cargo/ballast combinations was another major concern.

Finally, it was recognized that the great hazard to airship operation is the turbulence of the media in which it operates. Gusts and crosswinds during load/unload must be avoided or countered by thrusting, tethering, etc., and resisted by the hull structure. Thus, weather effects on ship safety are another major concern.

5.2 SYSTEM DESCRIPTION

The following describes in some detail the load/unload system designed for the Phase I and Phase II airships from the ground up to the load/lift interface system.

5.2.1 LOAD/UNLOAD SYSTEM ALTERNATIVES

Turbulence in the atmosphere complicates the consideration of load/unload systems parameters. These parameters would include:

1. relative operational elevation of the ship with respect to the cargo,
2. the portion of the total load/unload time in which the ship is involved with the cargo operations, and
3. the relative orientation of the ship and the cargo handling area.

Regarding the first parameter, the two alternatives are: 1) the ship operating above ground level, and 2) the ship at the ground elevation. To maintain position over the loading site, wind forces on the ship require that the ship either be tethered or that the ship use its vectoring capabilities, i.e., hover mode. Tethering has the advantage of positive control but has the disadvantages of subjecting the ship structure to a small number of concentrated loads and of requiring a large ground area if the tether lines have much slope away from the vertical. Hovering does not have the disadvantages of the tether system, but it would require high fuel consumption in the case of gusts.

If the ship is operating at ground level during the loading operation, then some form of mechanical attachment to the ground would be necessary. Since the ship is now in close proximity to the ground, damage from gusts could occur to the ship or to the cargo. Two modes of attachment would be possible in ground-level operations: "at mast" or "tethered".

"At mast" means a mode of attachment to the ground so that the ship moves under the influence of a crosswind to regain a stable equilibrium position with respect to the wind stream. The optimum point of attachment for the achievement of this equilibrium is at the nose of the ship. Thus, most previous ships have been attached to masts at the bow of the ship, although some "belly masts" were used which attached farther aft. If masted as discussed in Chapter 4, the airships would follow a circular path as if "weather vaned" in the wind. To load cargo in this mode of operation would require that the cargo and its loading equipment be capable of following the ship in its vaning movements.

The ship could also be tethered at the ground so as to maintain its orientation with respect to the cargo loading activity. However, gusts would induce large stresses in the tether lines, which would, in turn, transfer the load into the airship structure. For example, a horizontal component of about 333,000 Newtons (75,000 pounds) would be induced by a 6.1 meter/second (20 feet/second) gust acting broadside on the Phase II vehicle. There would be a corresponding increase in ship weight caused by the necessary increased structural strength to resist these forces. If the tethers are attached low on the ship, the horizontal forces produce a large overturning moment which endangers that part of the ship close to the ground on the leeward side.

It is obvious from the above discussion that the longer the loading/unloading time with the ship in close proximity to the cargo, the more hazardous is the operation. Many of the tasks conceived for the ship involve the handling of cargo as a number of small items. This is time-consuming as contrasted with the load/unloading of a single bulky item.

The final parameter is the relative rotational position of the ship to the load. In the "at ground" operations, this is no problem in the tethered mode. As previously noted, the masted .uning motion calls for an accompanying motion for the cargo operations. In the above ground mode operation, the tethered mode combined with some vectoring can maintain the orientation of the ship in line with that of the cargo operations. However, again this is accomplished at the price of large concentrated loads transferred into the structure, a wide area needed to anchor the tethers and some fuel consumption for the vectoring. In the hover mode, depending on the distance of the ship from the ground, the relative rotation of the ship with respect to the ground is possible within certain limits. The cargo can remain in a constant position and the ship can maintain an "into the wind" position.

Taking the above factors into consideration, the following general specifications were devised to guide the design of the load, unload system which will attempt to minimize the time involved in the exchange of cargo. Some implications of this decision are:

1. the unloading of a single bulk item each time even though the cargo represents divisible items,
2. the capacity for the ship to be disengaged from the ground during time-consuming cargo handling or "break-bulk" operations,
3. the ability to load/unload in a hovering mode so that landing and masting time are not required and so that remote site operation would be possible,
4. a single load/unload system to handle a multiplicity of cargo and single, bulky item loads, and
5. minimum weight to the ship structure.

5.2.2 Loading Grid Construction

The following discussion is concerned with containerized cargo operations. Single-item bulky cargo missions, passenger operations and special purpose modules will be discussed later. In view of the previous discussion in 5.2.1, the decision was made to design a load/unload system with the following characteristics:

1. same system for both containerized and non-containerized cargo,
2. load/unload operations from hover mode in normal operations,
3. no engagement of the ship in break-bulk operations,
4. and a flexibility of ballast operations.

The basic structure to meet these needs is a loading grid. The grid is a tetrahedral plate structure, as shown in the photographs in Figure 5-1. This type

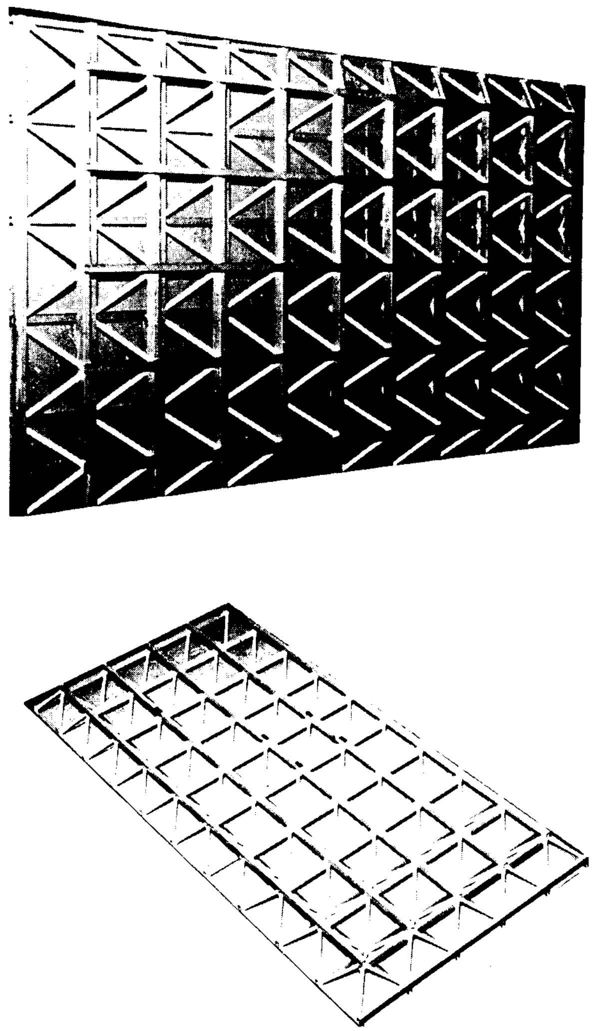

FIGURE 5-1

PHOTOGRAPHS OF THE TETRAHEDRAL PLATE

of construction was selected for its good strength/weight characteristics. The plan area dimensions for useful cargo area in both airships were determined by the use of standard 2.4 meters x 2.4 meters x 3.05 meters (8 feet x 8 feet x 10 feet) or 2.4 meters x 2.4 meters x 6.1 meters (8 feet x 8 feet x 20 feet) air cargo containers holding a minimum density of 72 Kg/m^3 (4.5 $pounds/ft^3$). The plan area aspect ratio that integrated well with the hull shape is 1 to 3. Thus, in Phase I the plan area is 7.3 meters x 19.5 meters (24 feet x 64 feet) and in Phase II it is 12.2 meters x 36.6 meters (40 feet x 120 feet). The overall depth of the grids will be 0.76 meters and 1.22 meters (2.5 feet and 4.0 feet) in Phases I and II, respectively. The loading grid would be supported normally at four points as shown in Fig. 5-2. The

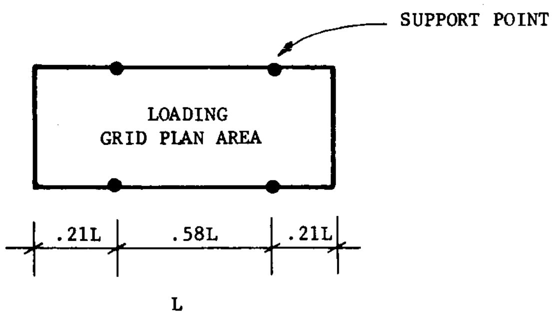

FIGURE 5-2

LOCATION OF LOADING GRID SUPPORT POINTS

location of the support points was chosen to equalize positive and negative moments assuming a uniform load over the entire grid. The support point locations could be changed under differing loading conditions to minimize force concentrations in the grid.

Grid operations will normally be as follows: the ship, with the loaded grid flush with its aerodynamic surface, approaches the unloading site and by vectoring takes a position on it. The grid is lowered from the ship at a speed of 0.1 meters/second (20 feet/minute) until it rests on the ground. The height of the airship above the ground will be chosen to avoid nearby obstructions and to aid in performing any rotational motion as would be necessary to maintain the ship in an "into-the-wind" mode. In normal operations at any site making use of the airship service, the prevailing wind direction would be known and the need for rotational relative movement would be minimal. As the grid settles to the nearby, ground, the ballast units are attached. The grid is then detached from the ship lines. The ship then flies to a near preloaded grid and exchanges ballast for the second grid. The second grid is then hoisted up into the ship until its surface is flush with the ship.

Actual loading of containers or non-containerized multi-item cargos onto the grid would be done at the site being serviced without the ship being involved. Such loading is labor intensive and time-consuming, and it is not desirable for the ship to be idle during this period.

Another concern in the grid construction and operation is that of effecting the trim of the ship. The responsibility for maintaining the center of gravity of the cargo grouping within a certain range would be the responsibility of the service personnel loading the grid. The weights of each individual cargo item and the distances from the side and end axes could be easily calculated by ground personnel. The centroid of the weight would be calculated and cargo shifted to meet the trim specifications.

The grid will normally be fully loaded with the net cargo payload of 22.7 x 10^3 kilograms (25 tons) for Phase I and 90.7 x 10^3 kilograms (100 tons) for Phase II. If the actual cargo requirements are less than this, the grid may be ballasted to make up the difference. Ballast operation will be discussed in the following section.

Normal operations will be in a hovering mode. If needed, the ship could be loaded while at the mast by extending the masting point some 6.1 meters (20 feet) above its normal elevation and lowering the grid. This distance would provide sufficient work space to load the cargo. Weather-vaning of the ship would require that the grid continue to move with the ship. This could be accomplished by means of detachable dollies, four or more of which could be placed within the tetrahedral wells of the grid. This would allow the grid to move with the ship. The dollies would automatically be left at the site as the grid was raised into the ship. Load cells mounted in the dollies and readable from the ground would provide a check on loading grid trim.

If the extension of the mast were less and the grid were lowered, the grid and dollie arrangement would serve as a "ride out" car for the Phase II ship to avoid kiting and "flying the ship at the mast"

5.2.3 Ballasting Alternatives

The two criteria for the development of ballast systems are a) adequacy, and b) flexibility. Adequacy includes capacity of weight transfer to equal that discharged and the safety of the system to assure no sudden loss of weight that could not be balanced by a corresponding loss in buoyancy. Flexibility refers to the desire to operate the same airship with a variety of payloads, in a variety of support situations, and with a variety of ballast materials.

5.2.3.1 BALLAST MATERIALS

Including the total useful payload,

the weight of the loading grid and possible additional payload from flexibility of range, etc., the total ballast weight needed in the Phase I and II airships could be 29.5 x 10^3 kilograms (65,000 pounds) and 119 x 10^3 kilograms (262,000 pounds), respectively. Readily available materials for various ballast modes are given in Table 5-1.

The following lists the ways in which ballast/cargo possibilities could be organized. The basic ballast material for transfer within the ship and between the ship and the loading grid, will be water. In the upper tetrahedral grid (to be discussed in Chapter 7), the in-line configuration of the tetrahedrons provide an appropriate structure for the insertion of long, baffled tanks of triangular cross-section. These tanks could contain a quantity of water equivalent to the cargo capacity of each ship. The tank could be oriented in the longitudinal direction at each outside edge of the upper grid. This location would minimize the contribution of the water to the bending moment in the upper grid. Provision would be made for pumping water into the tanks from an elevation of up to half the length of the ship. Provision would also be made for controlled discharge of the water from the upper grid to the ground. Finally, provision must be made for inflight transfer of water between the upper grid and the loading grid in both directions.

The loading grid will also have water ballast tanks of triangular cross-section. Their total capacity in each phase should equal 1.20 times the total ballast weight previously mentioned. The extra capacity is needed when the grid with dollies is acting as a "riding out car" in a masted mode. The orientation of the tanks could be roughly just within the sides of the grid between the normal support points, as well as in a transverse direction centered to either side of a transverse line joining opposite support points. The reasons for this configuration are two-fold:

1. The moment induced in the loading grid by the presence of the water is minimized and,
2. An optimum position is provided for using the tanks for the adjustment of trim on the loading grid with a minimum use of water.

The nominal depths of the Phase I and Phase II loading grids are 0.76 meters (2.5 feet) and 1.22 meters (4.0 feet) respectively. With attention to proper design these could provide a 0.91 meter (3.0 feet) and 1.52 meter (5.0 feet) modular grid dimension in plan view. In a containerized cargo mode, these areas do not need to be filled with upper surface materials. In a multi-item, non-containerized mode, some lightweight square platforms to fill particular grid modules could be developed to span between horizontal main grid members. The platforms, if interlocking when stacked, could also be used for rough trim aid by selected placement if they were needed at some forward location but were not presently being used for cargo support.

The open grid module volumes 1.52 meter x 1.52 meter x 1.22 meter = 2.83m^3 (5 feet x 5 feet x 4 feet = 100 ft.^{3}) in Phase II and 0.91 meter x 0.91 meter x 0.76 meter = 0.636 m^3 (3 feet x 3 feet x 2.5 feet = 22.5 ft.^{3}) in Phase I can also provide a further flexibility of ballast. High strength impermeable fabric bags would be developed that would fit this grid module volume and attach at the upper horizontal members. The bag volume could be increased by extending the height of the bags above the upper plane of the loading grid but this would necessitate an extra frame structure.

Many materials which are in abundant supply in some areas are in short supply in others. These materials, although ostensibly serving as ballast, could provide a form of payload in regularly scheduled routes when the grid was not fully loaded. Gravel, for example, would provide the full ballast weight in 50 bags in Phase II and 25 bags in Phase I. The bags could also provide a convenient means for the organization of ballast at unprepared sites where water ballast was not readily available.

TABLE 5-1

COMMON BALLAST MATERIALS

Material	Volume to equate ballast weight					
	Density		Phase I,		Phase II,	
	Kg/m^3	lbs/ft^3	m^3	ft^3	m^3	ft^3
Water	1000	62.4	29.5	1042	119	4200
Earth	1840	115	16.0	565	64.3	2278
Concrete	2400	150	12.3	433	49.5	1747
Steel	6250	390	4.7	167	19.0	671

At industrial and commercial sites that make scheduled use of the airship services, standard ballast units could be used that represent the full cargo payload. These would be made of denser materials such as steel. These units would be designed for safe but quick ballast transfer. Another necessity would be easy maneuverability by ground crews.

5.2.3.2 BALLAST SCENARIOS

The following group of ballasting operation descriptions partially illustrate the flexibility of the load/unload system.

Standard Cargo Operation: The Phase II ship approaches an industrial site, takes station, hovers, and lowers the grid to surface. Lines from slack/taut drums (to be described later) are slack for ballast. The ground crew has previously moved standard steel ballast units to the edge of a rectangular target area into which the grid has now been lowered. The four ballast units weigh 24.1 x 10^3 kilograms (5.3 x 10^4 pounds) each to ballast 90.7 x 10^3 kilograms (100 tons) of containerized cargo plus the grid weight. The steel occupies approximately 3.82 m^3 (135 $ft.^3$) in each unit. The units would be approximately 3.66 meters (12.0 feet) long, including tires, and approximately 1.22 meter (4 feet) in diameter. The ground crew now attaches the eight slack lines to the ballast units and the slack/taut drums transfer the loading cable tensions from the cargo grid to the ballast packs. The ship now vectors upward some 9.1 meters (30 feet) and then forward to a preloaded grid containing some 83.5 x 10^3 kilograms (92 tons) of non-containerized cargo (including 34.5 x 10^3 kilograms (38 tons) of pea gravel in 2.83 m^3 (100 $ft.^3$) fabric bags carried in the grid spaces). The balance of 7.3 x 10^3 kilograms (8 tons) of weight is water in the grid ballast tanks. The ship now descends 9.2 meters (30 feet). The ground crew attaches the slack cargo lines to the second grid. The slack/taut drums now transfer to the loaded grid; the slack ballast lines are detached. The ship now hoists the grid upward until it is flush with the ship undersurface and the ship moves forward to its next site.

Less Than Normal Payload: Some 54.4 x 10^3 kilograms (60 tons) of emergency medical supplies have been collected and loaded in 30 pallets of 1.81 x 10^3 kilograms (2 tons) capacity each. The airship approaches a disaster site wherein all modes of surface transportation have been blocked and which does not have an air field. The ballast difference of 36.3 x 10^3 kilograms (40 tons) consists of water in the upper grid tanks. The ship arrives at a designated site in the town, takes station, hovers and lowers the grid to the ground at a typical rate of 0.1 meters/second (20 feet/minute). The wind is at a constant direction and the ship and grid are oriented in that direction. A hose is lowered from the ship and connection is made with the town water supply through a fire truck. Another 59.9 x 10^3 kilograms (66 tons) of water are pumped up into the upper grid tanks. The grid is detached, the hoist cables raised into the ship and the ship returns for another load.

"Unprepared Site" Operation: A mining operation is to be developed in a remote area where there is no immediately available river or other body of water for ballasting. The "cargo" for this initial trip consists of fabric bags which will be filled with earth at the site for ballast on future trips, tubular members for frames to support the fabric bags while loading and a tractor mounted backhoe and front-end loader. The combined weight of the cargo is in the order of 5.4 x 10^3 kilograms (12,000 pounds). The fuel and ballast planning is done so that the arrival is 2.3 x 10^3 kilograms (5000 pounds) heavy. By means of vertical vectored thrust the ship hovers while the grid is lowered. As the vectored power is reduced, the grid acts as an anchor. The grid has been trimmed with extra water ballast to allow the backhoes to operate on filled panels near the edge of the grid. In the meantime, the empty fabric bags and frame members could be off-loaded. Finally the tractor is driven off a ramp while the vectored thrust would provide the balance of downward force needed, 1.4 x 10^3 kilograms (3000 pounds). On the return flight extra water ballast could be gained over some lake or river, after the ship has left the site. The combination backhoe and front-end loader is used in the period awaiting the next flight to fill the supported fabric bags with earth for the full 90.7 x 10^3 kilogram (100 tons) ballast necessary for a full grid load. The second and subsequent flights would be full payload flights bringing mining equipment.

It should be noted that the details of tradeoffs between fuel weight, the state of buoyant equilibrium and the use of vectored thrust in the above examples are purely arbitrary. They serve only to illustrate flexibility of ballasting procedures between the loading and among various ballast materials. The ballasting procedure would be tailored to each mission and many other scenarios could and will be devised.

5.2.4 HOIST SYSTEM DESCRIPTION

Many of the more promising missions for this system include the pickup, transportation and deposition, including erection, of large single-item cargos. At some stage of these missions, therefore, the total payload may consist of a single vertical load. These loads represent potentially the largest shear and static bending moment applied to an airship hull. The penalty for such single concentrated loads applied to the hull would be a greatly stiffened hull section at all positions at which the concentrated loads might act. This would mean increased weight necessitating an increased buoyant volume.

To avoid this penalty an interface must be provided that distributes these concentrated loads to the airship hull in a more uniform manner thus reducing the static shear and bending moments.

The method by which the load distribution has been accomplished for this airship is not the only method that could be used. A range of possible solutions has been dictated by the aerodynamic decision to make the cargo compartment contained within the hull during flight. The maintenance of clean hull surfaces helps to decrease drag and side area over which gusts can act. However, it does diminish the volume of the hull which is available for buoyancy and lessen the structural efficiency by interrupting the exclusively tension character of the hull structure.

Given the constraint of inclusion of the cargo area within the aerodynamically clean hull structure, the implied structural alternatives are: a) a structural level at the bottom of the ship with framing around the loading grid, and b) some structural system above the loaded cargo area, providing a ceiling for the cargo area, a floor for the buoyant volume, and a connection between the interrupted tension structure of the hull.

The ship must have the capacity to raise cargo into itself rather than rely on ground equipment to raise the cargo into the ship. There are two ways of organizing the suspension of loads from one or the other of these structures. One would involve an attached rail and movable hoists raising the load directly. The other could be a hoist and cable system involving fixed hoists and tie-off points.

Among the two types of hoist systems and the two structural levels, four logical possibilities appear. The cable hoist system cannot be located in the plane of the loading grid, so one of the four is eliminated. This leaves the following three:

1. a rail system above but resting on the lower structural plane using rolling dollies to support hoists above the grid level,
2. the attachment of the rail to the bottom of the upper grid with travelling crane type hoists, and
3. the support of a cable hoist system from stationary hoists in the upper grid structure.

Alternative number 1 was eliminated early because of the torsion and high moment induced into a structure that would contain the discontinuity of the hole representing the loading grid. Its accessories would also be bulky and the variable location of the hoists would require hull stiffening over a larger length of the ship.

An adequate decision between the latter two systems would require matrix structural analysis and/or finite-element analysis capability plus detailed structural design from the loading grid through the hull structure. The final decision would have involved tradeoffs of cost and weight savings. Such detailed analysis and design is beyond the scope and outside the time constraints of this study. Thus a more heuristic and arbitrary decision was made to use the stationary cable/hoist system, primarily because of the constant location of its reactions on the ship structure. This also made the design of the hull structure easier.

The following sections describe in detail the cable hoist system that was developed for these airships. It is not a completely developed system. Many of the components of the system represent present state of the art. Other components represent possible modifications of existing technology. These items will be pointed out where they are encountered.

5.2.4.1 SLACK/TAUT DRUM HOISTS

The heart of the load/unload system is the loading grid which has been described in paragraph 5.2.2. The grid is supported at four points, which provide for equal positive and negative moments when the grid is loaded uniformly. The next major component of the load/unload system encountered immediately above the loading grid are the slack/taut drum hoists. These hoists will be described in this section. Reference is made to Fig. 5-3 which illustrates schematically the entire cable hoist system.

Safety in ballasting requires that the ballast be attached before the load is detached and vice versa. If the load is suspended from the cables of the hoist system, they are taut. Yet the lines with which the ballast is to be attached must be slack to give maneuverability and ease of connection to the ballast. If in this load-taut and ballast-slack mode the load is released, the airship would rise quickly under an excess lift of approximately one-third of the gross lift of the airship until the ballast line slack were eliminated. This would result in impact loading into the

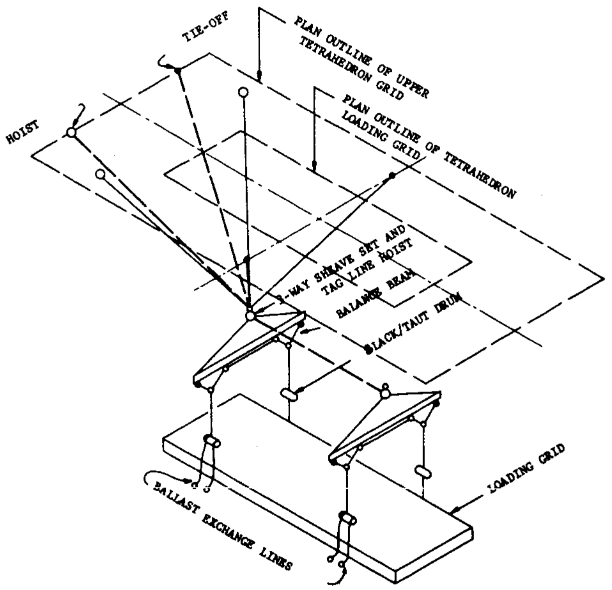

FIGURE 5-3
CABLE HOIST SYSTEM

airship structure and vibrations distributed throughout the airship system. Moreover, if the ballast were then to be exchanged again for load (the normal operation in the exchange of one loading grid for another), the longer, previously slack ballast line would now be taut and the shorter, previously taut load line would now be slack, but too short to reach the new load.

One possibility in avoiding the difficulty described above is to provide a redundant hoist system, one for the load and one for the ballast. Since the cable hoist system contributes a significant portion of the total empty weight of the vehicle, this alternative would delete too much capacity from the payload.

A better system is to provide a slack/taut drum in the line of the support lines to the loading grid. These slack/taut drums are within the state of the art of current rigging techniques. A schematic of such a drum is shown in Fig. 5-4. Such a slack/taut drum would solve the difficulty described above in the following manner.

After the slack ballast lines are firmly secured to the ballast packs, the slack/taut drum is operated to transfer smoothly the tension in the load lines to the ballast lines and to create slackness in the load lines. Then, with the excess lift having been safely transferred to the ballast lines, the slack load lines would be detached from the load. Now the ship could vector upward and horizontally to a new position over a preloaded grid and by a reverse process exchange ballast for the new grid.

The slack/taut drums would be sized for a minimum of 267 x 10^3 Newtons (30

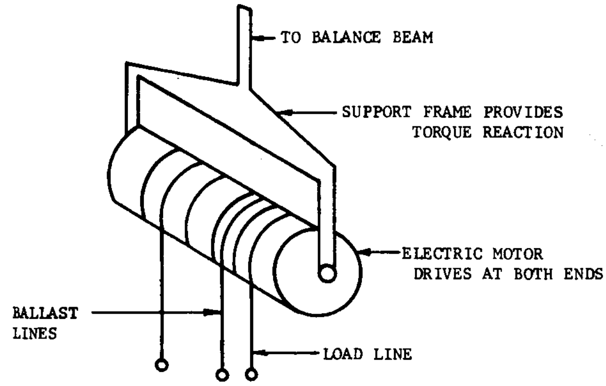

FIGURE 5-4
SCHEMATIC OF SLACK/TAUT DRUM

tons) pull, and would use 267 x 10^3 Newtons (30 ton) test Kevlar cables with a minimum factor of safety of 6.

5.2.4.2 BALANCE BEAM AND TAG LINES

The next element of the cable hoist system, moving up from the slack/taut drums shown in Fig. 5-3 is the balance beam and tag line hoist. The balance beam serves to spread the support lines from the central support labeled a "3-way sheave set and tag line hoist". From a pure flexure point of view, the balance beams need an aluminum section with a section modulus in the order of 1.8 x 10^{-3} m^3 (110 in.^{3}). This bending resistance would be accomplished by a section of approximately 74.6 kilograms/meter (50 pounds/foot) mass. Lateral stability difficulties in the ballast beam could be solved by use of Kevlar cable prestressing in a horizontal plane around queen posts projecting out in a horizontal plane from the side of the balance beam.

Each balance beam transforms the force of the two support lines into a single point. This point is located a short distance above the balance beam. At that point there will be a tagline drum to distribute the horizontal components of the cables between the two ends of the platform. Another purpose of the tagline and tagline drums is to provide the possibility for lateral movement between the two tagline drums. This will be particularly important in the case of the erection of a large slender single item from a horizontal position to a vertical position. This project will be discussed further in Section 5.2.5.2.

5.2.4.3 HOISTS AND CABLES

Directly above each tagline drum will be a three-way cluster of sheaves. Around these sheaves will pass cables up into the upper tetrahedral grid. At one end of each cable will be a hoist inset in the grid. After passing through the sheave, the other end of the cable will be tied off. Thus, each total payload will be suspended by twelve points of support, with motion commanded by only six hoists in the upper grid. The location of half of the upper grid hoists is indicated schematically in Fig. 5-3.

The selection of hoists currently available is difficult since the demand for weight savings is not as critical as it would be for airships. Some work has been done to develop new concepts and technology in the field of helicopter hoists (ref. 5-1) especially with respect to capacities ranging between 11.3 x 10^3 to 45.4 x 10^3 kilograms (12.5 to 50 tons). However, this work is presently in the development stage. For the securing of representative weight figures, the following procedure was used. Representatives of the Manitowoc Coastal Company and the Ingersoll-Rand Corporation were interviewed by phone. Information was received as to weights, pull capacity, line speed, drum size and costs of contemporary air-motor driven steel-constructed hoists. This material was put into the form of a rough curve from which costs and weights of various capacity hoists could be extrapolated. A factor of 2.3 was used to reduce the present steel weights to representative weights of aluminum and other light alloys were to be used in a program that would make such light hoists state of the art by the installation time of the LTA transportation system. Future development with composites and other materials could possibly reduce the hoist weights by another factor of two.

The most promising material for the development of light weight cables for use in the airship's hoist system is Kevlar. It has the highest specific tensile strength of any presently available material. With a present strength in the order of 275 x 10^3 Newtons/cm^2 (400,000 pounds/$in.^2$) and using a factor of safety of six against rupture, very lightweight cables could be designed. For example, 45.4 x 10^3 kilograms (50 ton) of test Kevlar cable with a factor of safety of six might weigh as little as 1.94 kilograms/meter (1.3 pounds/foot). A corresponding wire rope made of the strongest steels would weigh in the order of 10 kilograms/meter (6.7 pounds/foot). The most serious disadvantages of using Kevlar (ref. 5-2) are its degradability in the presence of ultraviolet light and its abrasion characteristics. These could be overcome in a variety of ways by using an opaque sheathing or finish of various materials including metal of some material such as Tedlar. This field of the development of Kevlar cables is one that would begin immediately upon the initiation of the research and development program of the LTA transportation system.

The majority of high-capacity, lightweight hoists today are powered by air motors. The hoists located in the upper tetrahedral grid even with the development of those hoists with lighter materials would also be air powered. The source of this power would be a gas turbine mounted in the upper grid driving an air compressor. The hoists operating lower in the system such as the tag-line drums and the slack/taut hoists would be electric powered with the power cables reeled out from the upper grid under a constant safe tension to ensure their noninterference in the operations of the hoist system.

5.2.4.4 ROTATIONAL CAPABILITY

In all load/unload operations the normal mode of operation will be from the hover position. This is to minimize the amount of time during which the ship is engaged with the ground. The purpose of this minimization is to eliminate as much as possible the potential dangers of weather. However, even in short time loading operations there would be the possibility of wind shifts. In the loading, transport, unloading and/or erection of large single bulky items the time involved in the ground interface operations would be longer and the possibility of weather disturbance higher. The best hover mode is "into the wind". Since the wind direction may change, however, the load/unload system must be capable of some relative rotation between the airship and its cargo.

In the cable hoist system selected for this system's craft, this rotational capacity is obtained by anti-symetric translation of the two support points at the three-way sheave set. This is illustrated in Fig. 5-5. The figure is a plan view

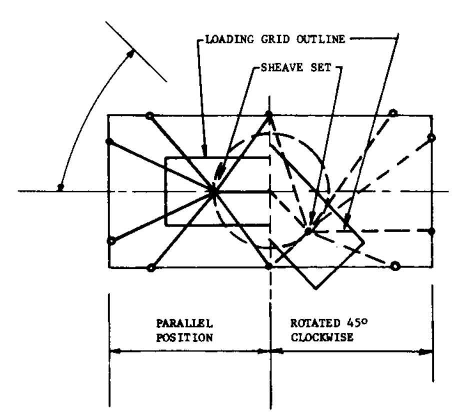

FIGURE 5-5

NORMAL ROTATIONAL CAPACITY OF CABLE HOIST SYSTEM

schematic of the cables and hoists from the upper grid down to the sheave cluster.

The left half shows the normal parallel alignment of the longitudinal axes of airships and cargo grid. The right half shows the grid rotated 45° from the parallel position. The rotational capacity is achieved by shortening of the side hoist cable in the direction of the sheave point translation and a corresponding shortening of the side hoist cable anti-symmetrically opposite the first. All other hoist cables would be lengthened. The full rotational capability would be 90° with a 45° capacity to each side of the parallel position.

In a previous article reporting a design study for a freight-carrying airship, Mowforth (ref. 5-3) investigated the range of potential rotational displacement of the load supported by four cables from the ship. The horizontal components of the tensions dictated the safe upper tension limit. The study used the height between load and ship as one of the parameters. The relevant figure from Mowforth's study is reproduced as Fig. 5-6. As is indicated,

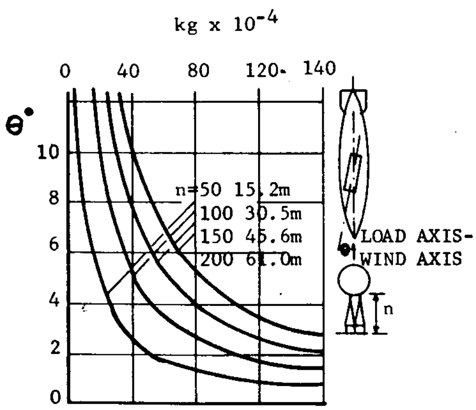

FIGURE 5-6

PERMISSIBLE LOAD MISALIGNMENT IN A 15.2 METERS/SECOND (30 KNOTS) WIND

the Phase II ship might have its rotational capacity increased in total by another 20° and the Phase I by an even larger amount.

Any weather condition producing the need for larger rotational capacities than those indicated above should be avoided.

5.2.4.5 WEIGHTS AND SPECIFICATIONS

Tables 5-2 and 5-3 represent a listing of weights and costs for the cable hoist system in both the Phase I and the Phase II ships. The weights for hoists, as explained previously, consists of corresponding contemporary steel constructed hoists divided by a factor of 2.3. The costs are essentially the same as competitive steel hoists of comparable line pull. The Kevlar cable weights are based on 1426 kilograms/m^3 (89 pounds/$ft.^3$). The costs of Kevlar cables is based on a $8.82/kilogram ($4.00/pound) competitive cost for materials suggested and a $13.23/kilogram ($6.00/pound) fabrication cost which represents R&D return for the development of the cable construction techniques.

5.2.5 SINGLE BULKY-ITEM MISSIONS

There will be a great deal of traffic in single bulky items for both the Phase I and Phase II vehicles. However, a larger Phase III vehicle with a payload capacity of up to 453.6×10^3 kilograms (500 tons) would have a unique capability of transporting and even erecting large reactor vessels, transmission towers, etc. A few special items should be mentioned in connection with operations regarding delivery of single bulky-item cargoes.

One distinctive aspect of these kinds of missions is that they will be more time-consuming in the firm attachment of cargo and ballast. Another aspect may be the requirement to change the cargo from a horizontal to a vertical position at the end of the mission. Fortunately, these missions in their present planning are very time intensive. One could expect, therefore, that sufficient time may also be used in the planning of the corresponding airship mission to allow for the arrangement of rigging, ballast, auxiliary equipment, etc., to be on site.

5.2.5.1 BALLAST

Ballasting considerations for a single bulky-item cargo fall into two categories--advance base and prepared site. An example of the former would be the delivery of an electric transmission tower to a rural site. An example of the latter would be the pick-up, transport and erection of a vertical cylindrical chemical industry reaction vessel.

The advance base site would not be completely unprepared in that previously delivered equipment would have arranged for adequate ballast at the site. The ballast could consist of excavation material and borrowed soil filled in fabric bags designed of Kevlar. It might consist of water either at the site or pumped to the site by previously arranged equipment from some nearby source. In a forest area,

TABLE 5-2

CABLE HOIST SYSTEM MASS AND COSTS - PHASE I

Item	Mass Kg	Mass (lb)	Cost
6 - 2.22×10^4N (2.5 Ton) main hoist	534	(1,175)	$ 22,200
6 - tieoffs	36	(80)	180
6 - sheaves	36	(80)	180
1 - 5.34×10^4N (6 Ton) tagline drum	207	(455)	6,000
4 - 6.22×10^4N (7 Ton) slack/taut drum	1,027	(2,260)	26,000
10 - blocks	59	(130)	300
2.22×10^4N (2.5 Ton test) Kevlar cable 1,500m)	218	(480)	4,800
10.7×10^4N (12 Ton) Kevlar cable (200m)	136	(300)	3,000
Balance beams	247	(543)	2,500
Gas turbine	106	(234)	Included in Power Costs
Compressor	150	(330)	
Tubing and accessories	68	(150)	
TOTAL	2,824	(6,217)	$ 65,160

TABLE 5-3

CABLE HOIST SYSTEM MASS AND COSTS - PHASE II

Item	Mass Kg	Mass (lbm)	Cost
6 - 8.9×10^4N (10 Ton) main hoists	2,140	(4,700)	$ 49,800
6 - tieoffs	118	(260)	600
6 - sheaves	118	(260)	600
1 - 2.2×10^5N (25 Ton) tag line drum	845	(1,870)	17,300
4 - 2.7×10^5N (30 Ton) slack/taut drums	4,120	(9,045)	80,800
10 - blocks	198	(435)	1,000
8.9×10^4N (10 Ton test) Kevlar cable (1500m)	870	(1,970)	19,200
4.4×10^4N (50 Ton test) Kevlar cable (200m)	355	(780)	7,800
Balance beams	985	(2,170)	10,000
Gas turbine	106	(234)	Included in Power Costs
Compressor	150	(330)	
Tubing and accessories	91	(200)	
TOTAL	10,096	(22,205)	$147,100

bundles of logs might prove a ballast alternative that would form a payload as well. The specific ballast used would be determined by the most convenient availability and the optimum costing of the project.

In the case of the prepared site delivery, standard ballast packs or high-density, small-bulk special ballast designed for minimum interference with the delivery process could be used. Again, water would also be a quite common ballast source.

The same concerns with safety and proper sequence of ballast operation would pertain to these missions as in multi-item cargo missions. In most of these missions, the weight of the cargo grid would be exchanged for useful payload.

5.2.5.2 SINGLE BULKY-ITEM MISSION

The following is a brief scenario to illustrate some of the special considerations necessary to the operation of transport and erection of a single bulky item. The object is a 88.9 x 10^3 kilogram (98 ton) cylindrical reactor vessel about 45.7 meters (150 feet) long. The pickup will take place at the manufacturing site with the vessel in the horizontal position. The vessel has been prerigged so that the points of support in the vertical position will be near the top of the vessel and the center of gravity of the vessel in the horizontal position during flight is just behind the center of buoyancy. All necessary attachment lines and quick-release lines will have been attached at the manufacturing site. The orientation of the vessels axis at rigging is in the direction of the prevailing winds of the area.

The ship approaches the site and takes station over it as directed by a ground officer and by using closed circuit TV. Standard ballast packs are suspended from the ballast lines. The cable hoist system is lowered and rotated as it is lowered, so that it straddles the vessel as the airship continues to vector into the wind. The slack load lines are attached to the vessel rigging, and when secure, the slack/taut drums are operated to transfer tension from the ballast to the load itself. Once the load is attached and secure, the slack ballast lines are detached, the ship vectors upward, rotating and snugging the vessel up under its lower surface.

As the airship approaches the delivery and erection site--a chemical plant complex under construction--crews are ready with all necessary auxiliary equipment.

Before approaching the erection site, the airship takes station over the nearest unpopulated area to perform the maneuver of transferring the vessel from a horizontal to a vertical orientation. In the specific airship rigging for this particular mission extra drum hoists have been placed in position between the balance beam and the slack/taut drums. (Refer to Fig. 5-3.) The extra drums have been loaded so as to provide some 122 meters (400 feet) of extra line length between the balance beam and the slack/taut drums.

The vessel in a horizontal position is first lowered by the upper grid main hoists about 30.5 meters (100 feet). Then the extra drums are activated, lowering the vessel an additional 30.5 meters (100 feet). Now the extra drum pair attached to the bottom of the vessel are activated to begin to lower the vessel. Simultaneously the tagline drums are operated to bring the 3-way sheave cluster sets together. This combined operation serves to maintain the center of gravity of the vessel and the cable hoist system within the same vertical line. Vernier control of the trim of the airship will be done by means of pumping between special water tanks suspended in the cargo space at extreme ends of the loading area upper tetrahedral grid. As the vessel reaches the vertical position, the lowering of the extra drums near the upper end of the vessel will have allowed a clearance between the upper end of the vessel and the balance beam construction. With the vessel in the vertical position the tagline drums will now be as close as permitted and the rear lines will be slack. The vessel is now effectively suspended from two of the load lines, but the entire load is still suspended from the twelve main upper grid suspension points without a major change in the loading experienced by these points. The main upper grid hoists and the extra drums are now activated to raise the vertical vessel to as close a position as possible, and the airship slowly proceeds the short distance to the erection site. The airship now takes station over the anchor site of the vessel. The pickup and rigging have been arranged so that if the ship is directed into the pervailing winds, the vessel will be in the proper orientation. The main hoist cables are now activated to lower the vessel from the ship to within 3 meters (10 feet) of the elevation of the anchor bolts. At the same time, high-pressure water hoses are lowered for connection to a water source at the ground from which ballast may be pumped into the upper grid ballast tanks. The water hoses are equipped with quick couplings in case of need for emergency release.

Flexible conduit has been sheathed over a small number of the anchor bolts of the foundation base of the vessel. These are used as the vessel is lowered to guide the anchor bolt holes over the appropriate anchor bolts. The latter operation is facilitated by the use of manually tensioned taglines at the base of the vessel that had been previously attached at the rigging site.

As the tower is now lowered onto its anchor bolts by means of movement of the main cable lines, several securing nuts are applied to the bolts and water is pumped at a fast rate up into the upper grid ballast tanks, proper trim being maintained by the varying rate of pumping in the water lines. As sufficient ballast is acquired by the ship, the rigging load lines are released by means of previously rigged release lines and the ship vectors upward, its mission completed.

5.2.6 Passenger Mode Operation

A number of the potentially profitable missions both for Phase I and Phase II vehicles involve the transport of passengers. Both of the vehicles could be easily modified to accept a passenger module or modules that would replace in weight the cargo hoist system and the cargo loading grid. This would leave the total normal usable payload available for passengers and needed supplies. Such passenger pods would probably be multi-story with part of the pod contained in what would normally be the cargo hold and the lower stories extending below the bottom surface of the ship's hull. As a general rule, if the ship is to be used in any other service, all services and support systems necessary to the passenger mode of operations in flight should be self-contained within the module.

Since passengers are discharged as a succession of small weight items, the ballasting operation has to be continuous. Water, pumped into or discharged from the upper grid tanks, would seem to provide the optimum ballast for this kind of continuous operation. If the passenger operations are organized so that loading and unloading of passengers is done simultaneously, the ballasting problems would be minimized.

Three conceivable passenger exchange systems could be used. In calm weather the ship could come near the ground a bit heavy. Its vernier elevation with respect to the ground would be controlled by vectoring of the engines. Permanent ballast anchor lines of constant length could then be attached to anchor lines from the ground. Vectoring of the engines would now be slowly reversed until the slack had been eliminated. In this mode, passengers could now be quickly unloaded and loaded in a flight mode similar to the present operations of the Goodyear Blimps. As the new flight of passengers would take their positions, the differential ballast could be adjusted by the ground crew by the addition of small shot bags. The ship would now vector down putting slack in the anchor lines which would then be released and the ship would vector upward for another passenger flight.

In gusty weather and for passenger flights of longer duration that require the slower exchange of baggage and logistics as well as passengers, passenger loading and unloading would normally be accomplished at a mast with the ship having the possibility of vaning. Two modes of operation would still be possible. One would be at a high mast through which the passengers would embark and leave the ship by means of a modification of the "skyway" or "jetway" presently used in jet airplane passenger embarking. The skyway modification would pivot with the airship as it vaned, with one end rotating about the mast. The skyway modification would be sized for a simultaneous loading and unloading of the passengers so as to minimize ballasting problems. Passengers would interface with the ship at a point on the under surface of the hull near the bow. An adequate sheltered walkway would be provided from the point of entry to the passenger quarters. Ballasting would be by means of water pumped into the upper grid tanks from facilities again in the high mast and through the bow.

A third and final possible mode of passenger exchange would also be accomplished with the airship masted. In this case the mast would be a low mast and the bottom of the passenger pod would be essentially at ground level except for the presence of castering wheels. A combination bus and water ballast pumping vehicle would carry passengers to the ship and move with the ship in case it vaned by proceeding in a circumferential path defined by the vaning movement of the rear of the passenger pod. Passengers could be simultaneously loaded and discharged with water pumped and returned to the bus/pumper accounting for the differential weight on each flight.

5.2.7 Special Purpose Modules

The use of the airship for various specific civic and commercial missions may very well require the use of highly specialized modules. Such missions might include hospital functions for emergency disaster relief, air-borne communications installations, mail-sorting in flight, etc. In general, the weight of the structure of the module could replace the cables and hoist system and the loading grid and would attach directly to the bottom of the upper tetrahedral grid. The personnel, equipment and support systems of the modules would be self-contained and would account for the net useful payload of the vehicle.

Attachment and detachment of the particular module would be infrequent and could best be accomplished in a hangar, with the module lifted into place and attached to the upper grid by ground hydraulic equipment.

5.3 SUMMARY

The decision to minimize the time in which the airship is engaged in load/unload operation has dictated that such operations be done normally from a hovering mode. The potentially large static shears and moments resulting from the concentration of the payload has dictated a cable hoist system that distributes the net payload into twelve separate reactions applied into the upper grid interface structure.

Ballast flexibility designed into the system will allow the use of water, arbitrary common materials contained in large volume fabric bags and standard high-density compact ballast packs as typical ballast materials.

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5-2 Niccuru, R. J., and Munson, J. B.: Investigation of Kevlar Fabric Based Material for use with Inflatable Structures. Sheldahl Co. Northfield, Minnesota (report prepared for Langley Research Center NASA, under contract CR-132411) April, 1974.

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CHAPTER 6

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6.1 INTRODUCTION

It is interesting to note that in many respects the airships of nearly half a century ago were in the front ranks of technological advances, often stretching the limits of engineering and materials science of that day to provide new techniques and materials. Today the situation is greatly reversed in view of the fact that no large rigid or nonrigid airship has been built since the 1930's and the 1950's respectively. Therefore, modern aerospace technology and materials science have been virtually unapplied to airship technology, particularly in the area of rigid airship design.

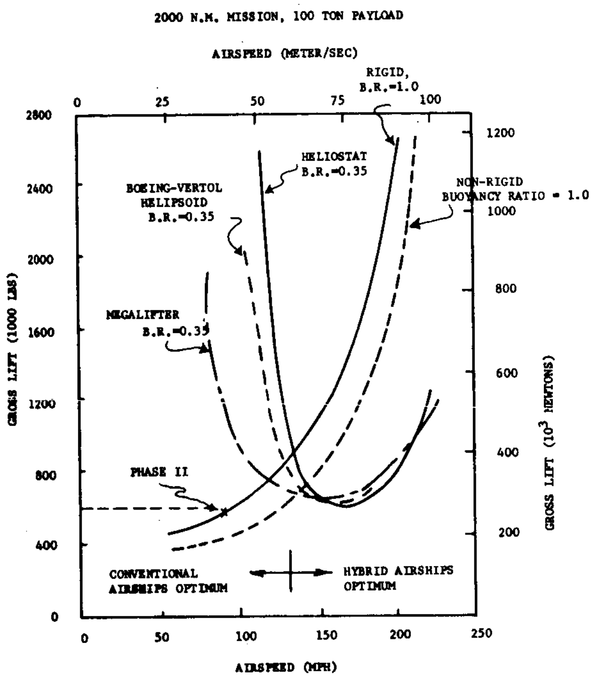

FIGURE 6-1

LIFT VS. SPEED

Recently a number of studies have been undertaken to investigate LTA vehicles and hybrid lifting bodies from the standpoint of their feasibility as modern airships. As expected, the shapes of the proposed craft varied greatly according to their intended application and mode of operation. For example, the Magalifter (ref. 6-1) might be classed as an airplane with a semibuoyant fuselage while the Goodyear Dynastat (ref. 6-2) and the Boeing-Vertol Helipsoid (ref. 6-3, 6-4) are representative of a class of semibuoyant, hybrid vehicles which will derive a great deal of aerodynamic lift through the shape of their hulls. The present study, on the other hand, reflects the design philosophy that the unique capabilities of a fully buoyant craft, in addition to the favorable rate of fuel consumption which occurs with low speed operation, directs us toward an airship whose shape and general appearance closely parallel that of the familiar classical airship. Figure 6-1, taken from the Boeing-Vertol NASA-Ames report (ref. 604) provides an interesting comparison between hybrid and conventional airship designs whose general performance characteristics closely match our Phase II airship. This figure illustrates the weight disadvantage of hybrid vehicles at low speeds, a region best suited for conventional airships of the rigid and nonrigid type. Over the velocity range considered, it is seen that nonrigid airships have a slight weight advantage over rigid airships, but that other factors (such as operating life, lifting gas retention, and load-lift interface considerations) make the heavier rigid vehicle more desirable at the present time.

Airship design (particularly for rigid airships) covers a wide range of aerodynamic considerations and relies heavily on aerodynamic theory. Like any large aircraft, airships are not well suited to the trial and error development techniques of the past.

In the present study, it has been necessary to limit the aerodynamic investigation largely to the areas of aerodynamic lift, drag, and stability factors. When an airship hull shape is analyzed, factors of prime aerodynamic importance are the total drag coefficient, the hull volume, the total wetted surface area of the hull, the fineness ratio, and the shape of the hull. The analysis of these factors, although seemingly straightforward, can be very complex.

6.2 SHAPE AND HULL GEOMETRY CONSIDERATIONS

6.2.1 AIRPLANE FUSELAGE SHAPES

For more than 25 years, airplane fuselages which have been in use have a long cylindrical center section. These shapes with a fineness ratio (length/maximum diameter) of about 10 were often selected for other than aerodynamic considerations. Airplane designers have continued to follow this trend and have even gone to fineness ratios as high as 15, although poor with regard to pressure distribution and volume to area ratios. There has been a recent trend toward thicker fuselages using a fineness of 6 instead of 10. These shapes, however, still are not very favorable from an aerodynamic standpoint.

A recent study (ref. 6-5) for VTOL airplanes suggested a new shape, which for a given volume, has less drag than conventional cylindrical shapes. (See Fig. 6-2) The objective of this shape is to maintain

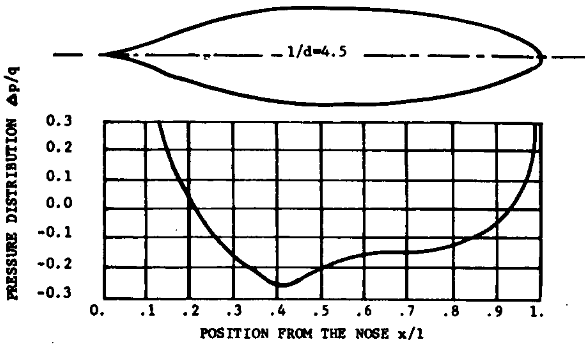

FIGURE 6-2

BODY OF REVOLUTION
SHARK SHAPE 1
SHAPE AND PRESSURE
DISTRIBUTION (INCOMPRESSIBLE)

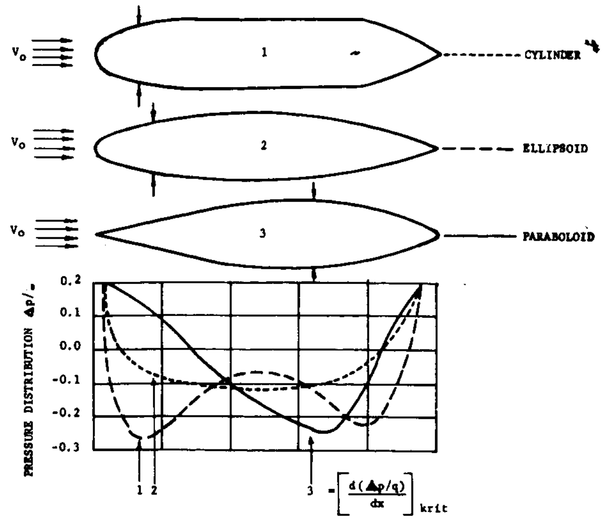

FIGURE 6-3

PRESSURE DISTRIBUTION
CYLINDER - ELLIPSOID - PARABOLOID
TRANSITION AT HIGH REYNOLDS NUMBER

a laminar boundary layer as long as possible along the length of the fuselage and then to avoid separation at Reynolds numbers in excess of 10^8.

This new shape has the following characteristics:

1. parabolic nose, rather than elliptical or circular nose (see Fig. 6-3)
2. circular cross section
3. fineness ratio of about 4.5.

It would provide these advantages:

1. Greater pressure drop at the nose, stabilizing the laminar boundary layer at high Reynolds numbers.
2. Minimum drag for a maximum volume.
3. Substantial gain in space near the center of gravity for accommodation of lifting engines or buoyant gas.

6.2.2 Airship Hull Shape Trends

The design of airships has followed airplane design to a great extent, high fineness ratios with cylindrical center sections developing into smaller cylindrical center sections and smaller fineness ratios with continuously curved fore-aft shapes. With a classical airship shape, a fineness ratio of about 5 seems to provide a maximum volume to drag condition (ref. 6-6, p. 74).

Recent studies have considered nonclassical airship forms, with fully buoyant, semi-buoyant, and semi-aerodynamic lift capabilities. Two of the more interesting shapes investigated during the course of this study are the Goodyear Dynastat (ref. 6-2) and the lifting body shape (ref. 6-7) shown in Fig. 6-4 which originated from NASA reentry vehicle studies. Both of these shapes have previously been proposed for airship designs operating in a semi-buoyant mode.

6.2.3 Submerged Vehicle Body Shape Trends

Since the airship is really a buoyant craft, both submerged and operating in air, much related information should be available from submerged vehicles operating in water. For security reasons, much current information on torpedo and submarine design studies is not available. Fig. 6-5 shows two significant shapes studied and used in submerged operations. The dolphin design (ref. 6-8) has an optimum operating condition in water at a Reynolds number of about 2.8 x 10^7. The airships in this study have Reynolds numbers approximately equal to 3 x 10^8. The fineness ratio of this shape is 3.33. The drag reduction of this shape when compared to a conventional torpedo is about 50 percent, under similar operating conditions.

In ref. 6-9, p. 132, it is stated that drag per unit volume of a bare torpedo body is minimized when the body fineness ratio is 6.5 with a tail cone fineness ratio of 3.9. Minimum drag per unit volume for a torpedo with a full tail surface occurs when the tail cone fineness ratio is 6 or greater (see Fig. (6-6).

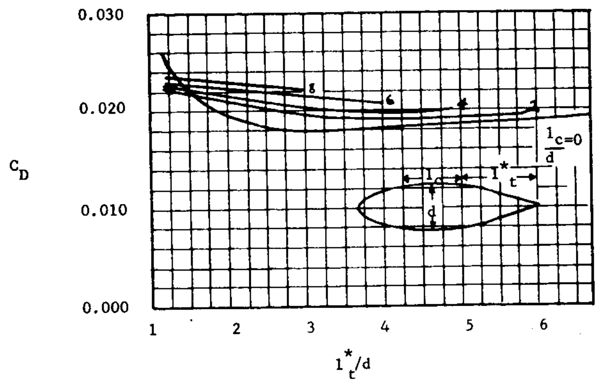

FIGURE 6-6

DRAG COEFFICIENT C_D BASED ON $(VOLUME)^{2/3}$ FOR STREAMLINED BODIES WITH CYLINDRICAL SECTIONS VS TAIL CONE FINENESS RATIO ℓ^*_t/d. PARENT TAIL-CONE SHAPE FROM DTMB SERIES NO. 58 FOR FULLY TURBULENT FLOW.

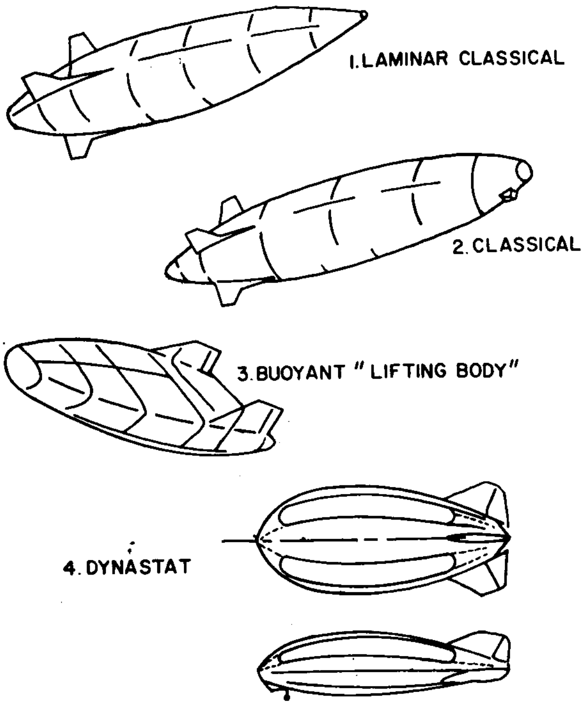

FIGURE 6-4

AIRSHIP SHAPES

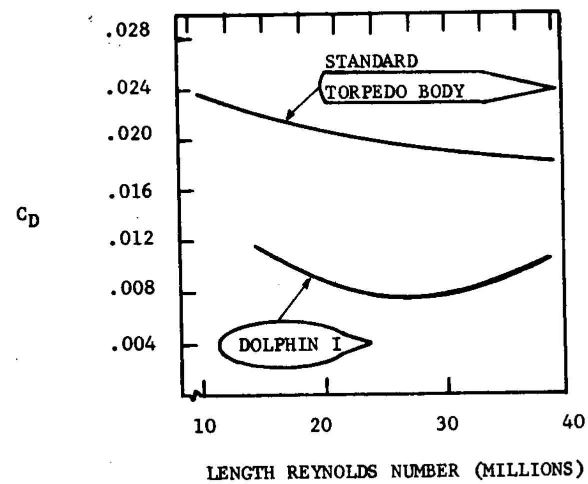

FIGURE 6-5

EXPERIMENTAL DRAG COMPARISON OF DOLPHIN VS STANDARD BODY, WHERE C_D IS BASED ON $(VOLUME)^{2/3}$

6.2.4 Areas of Difficulty

The disagreement in the conditions for optimum design is apparent. The optimum fineness ratio, on the basis of the above study, would appear to fall between 3.3 and 6.5. One concludes, therefore, that the optimum fineness ratio depends on a number of factors, such as hull geometry, Reynolds number, nose shape, and the fluid used for testing. These parameters obviously interact with each other in subtle and complex ways which do not easily lend themselves to theoretical analysis.

The most important factors are perhaps the Reynolds number and the existing boundary layer conditions (laminar, turbulent, or separated). Some of the shapes mentioned operate on different sides of the boundary layer transition region as shown in Fig. 6-7, and therefore are optimum in their area of operation. Reference 6-10 also discusses the problems associated with and the confusion resulting from extrapolating model test data obtained over the transition region ($Re \sim 10^6 - 10^7$) to full scale vehicles at large Reynolds numbers ($Re > 10^8$).

This is an area of study in which much work has already been done, but much correlation is still needed. The question of optimizing shapes needs to be clarified and answered. The theory of viscous fluid forces needs to be developed further; in addition, more wind tunnel and free flight data are needed at large Reynolds numbers.

6.2.5 Airship Hull Shape Analysis

For purposes of comparison, a brief analysis will be given for the following four shapes:

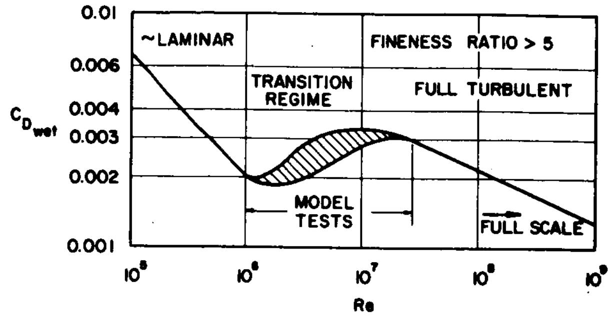

FIGURE 6-7

DRAG COEFFICIENT OF A BODY OF REVOLUTION AS A FUNCTION OF REYNOLDS NUMBER

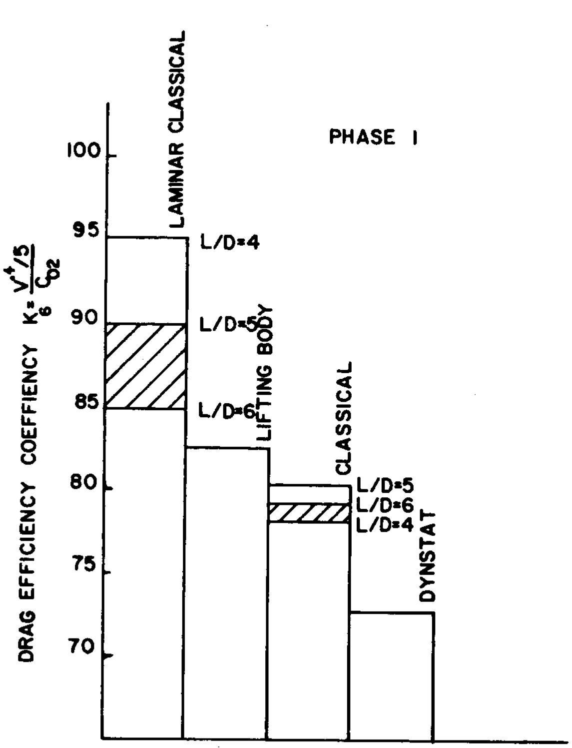

FIGURE 6-8

SHAPE EFFICIENCY COMPARISON

1. The Laminar Classical (Shark Shape)
2. The NASA M-2/F-2 Lifting Body Shape
3. The Classical Body of Revolution
4. The Dynastat Shape

For shape comparison purposes, the quantity drag efficiency coefficient $K_G = \phi/C_{Df}$ will be used (ref. 6-5), where $\phi = V^{2/3}/S_{wet}$ is a geometrical efficiency parameter, being greatest for those shapes with a favorable volume to surface ratio. Therefore, K_G itself will be greatest for those shapes with high geometrical efficiency and low aerodynamic drag. In Fig. 6-8, K_G is used to compare the four shapes under study. On the basis of this analysis, the four shapes were listed in order of decreasing values of K_G.

The following procedure was used in analyzing these shapes.

For the laminar classical and the classical shape of revolution, the volume (V), the length (L), the diameter (D), and the wetted surface area (S) were related using the following equations:

$$V = C_v L\pi \frac{D^2}{4} \qquad C_v = 0.65 \text{ (ref. 6-6), p. 49} \tag{6-1}$$

$$S = C_s' DL \qquad C_s' = 2.44 \text{ (ref. 6-6), p. 53} \tag{6-2}$$

where C_v (prismatic coefficient) and C_s' are volume and surface constants of proportionality respectively.

For the dynastat and the lifting body shapes, the volume, length, diameter, and wetted surface area were related from data respectively in ref. 6-2 and 6-7 and then scaled as follows:

$$\frac{L_1}{V_1^{1/3}} = \frac{L_2}{V_2^{1/3}} \tag{6-3}$$

$$\frac{L_1^2}{S_1} = \frac{L_2^2}{S_2} \tag{6-4}$$

The fineness ratio for both the Dynastat and the lifting body were calculated using

$$\text{Fineness ratio} = \frac{L}{\sqrt{\dfrac{4A_c}{\pi}}} \tag{6-5}$$

where A_c = cross-sectional area of the maximum diameter.

The coefficient $\Psi_v = 4(L/D)^{0.333} + 6(D/L)^{1.2} + 24(D/L)^{2.7}$ from Hoerner (ref. 6-11) is the constant of proportionality between C_{D_v}, the hull drag coefficient (based on hull volume, V, to the 2/3 power) and C_f, the skin friction drag coefficient. That is, $C_{D_v} = C_f\Psi_v$; therefore the total hull drag is $D = qC_{D_v}V^{2/3}$ where $q = \rho v^2/2$ is the stagnation pressure head (ρ is mass density of the fluid medium moving at free stream velocity v over the body of revolution). Combining the two expressions yields $D = (qC_f V^{2/3})\Psi_v$, from which it can be seen that a minimum in Ψ_v will result in minimum drag over regions where $qC_f V^{2/3}$ is fairly constant. The values of C_f were obtained from Hoerner (ref. 6-11, Fig. 22, p. 6-16), using a Reynolds number based on the length of the airship. From Figs. 6-8 and 6-9 it is seen that the optimum fineness ratio for a classical streamlined shape occurs near F = 5.

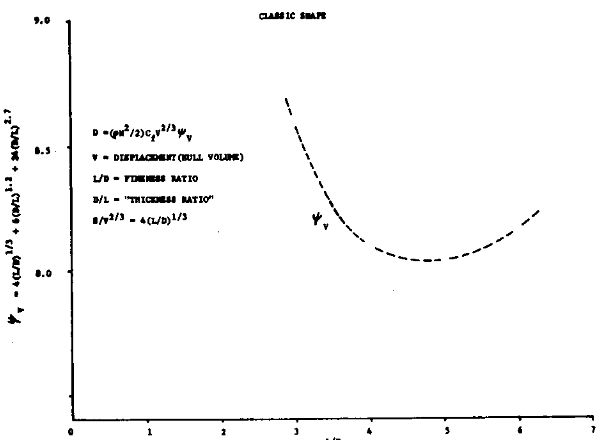

FIGURE 6-9

CLASSICAL SHAPE DRAG CORRECTION FACTOR

Comparing these shapes on the basis of the drag efficiency coefficient K_g alone, it is seen that the laminar classical and the NASA lifting body shapes excel over the classical streamlined shape. The difference in the latter case is slight, while the significantly higher drag efficiency coefficient of the laminar classical is impressive, largely due to improvements in the drag coefficient C_D.

Despite the apparent advantage of the laminar classical shape over other shapes considered, it was felt that any semi-empirical shape analysis of this type should be broadly interpreted as showing trends rather than predicting any absolute or fundamental advantage of one shape over another. Therefore, with this understanding in mind and for the following additional reasons, the classical streamlined body of revolution was chosen during the present study for purposes of calculation and illustration (Fig. 6-10). Some of the advantages of the classical shape are:

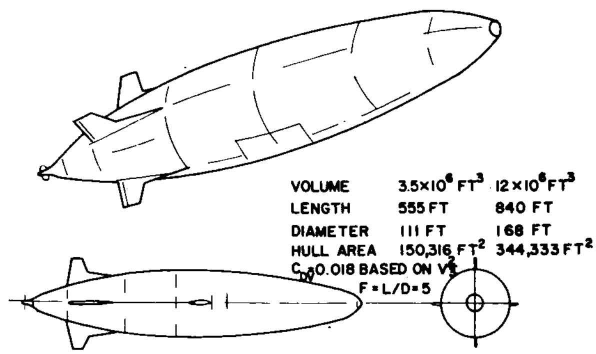

FIGURE 6-10

EXAMPLE SHAPE USED FOR CALCULATIONS

1. The existence of a large body of information and practical knowledge for these shapes (ref. 6-6, 6-2, 6-12).
2. The reliability and convenience of a theoretical analysis based on a simplified shape.
3. The structural integrity of a hull with a circular cross section.
4. The manufacturing convenience associated with a body of revolution.

Therefore, it was felt that off-the-shelf technology could be applied directly to the construction of even large airships in the classical shape with no technological risk. Furthermore, this shape represents a basic geometry, about which design changes could be made without greatly affecting the basic theoretical analysis.

6.3 AERODYNAMIC DRAG

6.3.1 Drag Reduction: Boundary Layer Control

While approximately six methods have been developed to control artificially the behavior of the boundary layer (B.L.), due to weight and velocity considerations, only the following two techniques could realistically be applied to airships:

1. Prevention of transition to turbulent flow and/or prevention of separation of the boundary layer (whether laminar or turbulent) by the use of suitable shapes (such as laminar airfoils);
2. Suction applied to the boundary layer.

The first is a passive technique, requiring no expenditure of energy to maintain boundary layer control, while the second method is active and energy intensive.

6.3.1.1 PASSIVE BOUNDARY LAYER CONTROL: PREVENTION OF TRANSITION BY USE OF SUITABLE SHAPES

It is generally known that a laminar boundary layer can support only very small adverse pressure gradients without the occurrence of separation. In the case of turbulent flow, however, the chance of separation is reduced compared to that of laminar flow due to the fact that in turbulent mixing motion there is a continuous exchange of momentum from the external flow towards the wall. Even for turbulent flow however, it is desirable to prevent separation by adopting a suitable shape.

Wind tunnel tests on bodies of revolution based on the well-known NACA Series 6 Profiles have revealed that laminar flow is preserved up to Reynolds numbers of about 5×10^6. This laminarity of the boundary layer is retained as the result of the stability effect of a substantial pressure drop down the length of the body. At high Reynolds numbers, however, the advantageous pressure gradients cease very close to the bow, at about 10 percent of the hull length, which means that laminarity at high Reynolds numbers is not maintained over most of the hull (ref. 6-5). That is, laminar characteristics cannot be expected for bodies of revolution with profiles based on the NACA Series 6 when the Reynolds number exceeds 10^7. In the present study, the Reynolds numbers at cruise conditions is about 3×10^8 for Phase I and 4×10^8 for Phase II; hence the major portion of each hull can be expected to be submerged in a turbulent boundary layer unless a suitable hull shape is employed. By choosing the proper shape, it may be possible to shift the point of transition in the boundary layer in the downstream direction, thus causing the drag coefficient to decrease, because laminar frictional drag is smaller than turbulent frictional drag, as shown in Fig. 6-7.

It has been established that the location of the point of transition in the boundary layer is strongly influenced by the pressure gradient in the external stream; therefore, with a decrease in pressure, transition occurs at much higher Reynolds numbers than with pressure increase, and furthermore, a decrease in pressure has a highly stabilizing effect on the boundary layer. The desired result is achieved by shifting the section of maximum thickness rearwards, thereby causing a large portion of the hull to remain under the influence of a pressure which decreases downstream and results in maintaining a laminar boundary layer. On the basis of Figure 6-3, which compares the pressure distributions across cylindrical, elliptical, and parabolic bodies of revolution, it is seen that the favorable decreasing pressure down the length of the latter body indicates that it should be possible to maintain a laminar boundary layer at the high Reynolds numbers of large airship hulls using parabolic nose shapes.

6.3.1.2 ACTIVE BOUNDARY LAYER CONTROL: SUCTION

By means of a suitable arrangement of slots in the hull of an airship, it should be possible to remove the decelerated fluid particles from the boundary layer before they encounter a sufficiently high adverse pressure gradient which could cause separation. Prevention of separation greatly reduces pressure drag on the hull. By applying suction, it is possible to shift the transition point downstream. Another effect of suction is to reduce the boundary layer thickness both before and after the transition point. Again, this has the effect of lowering the drag coefficient because laminar frictional drag is significantly smaller than turbulent drag. Conceptual studies and proposals for boundary layer control on airships (ref. 6-13, 6-14, 6-15) would seem feasible in the light of favorable but limited experimental results in this area (ref. 6-16, 6-17).

While more experimental work is needed before the actual benefits in reduced pressure drag versus the trade-offs in increased weight and fuel consumption can be assessed, the present study does recommend stern propulsion as a possible means of increasing the momentum of the boundary layer, thereby minimizing the chance of separation. This benefit, if realized in practice, would be a bonus in addition to several other outstanding advantages of stern propulsion, as will be discussed in paragraph 6.6.

6.3.2 HULL FORM: DRAG CONSIDERATIONS

Airship design has not yet been standardized to a single optimum shape. The problem of aerodynamic improvement in hull shape resolves itself into finding the form of least drag for a given volume.

Hulls are specifically designed to minimize pressure (or form) drag. The airflow boundary layer around a well-designed hull should remain attached to the surface until far aft, with the result that pressure buildup at the bow is balanced by similar pressures on the stern. An ideal hull has no form drag, in that no separation of the boundary layer occurs and stagnation pressure on the bow is balanced by pressure buildup on the stern.

While form drag on a streamlined, slender hull (with small frontal cross-sectional areas) can be quite small, frictional drag acting tangentially across the exposed hull's surface will always be present. Regardless of the smoothness of the hull, frictional drag is still substantial and is the largest single drag component of airships and submarines at all speeds (ref. 6-18).

When lengthening the hull to larger fineness ratios, pressure drag can be reduced, but at the expense of increasing the surface area for a given value. This has the effect of increasing surface frictional drag. On the other hand, lowering the fineness ratio improves the area to volume ratio, thereby lowering the frictional forces for a given volume, but with the result that pressure drag is now increased. In reality, experimentally determined drag as a function of fineness ratio (for a given volume) exhibits a broad nearly flat minimum, ranging from L/D = 4 to 8 (ref. 6-12).

In view of such a poorly defined optimum fineness ratio, structural considerations, as well as problems of construction and ground handling, have largely dictated the final choice of airship hull geometry. Form drag is generally considered negligible for fineness ratios greater than about 5 (ref. 6-11).

While the exact mathematical form of an airship for minimum drag should be based on additional model and wind tunnel testing, a few general observations can be made. For example, the entire hull profile should be a smooth meridional curve preserving continuity in the first and second derivatives (ref. 6-12). This indicates that parallel, cylindrical center sections should be avoided (even though the penalty with respect to overall drag is not particularly severe), and this has been done in the present design study. On the basis of linearized theory, a procedure is given in ref. 6-19, for computing the shape of a body of revolution such that the pressure drag for a given set of conditions is minimized. It can be shown that this procedure produces symmetrical hulls that are (unexpectedly) slightly blunted at both ends. The shape of such an optimized bow section differs from an ordinary parabola only in the vicinity of the nose itself.

Therefore, final decisions about the exact mathematical details concerning hull geometry should be based on actual modeling and testing for drag, stability, and boundary layer control.

6.3.3 Calculation of Drag Coefficients

The zero lift drag for both airship phases was calculated from a procedure recommended by Hoerner (ref. 6-11) and used by Havill and Williams (ref. 6-2). This method consists of summing the individual component drag coefficients as follows:

$$C_D = C_{D_{Hull}} + C_{D_{Fins}} + C_{D_{Engines}} + C_{D_{Misc.}} \qquad (6\text{-}6)$$

where the drag coefficients are based on the total hull volume to the 2/3 power. It should be noted that $V^{2/3}$, having units of area, represents a reference area for the airship. For Phase I, $V^{2/3} = 2.14 \times 10^3 m^2$ ($2.30 \times 10^4 ft^2$) and for Phase II, $V^{2/3} = 4.87 \times 10^3 m^2$ ($5.24 \times 10^4 ft^2$).

6.3.3.1 HULL DRAG

The relationship between $C_{D_{Hull}}$ and the surface frictional drag is given in (ref. 6-11) as

$$C_{D_{Hull}} = C_f[4(F)^{1/3} + 6(F)^{-1/2} + 24(F)^{-2.7}] = 8.02C_f \qquad (6\text{-}7)$$

where the fineness ratio F = (length/maximum diameter) = 5 for both Phase I and Phase II.

For Phase II, which will be used for illustrative purposes, the Reynolds number (based on length) at cruise conditions is 3.77×10^8, yielding a frictional coefficient $C_f = 0.0020$ extrapolated from (ref. 6-11, p.6-16, fig. 22) for F = 5. From eq. 6-7 above, this yields $C_{D_{Hull}} = 0.0160$ at cruise conditions. At V_{max}, the Reynolds number increases to $Re = 6.29 \times 10^8$, yielding a slightly lower value for the frictional coefficients, namely $C_f = 0.0018$. Again, from eq. 607 $C_{D_{Hull}} = 0.0144$ at V_{max} = 44.7 meters/second (100 miles/hour).

6.3.3.2 FIN DRAG

Using a typical airfoil, such as the NACA 0009 [thickness (t) equals 9 percent of the chord, c] for basic calculations, yields a Reynolds number $Re = 2.5 \times 10^7$ for a mean aerodynamic chord of 17.1 meters (56 feet) at cruise velocity. From the plot of C_f vs. Re, the frictional coefficient is found to be $C_f = 0.0026$. From Hoerner (ref. 6-11, p. 6-9), the fin drag coefficient based on frontal area S_o is given as

$$C_{D_o} = C_f[4 + 2\left(\frac{t}{c}\right)^{-1} + 120\left(\frac{t}{c}\right)^3] \qquad (6\text{-}8)$$

Hence, for the NACA 0009 airfoil, $C_{D_o} = 0.068C_f$, based on the frontal area of the fins; converting to $(Volume)^{2/3}$ yields

$$C_{D_{fins}} = 0.068\left(\frac{S_o}{V^{2/3}}\right) = 0.0011. \qquad (6\text{-}9)$$

Therefore, the total drag coefficient of hull and fins becomes

$C_D = 0.0160 + 0.0011 = 0.0171$ at cruise airspeed and $C_D \approx 0.0144 + 0.0011 = 0.0155$ at V_{max}. While the drag of engines and strut mounts is difficult to calculate accurately, an estimate based on the procedure of (ref. 6-2) can be used to show that the drag coefficient for the four side engines of Phase II, mounted in streamlined nacelles, is $C_{D_{nacelles}} = 4.2 \times 10^{-5}$, a negligible value. The struts or engine mounts will contribute several times more strongly than the nacelles to the total drag coefficient, but can still be neglected to a first order approximation. It should be noted that even on the much smaller Dynastat, $V^{2/3} = 800 m^2$ (8600 ft^2), which has a very unfavorable area to volume ratio compared to the vehicles in the present study, the six engines made only a 2 percent contribution to the total drag coefficient.

It can be expected that with proper streamlining the greatest drag component will be skin friction arising from the hull and fins. For the present study, the larger value of drag coefficient, $C_D = 0.0171$ was used for Phase II, while an identical calculation for the smaller, but faster Phase I airship with only two exposed engines yielded a somewhat higher drag coefficient: $C_D = 0.018$, again, based on $V^{2/3}$.

These low drag coefficients reflecting improvements in modern streamlining are quite consistent with full scale deacceleration tests conducted on various rigid airships. For example, tests on the R-33 yielded $C_D = 0.0173$, a value approximately 4 percent higher than predicted by complete model tests (ref. 6-10), and the gross drag coefficient of the U.S.S. Macon was given as $C_D = 0.019$ (based on $V^{2/3}$), (ref. 6-12).

6.4 AERODYNAMIC LIFT AND INDUCED DRAG

6.4.1 Aerodynamic Hull Lift

When an airship is propelled through the air at an angle of attack α, lift forces are generated in a manner similar to that of an airplane wing. It is true that the traditional airship's shape as a wing is poor and its aspect ratio is very small, but the size of the hull is so great that substantial dynamic lift can be generated during flight in a nose high attitude.

A limited amount of practical work is available with regard to the lift generated by three dimensional lifting bodies at the low velocities and high Reynolds numbers characteristic of airship hulls. The lift coefficient calculations for this study were accomplished by the use of

$$C_L = K_P \sin\alpha \cos^2\alpha + K_V \sin^2(\alpha-\alpha_V)\cos(\alpha-\alpha_V) \qquad (6\text{-}10)$$

(ref. 6-20, p. 4.2.1.2-3), where $K_V = \pi$, and for a circular cross section $K_P = 0.25$. Corresponding to a fineness ratio F = 5, the reciprocal of F can be considered an effective aspect ratio, A = 0.2, and the angle of attack for the onset of viscous lift is $\alpha_V = 16.5°$. For a horizontally oriented elliptical cross section hull, with a frontal span to thickness ratio = 2, $\alpha_V = 9°$. For a vertically oriented eliptical hull cross section with a frontal span to thickness ratio a/b = 0.5, $\alpha_V > 20°$. The plots of C_L vs α, angle of attack, are shown in Fig. 6-11. These calculations agree very well with experimental data obtained by Harrington (ref. 6-2).

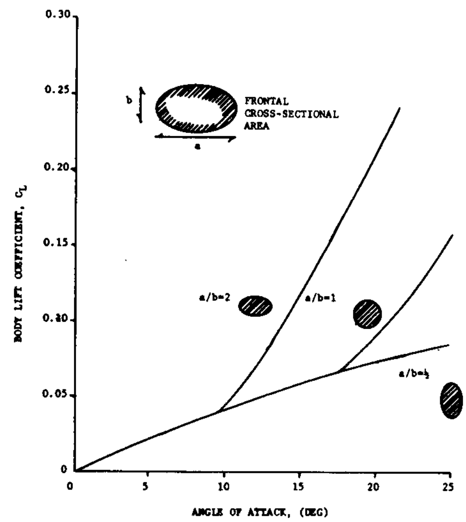

FIGURE 6-11

LIFT COEFFICIENT VS. ANGLE OF ATTACK

From this information the hull only lift of the Phase I and the Phase II craft was calculated and is shown in Fig. 6-12.

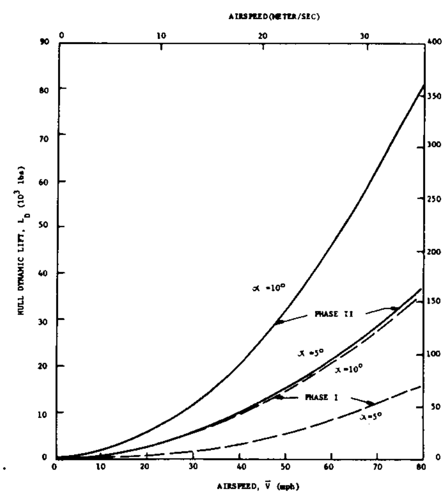

FIGURE 6-12

DYNAMIC LIFT OF HULL AS A FUNCTION OF AIRSPEED AND ANGLE OF ATTACK

The area used for these calculations is the hull planform area which was calculated as $A = 0.8$ (D x L) where D = maximum hull diameter and L = hull length.

6.4.2 Empennage Design Considerations

In order to correct the inherent directional instability of a long streamlined hull, airships have traditionally been equipped with tail fins or empennages. While the action of these fins can, to first approximation, be analyzed by airplane wing theory, their true aerodynamic properties are rather difficult to compute on the basis of classical wing theory because of the following secondary reasons:

1. The traditional airship fin, due to engineering reasons and hangaring requirements has been long, resulting in a very low aspect ratio. This causes spill over the edge to become important; hence the fin acts more like a wing tip than a true wing.
2. The roots of the fin are in a low velocity region within the boundary layer of the hull.
3. The angle of attack of the fins is influenced by the downwash from the forward portions of the hull. The magnitude of this induced force will vary over the length of a long fin.
4. The hull thickness between opposite fins is so large that it greatly affects the flow about the forces on the exposed fin surfaces.

While past practical experience has shown that a wide variety of fin forms and arrangements have been used with reasonable success, the final choice should be based on extensive wind tunnel testing. In the present study, however, the following recommendations will help meet some of the above problems peculiar to airship fins:

1. The fins should have a higher aspect ratio to minimize spill over and tip effects. Structural and hangaring problems with such fins will not be as they were in the past.
2. The fins should be moved forward in the style of ZMC-2. This effect, coupled with the higher aspect ratio, will partially lift the fins out of the lower velocity turbulent boundary layer thus increasing the effectiveness of the control surfaces. Moving the fins forward, however, results in a slight hull destabilizing effect.

6.4.3 Empennage Lift

Method I: A first approximation to the lift on a fin may be obtained on the basis of conventional airplane wing theory (ref. 6-12) as

$$L = \frac{2\pi q S \alpha}{1 + 2S/b^2} \qquad (6\text{-}11)$$

where $q = 1/2 \rho \alpha v^2$ = dynamic pressure head
S = the fin planform area (including the "buried" area through the hull)
α = angle of attack = pitch angle
b = fin effective span
c = fin chord
A = exposed (planform area of either the horizontal or the vertical surfaces)

Method II: If we assume that the hull at the location of the fins is sufficiently thick to minimize carryover through the hull, then we can use the basic lift equation

$$L = C_L q A \qquad (6\text{-}12)$$

where A = the exposed area of the horizontal fins (approximately half of the wetted exposed area). Taking the NACA 0009 as a typical airfoil (thickness to chord ratio 9 percent), then the lift is $C_L = 0.35$ at a nominal angle of attack $\alpha = 5^o$ and at Reynolds number comparable to that of the present design. The tabulated results of both methods are shown in Table 6-1 for Phase I, $\alpha = 5^o$. Method I, based on complete carryover of wing effectiveness through the hull, is probably high, while Method II, based on lift due to exposed fin area only is conservatively low. While it is reasonable to assume the true lift value will lie somewhere between these two extremes, the more conservative fin lift values of Method II based on an actual airfoil (NACA 0009) will be used in calculating the drag induced as the angle of attack varies.

6.4.4 Total Aerodynamic Lift

The total aerodynamic lift (hull and fins) is graphed in Figure 6-13 for $\alpha = 5^o$, a nominal pitch angle for airship operation. During the better part of most missions, the flight attitude of the airship lies between $\alpha = \underline{+}5^o$, with little lift benefit gained above $\alpha = 10^o$. Due to the penalty of induced drag, the most economical flight mode will occur for $\alpha = 0^o$.

6.4.5 Induced Drag

The induced drag component (drag due to aerodynamic lift) of the airship with fins increases with the angle of attack α approximately as the product of lift and tan α. That is, $D_i = L \tan \alpha$. This holds for airship hulls, with or without fins, over a wide range of angles of attack α (ref. 6-12). Hence as the angle of pitch increases so does the lift, and at the same time the induced drag forces increase. Therefore, as a consequence of the increased

TABLE 6-1

COMPARISON OF EMPENNAGE LIFT CALCULATION METHODS PHASE I, $\alpha = 5^o$

Velocity		Method I Lift		Method II Lift	
m/sec	(mph)	Newtons, 10^3	(lbs, 10^3)	Newtons, 10^3	(lbs, 10^3)
8.94	(20)	7.65	(1.72)	4.58	(1.03)
17.88	(40)	30.51	(6.86)	18.33	(4.12)
26.82	(60)	68.72	(15.45)	41.23	(9.26)
35.76	(80)	122.14	(27.46)	73.30	(16.48)

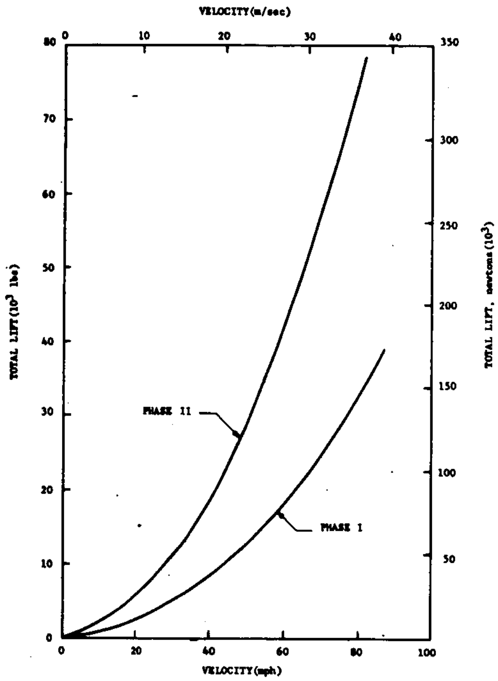

FIGURE 6-13

TOTAL AERODYNAMIC LIFT (HULL + FINS) AT PITCH ANGLE $\alpha = 5^o$ AS A FUNCTION OF VELOCITY

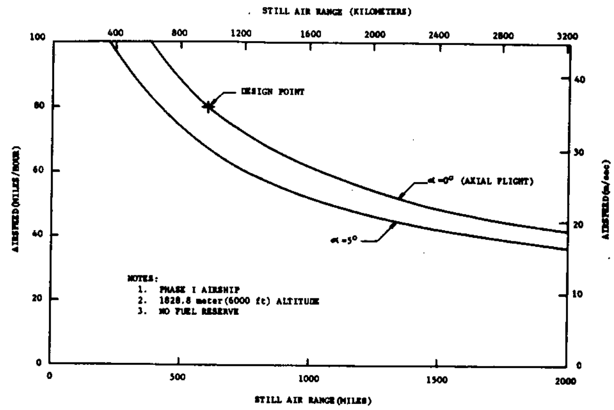

FIGURE 6-14

EFFECT OF ANGLE OF ATTACK ON RANGE

drag, the airship's forward velocity drops at a constant power setting. On the other hand, the power during pitched flight must be increased to maintain the same forward velocity experienced during axial flight ($\alpha = 0$). Therefore, the penalty of gaining aerodynamic lift through pitched flight is to lower the range of the airship through the increased power demands in order to maintain normal cruise velocity. This effect of range is illustrated for Phase I at $\alpha = 5^o$ as a function of velocity in Fig. 6-14. It is seen that the Phase I cruise conditions (with no fuel reserve) of 965 kilometers (600 miles) at 35.76 meters/second (80 miles/hour), is reduced to 676 kilometers (420 miles) for $\alpha = 5^o$, if the same velocity is to be maintained. This represents an increase in aerodynamic lift of 1.45×10^5 newtons (32,600 pounds) with the penalty of having to increase the power requirements approximately 42 percent above axial cruise conditions.

6.5 PERFORMANCE PARAMETERS

6.5.1 PROPULSIVE POWER VS. AIRSPEED

The aerodynamic drag at velocity v is given as

$$D = 1/2\rho v^2 C_D V^{2/3} \qquad (6\text{-}13)$$

where ρ = mass density of air
V = total hull volume displacement
C_D = drag coefficient based on $(\text{Volume})^{2/3}$

The propulsion requirements for the airship can be determined from the relationship between power, force (drag), and velocity, where

$$\text{Power} = D \times v \qquad (6\text{-}14)$$

$$\text{Power} = 1/2\rho v^3 C_D V^{2/3} \qquad (6\text{-}15)$$

This formula, which assumes no power transmission losses, can be modified to include the total propulsion efficiency η_T as follows:

$$\text{Power} = \frac{C_D \rho v^3 V^{2/3}}{2\eta_T} \qquad (6\text{-}16)$$

For both Phase I and II the overall propulsion efficiency is assumed to be 0.80 which is somewhat below typical propeller efficiencies of 0.85. The density of the standard atmosphere at cruise altitude was used for both phases. The drag coefficients, as previously calculated, are used in eq. 6-16 which is plotted in Fig. 6-15. The sizing of engines is based on the propulsive power requirements at maximum speed as taken from this power-velocity curve. For Phase I this is 2.09 x 10^6 watts (2800 horsepower) and for Phase II, 4.57 x 10^6 watts (6125 horsepower).

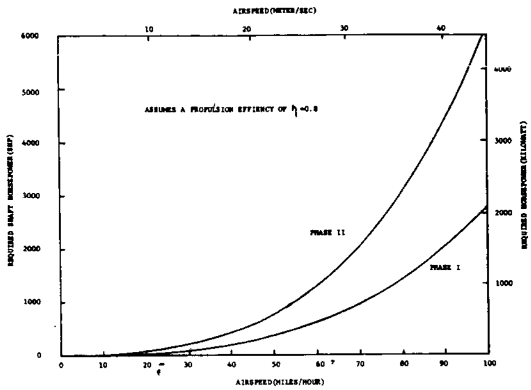

FIGURE 6-15

VARIATION OF REQUIRED HORSEPOWER WITH AIRSPEED

In view of the fact that power is proportional to the cube of the velocity, severe demands are made on power for even modest increases in airspeed. For example, in order for the Phase II airship to increase its speed only 4.47 meters/second (10 miles/hour) above cruise velocity, it will require a 59 percent increase in power. For either the Phase I or Phase II airship to double its velocity anywhere along the power-velocity curve requires an eight-fold power increase. This strong velocity dependence on the power requirements makes it readily apparent that lower speeds will quickly yield greater endurance and economy of operation from the standpoint of fuel consumption.

6.5.2 Mission Capability: Payload Range Summary

The performance of both airships during a mission, in terms of cargo weight carried as a function of range, is illustrated in Fig. 6-16. As indicated, the design points under cruise conditions are 2.27 x 10^4 kilograms (25 tons) at 35.8 meters/second (80 miles/hour) for Phase I, and 9.07 x 10^4 kilograms (100 tons) at 26.8 meters/second (60 miles/hour) for Phase II. It is readily apparent that even modest increases in speed result in a rather severe penalty in decreased range for a fixed fuel capacity. This

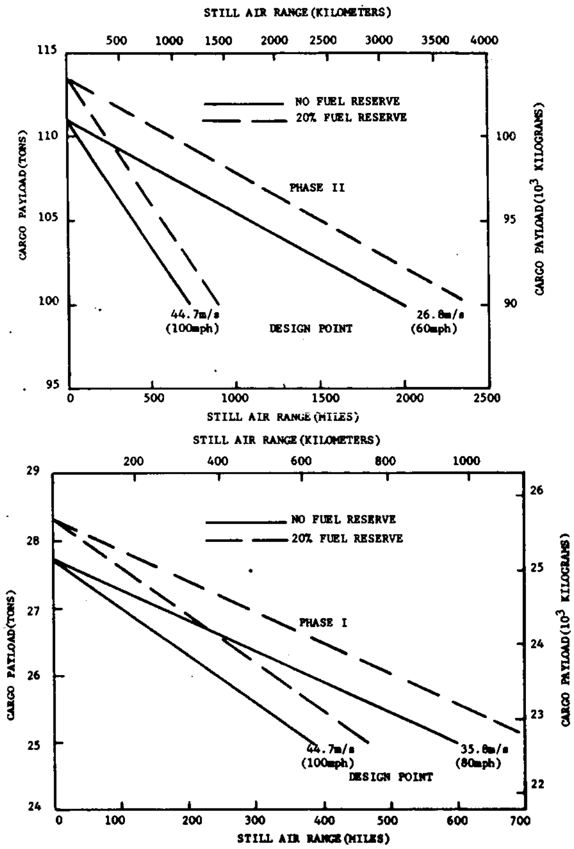

FIGURE 6-16

PAYLOAD RANGE SUMMARY

emphasizes the direct one-to-one trade-off between fuel and cargo weight. The basic fuel weight necessary at cruise conditions in still air can be obtained from the equation

$$W_f = \frac{SFC \times POWER \times RANGE}{VELOCITY} \qquad (6\text{-}17)$$

where the specific fuel consumption (SFC) is assumed to be 0.30 kilograms/kilowatt-hour (0.5 pounds/hp-hour).

The power corresponding to the airship velocity is obtained from Fig. 6-15. Once the basic fuel weight is known for a given mission, then the range of the airship in still air can be solved from eq. 6-17 as a function velocity.

From Fig. 6-16, it is readily apparent that range drops rapidly with increasing velocities. For example, the 3218 kilometer (2000 mile) Phase II mission at cruise velocity, drops to 1160 kilometers (720 miles) at 44.7 meters/second (100 miles/hour). The vertical intercepts on the mission capability graph yield the zero range, dead-lift maximum cargos of the airships. For example, at zero range, both the Phase I and Phase II airships can swap fuel (with a 20 percent reserve) and cargo on a one-to-one basis to increase their cargo loads by approximately 13 percent above the design point.

It is interesting to consider the other extreme of the cargo-range performance relationship. If the airships were flown with all cargo replaced by usable fuel, which is in addition to the nominal fuel load (at 20 percent reserve), then the design point cruise ranges are multiplied by the factors tabulated in Table 6-2.

TABLE 6-2
RANGE FACTORS FOR NO CARGO

Velocity		Range Factors	
m/sec	(MPH)	Phase I R/R_{cruise}	Phase II R/R_{cruise}
17.88	(40)	42.08	23.11
26.82	(60)	18.67	10.27
35.76	(80)	10.5	5.78
44.70	(100)	6.73	3.70

This means that Phase I, with an endurance of 78.8 hrs, could travel 10,800 kilometers (6300 miles) at cruise velocity; at half its normal cruise velocity, however, it could circumnavigate the earth in 631 hours. Phase II has an even more impressive endurance capability. At normal cruise velocity its range would be 33,050 kilometers (20,540 miles), while at 2/3 cruise velocity its range is extended to 74,368 kilometers (46,220 miles) with an endurance of 1155 hours (6.88 weeks).

While such zero cargo extreme endurance missions are possible, relief crews and increased expendable provisions would undoubtedly reduce these figures somewhat. Trim and ballast control would be of paramount importance on any long endurance mission. Possible solutions include inflight water recovery (easy with conventional gasoline engines, but increasingly difficult with diesels and gas turbines), collection of condensed moisture from the airship hull itself (pioneered by the Graf Zeppelin), and direct water pump-up (by means of extended hoses) from lakes, oceans, or designated bases, including ships. Ballast adjustment to replace consumed liquid fuels should occur no more often than once each 24 hours, amounting to only 2134 kilograms (4704 pounds) at 2/3 cruise velocity and 7144 kilograms (15,876 pounds) at 26.82 meters/second cruise (60 miles/hour) for Phase II.

Missions of extreme duration would be valuable in wildlife and resource surveillance and intercontinental cruises ("Show of the Flag") for national prestige and international goodwill, in addition to providing airbourne military command posts.

6.5.3 Effect of Headwinds (Phase II)

In general, the airships will seldom operate in still air, and allowances must be made for additional fuel in order that the craft can operate at cruise velocity over a wide range of atmospheric conditions. The range and endurance of an airship can be greatly reduced by the action of headwinds as is seen in Fig. 6-17. The hori-

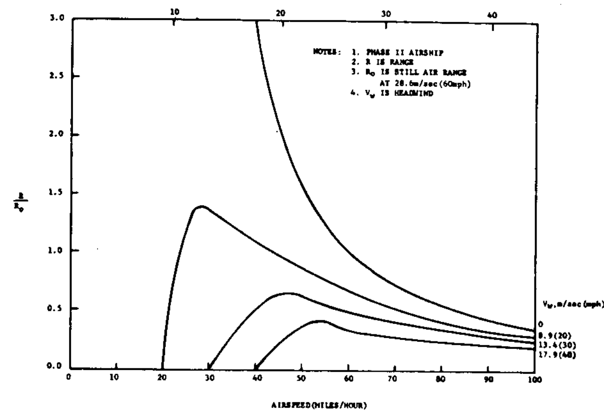

FIGURE 6-17
EFFECT OF HEADWIND ON RANGE

zontal intercepts represent zero ground speed, in which case the airship is making no forward motion. This situation, however, could be considered normal if the craft is pointed upwind in a station-keeping or extended hovering mode of operation. For any headwind $V_W > 0$, speed will be sacrificed. The performance of Phase I under the influence of headwinds is analogous to that shown for Phase II.

6.5.4 Drag to Weight Characteristics

An important parameter for the comparison of the performance of Heavier-than-air (HTA) craft is the drag to lift ratio. In the case of a fully buoyant or LTA craft, where gross buoyant lift is equal to gross weight, the ratio becomes drag to gross weight. For large, fully buoyant craft, this ratio is largely governed by surface frictional forces; therefore, the friction coefficient C_f becomes the best index of the vehicle's energy consumption and is probably the single most important determinant of its economic performance. This is illustrated by the following argument:

The energy E consumed per trip of range R by an airship having total operational weight W and drag D, is given as

$$E = DR \qquad (6\text{-}18)$$

If T = the measure of transportation effected (say kg·km or ton-miles), then

$$T \sim WR \qquad (6\text{-}19)$$

Hence, the ratio of energy consumed to transportation generated is just the drag to weight ratio: that is,

$$\frac{E}{T} \sim \frac{D}{W} \qquad (6\text{-}20)$$

The drag to weight ratio, therefore, is intimately related to the transportation efficiency, in that a vehicle of the type under consideration consumes fuel in direct proportion to its D/W ratio, and as this ratio goes up, the range and endurance of the craft decreases. The drag to weight ratio can easily be shown to be directly proportional to the square of velocity v and inversely proportional to the length of the airship L (ref. 6-18): that is,

$$\frac{D}{W} \sim \frac{v^2}{L} \qquad (6\text{-}21)$$

This relationship supports the design philosophy of the present study that an airship should be fairly large and operate at low speeds for greatest economy based on purely aerodynamic considerations. Therefore, the larger Phase II airship, operating at a lower cruise velocity than the Phase I craft will show a lower, hence more favorable drag to weight ratio as shown in Fig. 6-18. Both vehicles, however,

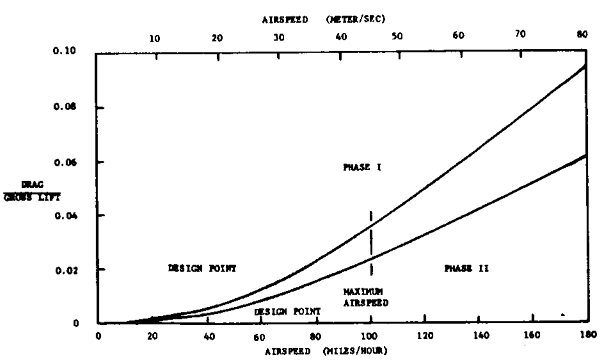

FIGURE 6-18

VARIATION OF DRAG TO LIFT RATIO WITH AIRSPEED

due to their fully buoyant design are truly floating craft whose D/W characteristics are much better than that of all types of HTA craft whose lift is generated by aerodynamic forces derived from relatively high expenditures of energy

6.5.5 Total Lift Summary

The major sources of lift for the Phase I and II airships, presented in Fig. 6-19, include

1. the gross static lift
2. the VTOL capability, including Thrust Vector Control (T.V.C.)
3. the aerodynamic lift at cruise conditions.

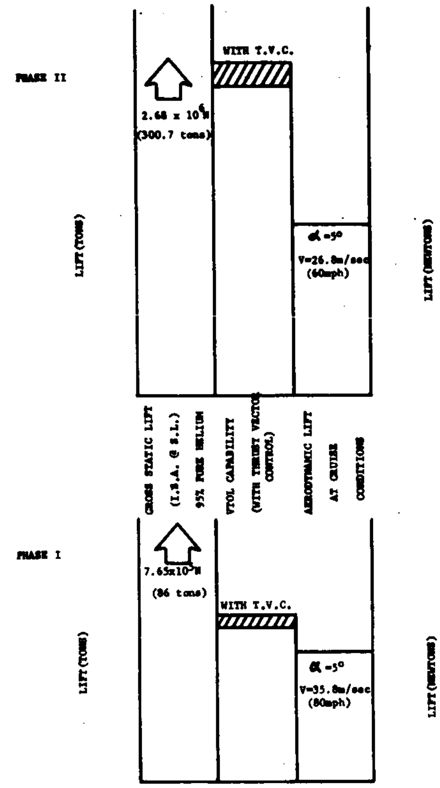

FIGURE 6-19

TOTAL LIFT SUMMARY

By far, the greatest lift component is due to the static buoyant lift at takeoff. This is measured at sea level in the standard atmosphere and for an assumed helium purity of 95 percent and is 2.68 x 10^6 Newtons (300.7 tons) for Phase II and 7.65 x 10^5 Newtons (86 tons) for Phase I. With the present hull construction, modern ballonet films and elastometers, and improved purification techniques, it should be possible to maintain helium purity above 98 percent, thereby resulting in an added static lift benefit.

The maximum thrust available for Vertical Takeoff and Landing (VTOL) from the side-mounted engines is 1.78 x 105 Newtons (20 tons) for Phase I and 3.56 x 10^5 Newtons (40 tons) for Phase II. Additionally, a maximum increase of 1.5 percent lift could be provided by the compressed air thrustors. Normally, these thrustors would never be used to produce VTOL lift, but rather would serve to provide Thrust Vector Control (TVC).

The aerodynamic lift is also presented in Fig. 6-19. At cruise conditions and a 5^o angle of attack, it amounts to approximately 7.3 percent of the total static lift for Phase II and 19.8 percent for Phase I. While much of the aerodynamic lift of the Phase I ship is due to its higher cruise velocity, even at the same speed, the smaller ship will produce a greater percentage of aerodynamic lift to its total static lift. This is consistent with the fact that aerodynamic lift is proportional to the square of the linear dimensions of the ship (area) while the buoyant lift is proportional to the cube of the dimensions (volume). In conclusion, the lift summary indicates that loads due to rain and sleet (which are also proportional to surface area) as well as variations due to superheat (as discussed in Chapter 8 under Thermodynamic Management of Lift) should not, under most circumstances, seriously affect the performance of either airship. In many cases, normal superheat for the airships (particularly while at cruise conditions) will only be a small perturbation on the total lift summary diagram.

6.6 PROPULSION SYSTEM-INTRODUCTION

The primary propulsion system for the airship must provide

1. The forward forces necessary to meet the airspeed requirements of the airship.
2. The vertical lift and downward forces necessary to provide the required hover and load-lift capabilities.

Additional propulsion system requirements and capabilities which must be taken into consideration and evaluated in terms of trade-off advantages and penalties include the following:

1. minimum specific weight, kilograms/kilowatts (pounds/hp)
2. minimum specific fuel consumption (SFC)
3. ability of the engines or the propellers to be swivelled or gimballed to vary the thrust direction
4. ability to meet the environmental requirements for noise and pollution
5. the availability of the system with little or no further development
6. low maintenance costs
7. reliability
8. use of available and low cost fuels.

The first two considerations alone are of primary importance in choice of a propulsion system for airships. Therefore, the 1975 state of the art specific engine weight and specific fuel consumption is presented in Fig. 6-20 for comparison among the various engine types.

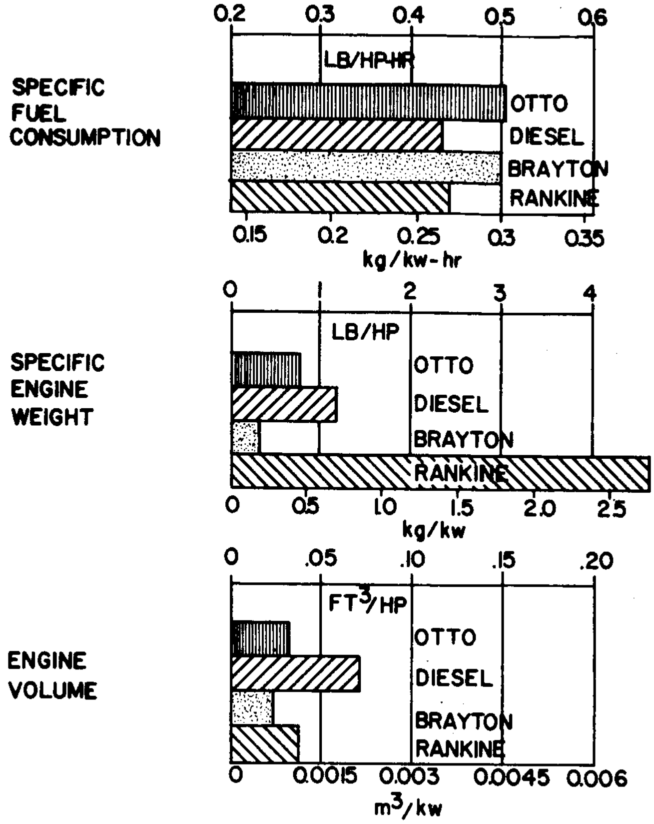

FIGURE 6-20

STATE OF THE ART OF TYPICAL ENGINES

Five alternative power plants for the missions to be undertaken by the airships were examined for this project:

1. Reciprocating Piston (OTTO cycle)
2. Reciprocating Piston (Diesel)
3. Rankin Cycle Engine
4. Turbojet
5. Turboprop

6.6.1 Reciprocating Piston Engines (OTTO CYCLE)

The reciprocating gas engine (Otto cycle), which is readily available, has a SFC comparable to the gas turbine. Supercharged, the SFC is even better; however, this adds a degree of complexity which decreases the engine reliability and increases maintenance costs with an additional weight penalty. The specific weight of this engine, though less than that of the diesel, is still excessive compared to the gas turbine. Also, the fuel cost is higher than with either diesel or gas turbines and the risk of fire is significantly higher.

6.6.2 DIESEL ENGINES

While the reciprocating diesel engine has the most favorable SFC, it is penalized by a low power to weight ratio and is probably incapable of being developed beyond about half the size of the gas turbine. Therefore, its low SFC will be effective only over missions of long endurance.

The Nomad diesel engine which operates on a compound cycle is an interesting engine to examine for use in airships. The special advantage of the Nomad is its very low SFC of 0.21 kilogram/kilowatt-hour (0.35 pounds/hp-hour). The air is first compressed by means of the turbo-compressor and then enters the diesel portion of the engine. The compressor itself is driven by exhaust gases from the engine. The Nomad is a fairly complex engine, consisting of 12 cylinders and provides a maximum power of 3058 kilowatts (4100 hp). The engine, which was developed by Napier of England in 1954, is not believed to be available today; however, its low SFC of a low grade fuel could make it more attractive for airship use in the future (ref. 6-22).

6.6.3 RANKINE CYCLE ENGINES

It is of interest to examine a hydrogen fueled Rankine cycle engine for possible airship use. Due to the high heating value of liquid hydrogen per unit weight of fuel, a possible specific fuel consumption of .0911 kilograms/kilowatt·hr (0.15 pounds/hp·hour) is reported. This estimated low figure, along with the nonpolluting combustion products, makes this an interesting condidate for airships on missions of extreme duration where the ultimate goal of airship engines would be the highest overall efficiency based largely on low specific fuel consumption criteria.

The problems with this type of approach are numerous but include the following:

1. Massive cost requirements to develop the new engine.
2. Very low volumetric heating value of hydrogen (approximately one-fourth that of hydrocarbon fuel).
3. Very large heavily insulated fuel tanks to contain liquid hydrogen.
4. Heavy system components [estimated at 8,548 kilogram (18,850 pounds) to produce 1492 kilowatt (2000 horsepower)]. This is compared with a turboprop engine using hydrocarbon fuel which will produce 1492 kilowatt (2000 horsepower) and weigh less than 272 kilograms (600 pounds).

6.6.4 GAS TURBINE ENGINES

The most suitable power plant for propulsion of airships is the gas turbine. It has been developed to a high degree of perfection, reliability, and efficiency. It offers a high power to weight ratio with simplicity of installation. Any number of light weight gas turbines have been used in helicopters and other VTOL craft. Table 6-3 lists some representative gas turbines and indicates the range of available engines. A SFC of 0.3 kilograms/kw-hr (0.5 pounds/hp/hr) has been assumed in the present study. Several gas turbines under development at the present time have improved this figure considerably. The many advantages, including light weight, low maintenance, freedom from vibration, and simplicity, make the gas turbine propeller unit (turboprop) the best propulsion unit for airships in the 1970's.

The turbojet engine was ruled out because it is best suited to high speed flight operations and its high temperature, high velocity exhaust may crease unforeseen problems during hovering operations involving ground personnel. At the same time, compared to the turboprop, the turbojet is highly inefficient during the hover mode (ref. 6-24).

6.6.5 PROPULSION DURING HOVERING

Hovering or station keeping is one of the most important aspects of the airship operations. To accomplish many of the more profitable missions, the ability to remain in a stable position a short distance above the ground while refueling or unloading ballast or cargo is necessary.

6.6.5.1 ENGINE CONSIDERATIONS

The Phase I airship will have two side-mounted engines and one stern-mounted engine. The Phase II airship will have four side-mounted engines and one stern engine. The side-mounted engines of the Phase I airship will be located at the center of gravity of the airship whereas the Phase II airship will have four side-mounted engines approximately equal distances fore and aft from the center of gravity so that equal moments may be produced to balance the cargo during load and unload operations.

For example, and for purposes of sizing and comparison only, the Phase I and Phase II airships will use the Lycoming T-53 L-13 turboprop engine or a similar version of this engine. Not only is its specific weight low but the structure supporting it from the hull can be made much lighter than with piston engines of comparable power. Furthermore, it requires no major cooling and is so small and compact that mounting them inside the hull is not justified (each engine has a frontal cross-section of $0.27 m^2$ ($2.9 ft^2$). As a typical turboprop engine, the T-53 L-13 engines have a takeoff rating of 1044

TABLE 6-3

TURBOPROP ENGINES

		SFC Kg/ kw-hr	SFC lb/ hp-hr	POWER Kilowatts	POWER SHP
U. S. Manufacturer					
LYCOMING	T53-13B	.35	.58	1044	1400
	LTC4V-1	.249	.41*	3730	5000
	PLT-27	.26	.43*	1529	2050
	ALF 502H	.25	.42*	4849	6500
	LTP	.322	.53	388	521
GENERAL ELECTRIC	T58-GE-16	.29	.48	2928	3925
	T58-GE-10	.31	.51	2126	2850
	T65-GE-3	.29	.49	2297	3080
	T64-GE-415	.28	.47	3267	4380
	T64-GE-P4D	.29	.48	2536	3400
ALLISON	T-56-A14	.30	.50	3662	4910
Foreign Manufacturer					
CANADA	PT6A-41	.36	.59	634	850
	PT6A-45	.35	.57	713	956
	PT6A-50	.35	.58	671	900
	PT6T-3	.36	.60	932	1250
	PT6T-6	.36	.59	1010	1360
FRANCE	ASTAZOU XVIG	.32	.53	719	965
	ASTAZOU XX	.28	.46	907	1217
	ASTAZOU XVIII	.30	.50	768	1030
	TURMO III C4	.36	.60	978	1312
ENGLAND	MK 529	.35	.58	1417	1900
	RS 360	.32	.53	619	830
	H-1400-3	.33	.54	1044	1400

*IN DEVELOPMENT (adapted from ref. 6-23)

kilowatts (1400 shaft horsepower), a normal power rating of 932 kilowatts (1250 shaft horsepower), and a weight of 240 kilograms (530 lbs.). From the power vs. speed curve, it can be seen that five such engines will propel the Phase II ship at its maximum velocity of approximately 44.7 meter/sec (100 miles/hour). The airship, operating with one such engine mounted in the stern, will be able to achieve a velocity of 25.5 meters/sec (57 miles/hour). The Phase I airship is slightly overpowered with three L-53 engines operating at cruise power, as the ship would achieve a velocity of approximately 49.2 meters/sec (110 MPH). Operating with stern engine only, the Phase I ship would achieve a velocity of approximately 34.4 meters/sec (77 MPH). It is interesting to note that both Phases, operating with a single L-53 stern engine at its nominal power rating, will very nearly achieve their design cruise velocity. It is intended that the side engines on both Phase I and Phase II will swivel through 90° allowing engine thrust to be directed in either the vertical or horizontal plane. This permits the craft to achieve VTOL and hover capabilities with large variations in propulsion lift from the neutral buoyancy condition.

6.6.5.2 PROPELLER CONSIDERATIONS

The three-bladed prop-rotors selected for the airship designs are of a high-twist design with a wide chord suitable for both a lifting and normal flight mode. The propellers will be fully reversible. Reduction gearing between the engine and propeller-rotor is necessary to assure that the propeller tip speed does not reach sonic velocity. The design slipstream velocity for this propeller is approximately 21.3 meters/second (65 feet/second) during hover operations.

6.6.6 STERN PROPULSION

Wind tunnel tests were conducted at the Langley Research Center in Virginia on a 6.72 meters (20.5 foot) model airship using stern propulsion (ref. 6-25). The items investigated were.

1. Various propeller designs
2. Propeller thrust
3. Moment characteristics
4. Hull pressure, boundary layer effects
5. Wake characteristics

Some conclusions which might be made from this investigation were

1. Stern mounted propellers are more efficient because they operate in the low velocity wake of the airship.
2. Stern mounted propellers, by adding momentum to the boundary layer, may delay or help prevent separation of the boundary layer.
3. Airship crew and passenger fatigue would be reduced because of the noise and vibration being so far from the cabin.

It is intended that the stern propulsion unit be gimballed through a cone of approximately 15 degrees. This will provide the pilot with an additional flexibility and maneuvering advantage during hovering and flight operations.

6.6.7 Thrust Vector Control Systems

The fine or vernier control of airship position will be accomplished by the use of thrustors, a concept developed and presented in an unpublished design memo dated November 20, 1974, by V. H. Pavlecka of Turbomachines, Inc., Irvine, California. These thrustors, which consist of high energy air jets, will be commanded by the onboard computer and the pilot.

6.6.7.1 TYPE OF THRUSTORS

The thrustors as shown in Fig. 6-21 and Fig. 6-22 permit the computer selection of any of five directions from each individual thrustor. Phase I thrustors will produce 2240 newtons (500 pounds) of force each and the Phase II thrustor will produce 4480 newtons (1000 pounds) each. The thrust is produced by the use of compressed air generated by an onboard compressor. The air compressors are driven by auxiliary power units. Typically, the continental 142 engine could be selected for this purpose. 261 kilowatts (350 horsepower) may be produced at the maximum continuous rating condition with this auxiliary unit.

6.6.7.2 LOCATION OF THRUSTORS

The thrustors are mounted in two rows around the airship located 90° apart and as far forward and aft as possible.

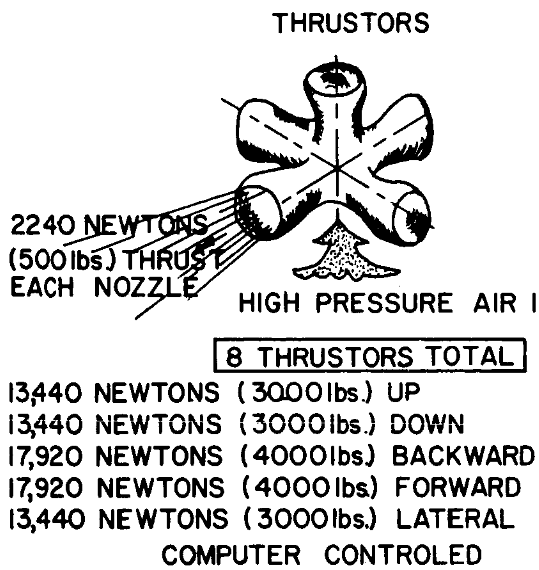

FIGURE 6-21

THRUSTOR SPECIFICATIONS - PHASE I

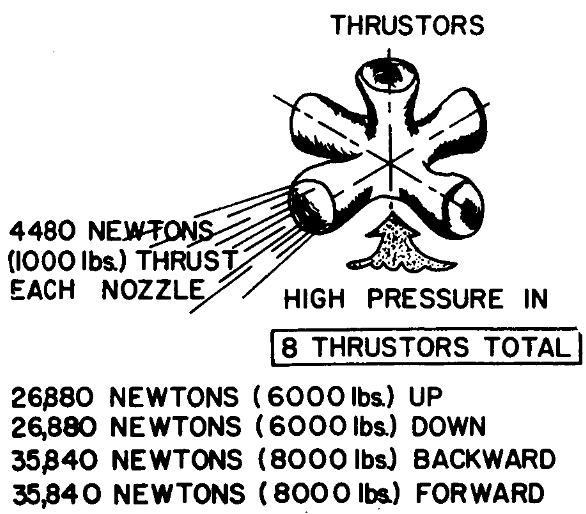

FIGURE 6-22

THRUSTOR SPECIFICATIONS - PHASE II

The location of the thrustors in the forward and aft positions will produce the maximum moments for positioning the airship during the hovering or vectoring modes of operation.

6.6.7.3 THRUSTOR ENERGY REQUIREMENTS AND PERFORMANCE

The Phase I airship will have eight individual thrustors each of which will provide a thrust of 2240 Newtons (500 pounds). A maximum upward and downward force of

13.440 Newtons (3000 pounds) may be provided by the thrustors. In addition, a backward and forward force of 17,920 Newtons (4000 pounds) may be generated by the thrustors.

The Phase II airship thrustors are similar to the Phase I airship thrustors except that each will provide 4480 Newtons (1000 pounds) of thrust in any of five possible directions. A maximum possible upward and downward force of 26,880 Newtons (6000 pounds) is provided by the Phase II thrustors and a maximum of 35,840 Newtons (8000 pounds) in the backward or forward directions.

The Phase II airship thrustors will require approximately 8.16 kilograms/second (18 pounds/second) of airflow when operating and an exit velocity of Mach No. 1.6 at the design operational condition. They should be small and light weight [less than 11.33 kilograms (25 pounds)].

6.7 SUMMARY

In order to predict the performance and flight characteristics of large airships, it is necessary to determine the magnitude of the principal aerodynamic forces and moments acting on the vehicle. Due to an intense and continuous period of development, such predictions are quite reliable for conventional HTA craft. The situation for LTA craft is quite different, however. The scale of airships in speed, size, shape, and mass distribution requires extrapolations to Reynolds number ranges, wetted surface areas, and vehicle response rates which are unfamiliar to the modern aeronautical engineer. In addition to the fact that data relating to the aerodynamics of airships are less numerous than for HTA craft, most of the existing LTA technical literature dates back to the 1920-30's, a period characterized by fairly rudimentary wind tunneling and flight test instrumentation. In view of the shortcomings found in the body of existing airship literature, it would be advisable to conduct tests over the regions of the very large Reynolds' numbers which will characterize modern airships.

As this study has indicated, the airship's total profile drag is dominated by hull and control surfaces, the latter contribution complicated by interference effects of the hull on the fins. Conversely, bow planes, even if relatively small, could produce substantial interference effects on the hull itself. It is very difficult to describe the flow fields in the fully turbulent region of stern fins. The problem is complicated even further if no provision for BLC is made and the fins are located behind the point of separation. This undesirable separation of the fully turbulent boundary layer organizes into a set of body vortices as the angle of incidence increases, thus greatly perturbing the lift, stability, and control characteristics of the fins. Another empennage design complication is the very pronounced carry-over lift induced between the hull and the fins (fins joined to the hull may produce from 40-60% more lift than the fins alone).

In this study the aerodynamic drag calculations were based on hull and fin skin friction considerations only. From the standpoint of hull drag, this is consistent with the observations of most investigators that at fineness ratios above approximately five, hull pressure drag is negligible compared to frictional hull drag. If the hull's surface area is reduced (by lowering the fineness ratio), then the associated skin friction will also decrease. However, this increases the pressure drag resulting from the separation of the turbulent boundary layer from the hull. Therefore, some type of boundary layer control is desirable from the standpoint of delaying or eliminating separation, thereby (1) reducing hull pressure drag and (2) improving the aerodynamic effectiveness of the fins and control surfaces.

The rigid airship hull could be fairly easily modified for active boundary layer control through suction slots, the extra ductwork and power requirements would make this a heavy, energy-intensive system. While more research is needed in this area, passive techniques can be used in an attempt to delay boundary layer separation or at least to modify its adverse effects. Favorable possibilities include adopting new hull shapes, applying stern propulsion, and increasing the aspect ratio of the fins and moving them somewhat forward along the hull.

Streamlining the hull and minimizing all protrusions from the hull will improve the overall airship drag profile. Due to the small size of the modern gas turbine, retraction of engines not needed during low speed cruise conditions will be unnecessary.

The gas turbine (turboprop) engine with its high reliability and very favorable specific fuel consumption and power to weight ratio is the best present choice of power plants for airship use. Turboprop engines represent virtually no technological risks and are available in many off-the-shelf models covering a wide power range.

As liquid fuels continue to rise in price, the most economical airships will be large, fully buoyant craft, operated at low speeds. While pressure rigid airships could be designed for cruise conditions between 160-320 kilometers/hour (100-200 miles/hour), the strong cubic dependence of propulsion power on velocity makes high speed operation even less attractive in the face of an energy crisis. Fully buoyant airships have the highest lift to drag ratio of any air vehicle, and like any floating craft (a ship, for example) can, by simply reducing power, achieve truly remarkable increases in both range, economy of operation, and mission endurance. It is probably more accurate to think of the airship with its unique characteristics as a fast ship rather than view it as a slow "airplane".

This chapter has examined aerodynamic considerations associated with the airship's airframe and propulsion design and operations. At the conceptual design level, this study has verified and accepted the immediate technical feasibility of large airships. However, much work remains to be done in the various areas of aerodynamic optimization before a production design is undertaken.

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CHAPTER 7

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7.1 INTRODUCTION

From a structural configuration viewpoint, without regard to airship utilization, mission, or aerodynamics, a logical relationship can be shown for airship configurations which have and have not been built in the past. Figure 7-1 shows this airship configuration relationship. From the simple gas bag, the free-flight balloon the addition of aerodynamic shape along with directional and speed controls and devices leads to the nonrigid airship. Directional in this case is taken in the most general sense and includes the use of ballonets for vertical motion.

If the fabric covering were replaced by a metal skin, the pressure shell airship would have been developed, but past material and structural constraints lead directly to the pressure monocoque due to the need for stiffening transverse rings and longerons. The ZMC-2, built in 1929 for the U. S. Navy, was the only successful pressure monocoque configuration ever built and flown. Further data and description of this design form, usually referred to as a metalclad or pressure rigid in the literature, is given in Paragraph 7.5. The pressure shell as a pure form has not been built, and is therefore shown within a dashed outline.

Another direction was also taken to provide some alternative structural form to support loads--the addition of a stiff exterior keel and thereby the creation of the semirigid airship. This configuration was not fully successful in the past for it was found that the relatively stiff keel placed excessive forces into the flexible envelope. This form might be of interest for future development if sufficient articulation and flexibility could be attained while still providing the load carrying ability required for a cargo-carrying airship.

If the semirigid airship logic is further extended so that ballonets are replaced by individual gas cells and complete exterior framing is used, the rigid airship configuration is the result.

The use of exterior framing required the use of an exterior fabric for aerodynamic purposes and the use of netting and additional framing to transfer the gas cell load to the airship's structure. If these coverings and load transfer structures were replaced by a stiffened shell, thereby gaining overall structural length improvement in addition to performing the covering and containment functions, the semi-monocoque rigid configuration occurs. This again is a configuration which has not been built in the past.

Had lift gas compartmentation and a strengthened hull and framing to accommodate this compartmentation been added to the previous metalclad design, as well as possible hull penetrations, the semi-monocoque rigid configuration would have evolved.

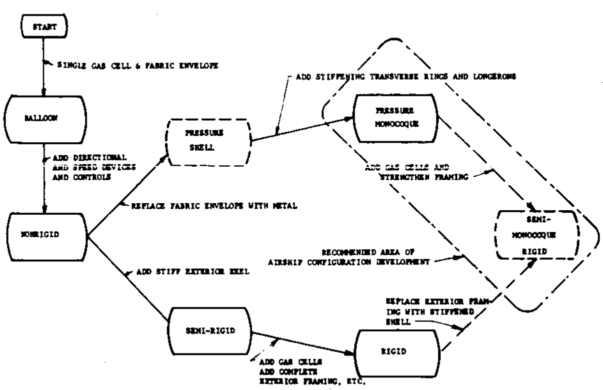


FIGURE 7-1

AIRSHIP CONFIGURATION RELATIONSHIPS

7.2 STRUCTURAL CONFIGURATION EVALUATION

As airship buoyancy gas volumes increase, such as from the nonrigid to the rigid configuration, physical designs or mechanisms are necessary to contain, restrain and manipulate discrete volumes in order to

1. Prevent total, catastrophic ship failure in the event of partial envelope rupture
2. Vary the magnitude of lift along the length of the airship
3. Prevent or reduce gas "surging" due to acceleration/deacceleration or rapid altitude changes
4. Trim and stabilize the ship
5. React to the expansion and/or contraction due to altitude and/or meterological changes, and to possibly
6. Pressurize the gas to maintain aerodynamic shape and/or reduce the hull compressive stresses due to the aerodynamic moment

The first three requirements have usually been met by gas envelope compartments; the last three by use of some form of ballonet. Small nonrigids of up to $42.5 \times 10^3 m^3$ (1.5×10^6 ft.^{3}) had ballonets, but no compartments. However, even nonrigids, if of large volume, will require compartmentation for the reasons cited. All rigid airship designs were actually based on a series of partially inflated gas cells restrained by some form of netting to transfer lift longitudinally as well as transversely to satisfy the first five requirements; the sixth requirement was met by external structural frameworks. Fig. 7-2 is a schematic of the possibilities of compartmentation and ballonets.

In Fig. 7-2 it is recognized that the gas envelope's compartmentation could be by individual gas cells, such as in past rigids, by gas cells created by the subdivision of the envelope by partial or complete use of the exterior covering, or by a variation of a pressurized ship such as the ZMC-2. The five approaches to compartmentation of Fig. 7-2 could be in vertical or horizontal form and accomplished by netting, diaphragms, structural shells, or combinations thereof. Depending on the construction approach and the operational concept of the airship, ballonets may or may not be required. Individual gas cells, whether complete or partial, will require no ballonet if pressurization of the gas is not required for aerodynamic shape, prestressing of the structure in tension, or accommodation of gas expansion or contraction.

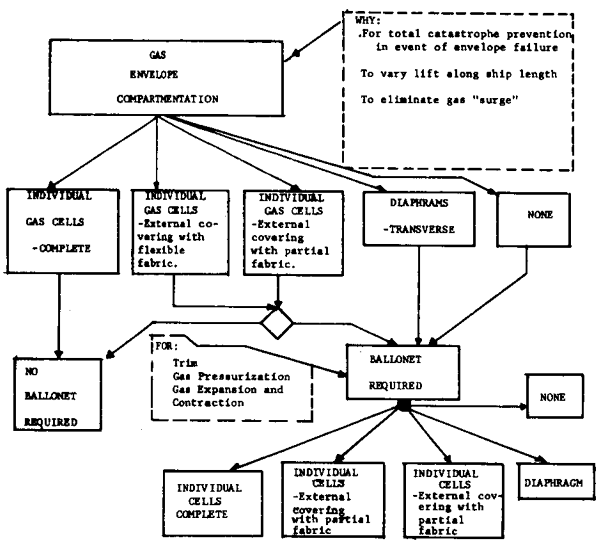


FIGURE 7-2
GAS ENVELOPE COMPARTMENTATION
AND BALLONET METHODS

Individual gas cells can have their vertical lift transfer and longitudinal restraint accomplished by netting, diaphragms or structural shells. The major disadvantage of this system is the requirement of a supplementary outer covering for aerodynamic purposes if netting is used to transfer the vertical lift. Additionally, complete gas cell material, transverse restraining materials and secondary structural members are required which do not add to the overall structural strength. To illustrate the relative magnitudes that can be involved in such a system, the rigid airship Los Angeles's empty weight was 38,075 kilograms (83,940 pounds) (ref. 7-1); the outer covering, netting and wiring weighed 5535 kilograms (12,202 pounds) or 14.5 percent of the empty weight and the gas cells weighed 4082 kilograms (9000 pounds) or 10.7 percent of the empty weight. Structurally, the longitudinals and miscellaneous stiffening accounted for 4926 kilograms (10,860 pounds), or 12.9 percent of the empty weight. The transverse frames, fins, rudders and elevators totaled 8197 kilograms (18,072 pounds), or 21.5 percent of the empty weight. The remaining 15,334 kilograms (33,806 pounds) of the empty weight was in equipment, motors, controls, compartments, quarters, etc. It would obviously be more structurally efficient, and also assist in reducing the main member sizes and weights, if the 25.2 percent of the empty weight devoted to individual gas cell material and vertical and horizontal restraints also contributed to the structural strength.

Based on a typical main bay, approximate comparable figures (ref. 7-2) for the ZRS-4 Akron are shown in Table 7-1.

TABLE 7-1 ZRS-4 AKRON BAY MASS

ITEM	KG	(LBS)	PERCENT
1 bay (empty)	4969	(10,955)	100.0
Outer covering & side panel wires	1041	(2,295)	20.9
Gas Cells	1098	(2,420)	22.1
Longitudinals	1061	(2,340)	21.4
Transverse frames	1769	(3,900)	35.6

Equipment, motors, controls, compartments and quarters, etc. are not included because of the basis used. The completed airship, however, had a mass of 109,931 kilograms (242,356 pounds) of which 9,979 kilograms (22,000 pounds) was in gas cells and 5,125 kilograms (11,300 pounds) was in outer covering, (ref. 7-3).

Again, at least 13.7 percent, not including netting and supplemental framing, of the mass of the entire airship is used to contain and restrain the gas or form the aerodynamic shape without contributing to the overall structural strength.

The structural advantages and efficiencies to a monocoque configuration are therefore obvious, particularly when considering airship missions involving heavy, relatively concentrated loads. The technological advances in materials and structural analysis capabilities also help create the setting for the recommendation that the airship configuration to be used in this study be in the pressure or semi-monocoque area.

7.3 LOAD/LIFT INTERFACE

The reasons for a load/lift interface structure were discussed in Chapter 5. Multi-item cargos will be discharged as single items using the loading grid supported at four points. Single, bulky-item cargos would, at the time of erection, be supported by as few as two points. This represents, longitudinally along the hull, a single concentrated load. Such concentration of one third of the total gross lift presents potentially large static shear and bending moments induced in the hull in the cargo loading area. If the loads are movable, the strengthening of the hull and the resulting weight would be necessary throughout a large range of the hull structure.

To avoid this penalty, the payload resultant must be distributed throughout as much of the longitudinal dimension of the airship as possible. This has been partially accomplished by use of the cable hoist system which divides any load into 12 concentrated loads. It is now appropriate to discuss the load/lift interface structure into which these concentrated loads will be transferred. The structure will in turn distribute these concentrated loads into the hull structure more uniformly.

The type of structure selected for the load/lift interface is the same as that selected previously for the loading grid, the tetrahedral platform grid. Its shape has already been described in Chapter 5 and photographs of the grid are shown in Fig. 5-1. The upper tetrahedral grid in the Phase II vehicle will have a nominal depth of 0.91 meters (3 feet). Its bottom will be located nominally 4.57 meters (15 feet) above the bottom of the ship at the point of maximum diameter. See Fig. 7-3. It will be constructed of 2014-T6 aluminum alloy extruded shapes (ref. 7-4) mechanically connected. The cross sections of the extruded members would be shaped so as to ensure sufficient section modulus as to allow for allowable design stresses of 2.07×10^8 Newtons/m^2 (30,000 pounds/in^2), (ref. 7-5). Under these specifications with total payload ballast capacity and a maximum buoyant pressure of 34.2 centimeters (13.5 inches) of water, a mass of 2.25 kilograms/m^2 (0.462 pounds/ft^2) is indicated for the upper grid structure. The 0.91 meter (3 feet) nominal depth of the grid will result in a plan square module of 1.29 meters (4.25 feet). At every six module dimensions in the longitudinal direction of the loading area the loading grid would be supported by a line support coming from the radial Kevlar cables in the plane of a transverse stiffening ring. The resulting distance between stiffening ring/cable planes in the loading area is thus 7.77 meters (25.5 feet). Eight of these 7.77 meters (25.5 feet) bays would then define the loading area and the longitudinal extent of the upper load/lift grid, 62.2 meters (204.0 feet). The transverse dimension in the upper plane at the maximum diameter of the ship would be in the order of 31.6 meters (103.8 feet) with the outer edges shaped to conform to the outer hull shape.

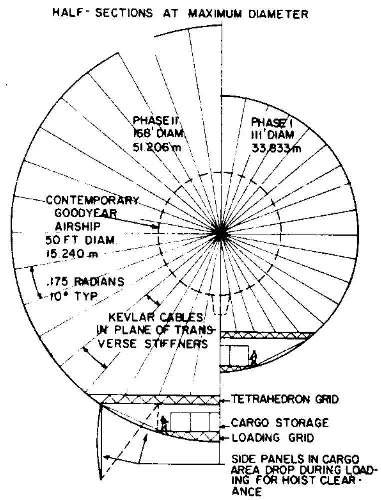


FIGURE 7-3
HALF SECTIONS AT MAXIMUM DIAMETER

The Phase I vehicle upper grid has a nominal depth of 0.61 meters (2 feet) resulting in a 0.863 meters (2.83 feet) plan square module. Six of these module dimensions give a support distance of 4.18 meters (17.0 feet) in the longitudinal dimension and an overall longitudinal loading area dimension of 41.5 meters (136.0 feet). The maximum upper plane transverse dimension is 23.5 meters (77.0 feet). See Fig. 7-4 for a schematic of these dimensions for both Phase I and Phase II.

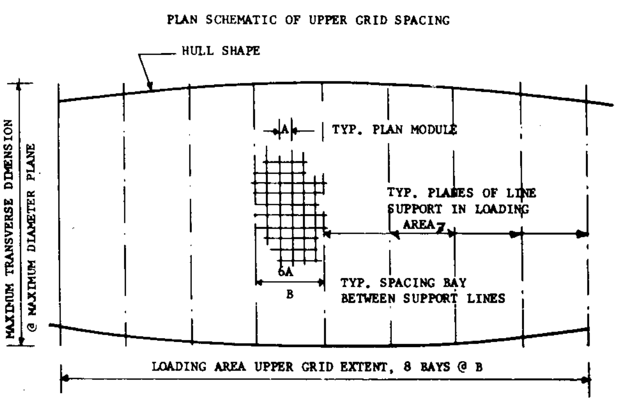


FIGURE 7-4
PLAN SCHEMATIC OF UPPER GRID SPACING

The upper tetrahedral grid is extended beyond the loading area in the same horizontal plane until it ends at its intersection with the upward curving bottom hull shape. Within these two extra-loading-area zones, the grid would no longer be solid but would serve primarily as hull strengthening, support of auxiliary equipment, etc. It is estimated that some 80 percent of its solid plan area in these regions would be eliminated.

The hoist system is fixed in the upper grid, supported within the bottom plane modules. Along the outside edges of the grid, ballast tanks would be integrated into the grid construction. The side plates of the tanks would transfer their load into the tetrahedral members by means of tension. Transverse baffle plates in the banks would also be built in planes defined by tetrahedral members and would serve as transverse stiffening diaphragms for the tanks and also for surge prevention.

The bottom longitudinal members of the grid would provide a support plane for many future modifications of the load/unload system for specific special missions.

7.4 LIFTING GAS MANAGEMENT

7.4.1 SELECTION OF A LIFTING GAS

There were a number of parameters considered when selecting the lifting gas for the Phase I and Phase II vehicles. The first, obviously, was that the gas have a density less than air. Then, by Archimedes Principle, the lift was calculated as

$$LIFT = \{[\rho_{air} - \rho_{gas}]\frac{g}{g_c}\} \cdot V \qquad (7\text{-}1)$$

where

ρ_{air} = density of air

ρ_{gas} = density of gas

g = acceleration of gravity

g_c = dimensional conversion factor

V = volume of gas

The lift forces for 1000m^3 (1000 ft^3) of various gases in air at standard conditions are tabulated in Table 7-2.

Consideration of possible gases, based on the lift ability advantages alone, points to, in order of decreasing preference, hydrogen, helium, steam, methane, ammonia, natural gas, and hot air as possible lift gas selections.

Safety is another factor investigated before a selection was made. Helium, steam, and air are nonflammable. Flammability limits for hydrogen, methane, ammonia, and natural gas in air are also given in Table 7-2.

The flammability limits in air saturated with water vapor for hydrogen at standard temperature and pressure are 4 percent to 75 percent hydrogen by volume, (ref. 7-7, 8). According to (ref. 7-9), the contamination of hydrogen with air is a serious problem, and leaks into a closed area can be particularly hazardous. But because of its low molecular weight and very high diffusion coefficient, hydrogen will diffuse to a nonexplosive mixture in an open area very rapidly (ref. 7-7, 8). Another problem in using hydrogen as a lifting gas is that leak sites are very difficult to locate. For outdoor operations, portable detectors of the combustion meter or thermal conductivity type are used. Also, Rocketdyne (ref. 7-7) has developed a tape that uses the unique hydrogen absorption characteristic of palladium to change the color of a thermochromic paint to detect hydrogen leakage.

For continuous hydrogen leakage monitoring of the atmosphere during filling, launching, landing, and refilling operations, a catalytic combustion detector with multiple remote-sensing heads could be employed. This detector samples by diffusion and convection and was used in the static test firing of the J-2 rocket engine (ref. 7-7). A detector system of this type would automatically warn of leaks by audio or visual signals and could activate safety control circuits as it monitors continuously the accumulation of hydrogen. These are facts which were weighed very carefully in the selection of the lifting gas for the Phase I and Phase II airship designs.

As previously mentioned, helium, steam, and air are completely safe. Nonexplosive mixtures of helium and hydrogen are also possible. Experiments have revealed that a gas mixture of approximately 10 percent hydrogen and 90 percent helium will not explode or burn (ref. 7-10).

Another major factor in choosing a lifting gas was the cost. Quoted 1975 helium prices were \$1695/1000m^3 (\$48/1000 ft^3). The price of hydrogen was, in contrast, only \$230/1000m^3 (\$6.50/1000 ft^3). (Prices were obtained in a telephone conversation with the Chemtron Corporation of Houston in July 1975.) Table 7-2 contains costs per 1000m^3 (1000 ft^3) of the other lighter-than-air gases selected. It should be noted that the \$3.50/1000m^3 (\$0.10/1000 ft^3) price for steam is the cost to heat water at 21° C (70° F) to 100° C (212° F) steam at \$.01 per kilowatt hour; hence this price does not reflect the cost of the energy required to maintain the steam at a temperature above the condensation level. This operating cost was estimated for the Phase II

TABLE 7-2

LIFT GAS CHARACTERISTICS AND COSTS REF. (7-6)

Lift Gas	Lift newton/10^3meter^3	Flammability in Air % by Volume Lower	Upper	Gas Cost \$/10^3meter^3	Specific Heat x10^{-3} joules/kilogram °K
Steam (100°C)	6126	0	0	3.53	1.864
Helium	10367	0	0	1695.10	5.24
Hot Air (100°C)	2670	0	0	60.03	1.022
Hydrogen	11152	4.0	74.2	229.54	14.37
Natural Gas	4241	4.5	14.5	45.91	2.208
Methane	5341	5.0	15.0	70.63	2.229
Ammonia	5027	16.0	27.0	194.23	2.179
Air (STP)	0	0	0	0	1.006

Lift Gas	Lift lb/10^3ft^3	Flammability in Air % by Volume Lower	Upper	Gas Cost \$/10^3 ft^3	Specific Heat Btu/lb m °R
Steam (212°F)	39	0	0	.10	.445
Helium	66	0	0	48.00	1.25
Hot Air (212°F)	17	0	0	1.70	.244
Hydrogen	71	4.0	74.2	6.50	3.43
Natural Gas	27	4.5	14.5	1.30	.527
Methane	34	5.0	15.0	2.00	.532
Ammonia	32	16.0	27.0	5.50	.520
Air (STP)	0	0	0	0	.240

vehicle at cruise conditions as \$737/hour.

Only marginal cost savings would result, however, if a safe mixture of hydrogen and helium were used in lieu of pure helium, and very little additional lift would be gained. To reduce the cost of the lifting gas using a hydrogen mixture, large amounts of hydrogen must be used. To accomplish its use, safely, possible containment schemes of hydrogen in helium were also considered in this selection procedure.

Availability was another parameter studied in this investigation. Hydrogen, steam and air all are readily obtainable. The supply of helium presently exceeds demand; thus the helium extraction facilities of many plants are not operational.

Reference 7-11 predicts that by 1990 the demand of helium will no longer exceed the supply. The future of helium at this point will depend upon the actions that have taken places before this time with regard to

1) the release by the Government of helium from its stockpile,

2) the actual demand for helium,

3) foreign production of helium, and

4) private storage of the excess helium production capacity which exists at the present time.

Eventually, helium may have to be extracted from the atmosphere, and this cost is projected to be between \$105,940 -\$211,880/1000m^3 (\$3000-\$6000/1000 ft^3) (ref. 7-11).

The specific heat at constant pressure is another property of a lifting gas that under certain conditions would be important. For example, the specific heat of a lifting gas would play a part in considering the effects of superheat and also the question of heating the gas to increase lift. In this regard, it should be remembered that the specific heat of air is 1009 joules/kg°k (.241 Btu/lb°F). The specific heat of hydrogen is

14,200 joules/kg°k (3.39 Btu/lb°F) and that of helium is 5229 joules/kg°k (1.248 Btu/lb°F). A mixture of hydrogen and helium would have a specific heat between that of hydrogen and helium. Specific heats for other gases are listed in Table 7-2.

After considering alternative schemes, selecting several lift gases for study, and investigating the characteristics of these gases with regard to the parameters of safety, gas cost, availability, liftability, and operating cost, a decision matrix was used to select the lifting gas. Table 7-3, a lift gas selection matrix, contains the rating factors used in the analysis. The ratings ranged from zero to one, with one representing the highest rating.

Helium, a nonflammable gas, was rated 1.0 for the parameter safety. Hydrogen, as was previously mentioned, has flammability limits between 4 percent and 74 percent hydrogen in air by volume. Thus it was assigned a low number. An important factor regarding safety relates to the cost of insuring airships. A telephone conversation with the company that insures the Goodyear blimps indicated that an airship filled with hydrogen would not be insurable. The risk would simply be too great.

Since hydrogen is the best gas for lift, it was given a 1.0 rating. Helium was rated at .926. This value is the ratio of the lift of helium to the lift of hydrogen. The remaining rating factors were determined in a similar fashion.

The weighting factors used for the parameters were equal. With this weighting system and the rating factors assigned, the matrix shows that helium is the best possible lift gas for the Phase I and Phase II airships.

7.4.2 Ballonet System

The Phase I and Phase II airships will each contain six ballonets having an air volume capacity of approximately 20 percent of the helium displacement volume. The ballonets are constructed to surround a transverse rim frame and are positioned as shown in Fig. 7-5. Each ballonet is fabricated by attaching the ends of two diaphragms. These ends are bonded to the inside skin of the shell. Because of their location, the ballonets create gas cells.

This spaced cell design allows airship flight (at reduced cargo weight) even if the outer shell is damaged and the helium gas from one or two cells is lost. Another advantageous feature is that with the diaphragm distribution pattern, adjustments for trim will be easy to perform. A disadvantage with this design is the increased surface area resulting from the nonspherical shape of the ballonets. This, of course, means more diffusion of helium and air. However, with the use of the materials mentioned in section 7.7.5, helium loss or contamination will be almost negligible.

7.5 HULL STRUCTURE

As a result of the structural configuration evaluation discussed in paragraph 7.2, a pressure monocoque configuration, similar to the ZMC-2 concept was considered.

7.5.1 Pressure Monocoque Structure

In taking a conceptual design approach, in order to decide to proceed further, past data were collected on not only the ZMC-2, but also on proposed designs. Tables 7-4A and 7-4B summarize

TABLE 7-3

LIFT GAS SELECTION MATRIX

PARAMETERS	GASES CONSIDERED						
	HELIUM	STEAM	HOT AIR	HYDROGEN	METHANE	NAT. GAS	AMMONIA
SAFETY	1.00	.90	.95	.01	.04	.04	.03
GAS COST	.005	.95	1.00	.06	.12	.20	.04
AVAILABILITY	.80	.95	1.00	.90	.80	.80	.80
LIFT	.926	.55	.244	1.00	.479	.372	.44
OPERATING COST	1.00	.01	.02	.95	.95	.95	.95
	3.731	3.360	3.214	2.920	2.389	2.362	2.260

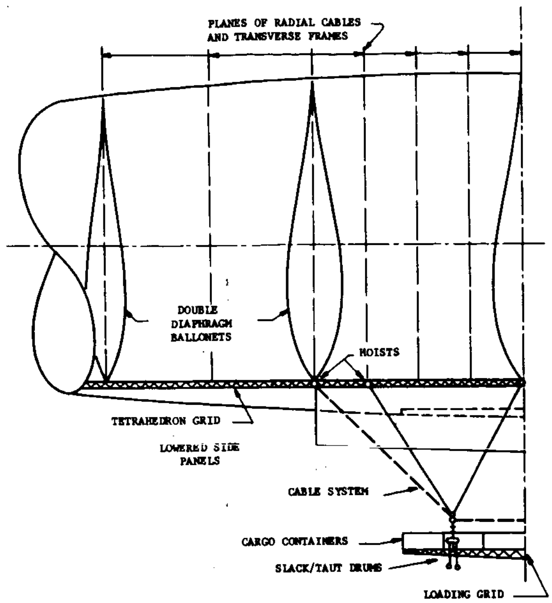


FIGURE 7-5

CROSS-SECTION NEAR LOADING AREA

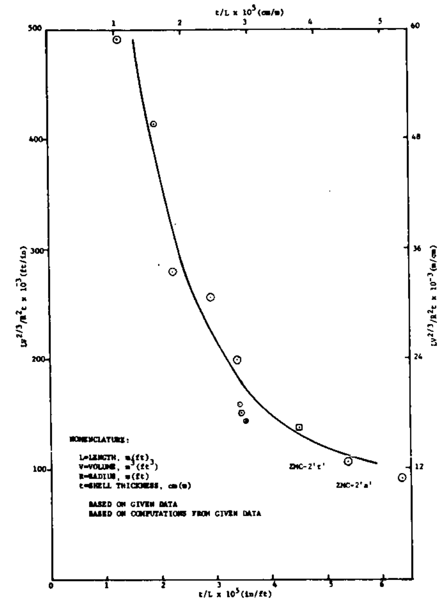


FIGURE 7-6

RELATION OF GEOMETRY TO SHELL THICKNESS FOR PRESSURE MONOCOQUE DESIGNS

the collected data. Since only the ZMC-2 was actually built, the data from many of the proposed designs are incomplete. However, based on the given data, Fig. 7-6 was developed. With this figure, an iterative process can be used to obtain an estimate of the aluminum shell's average thickness given the general values of displacement volume, length and radius of the proposed airship.

In reviewing Fig. 7-6, the reader will note that there are two plotted points for the ZMC-2. The "a" point indicates the values for the actual ship built, whereas the "t" point indicates that which could have been built if the Alcad material had been available. One of the confused items in the literature is the thickness of metal used to construct the AMC-2. It was intended to construct the airship of plain Duraluminum .0232 mm (,008 in.) thick but as a result of exposure tests, which showed serious deterioration, Alclad sheets .2413 mm (.0095 in.) thick were substituted. At this point, it was necessary to scrap the partially completed airship, one fourth of the hull, and to start over again (ref. 7-12). The thicker Alclad sheet was the thinnest that could be rolled at that time and was not a reflection of a previously inadequate shell thickness.

Using Fig. 7-6, the Phase I airship of 99,109 m^3 (3.5×10^6 $ft.^3$) displacement the shell thickness would be about 254 mm (.01 in.), on the average. This value, as seen from the figure, would be very approximate. The past designs were based only on an aerodynamic moment of

$$M = .02438q\ LV^{2/3}\ (N\text{-}m.) \qquad 7\text{-}2a$$

in metric units, or

$$M = .018q\ LV^{2/3}\ (ft\text{-}lbs) \qquad 7\text{-}2b$$

in English units,

where V is the displacement volume, m^3 (ft^3)

L is the overall length, m (ft)

q is the aerodynamic pressure, N/m^2 (lb/ft^2).

The estimated unit mass for the shell only would then be about .71 kilogram/m^2 (.145 pounds/ft^2). With an estimated surface area of 13,965 m^2 (150,316 ft^2), the total shell mass would be about 9888 kilograms (21,800 pounds). It has been traditional in pressure monocoque designs to assume the shell provides no strength or stability with respect to compressive stresses; therefore, longerons must be added to resist the compressive forces when the envelope is not pressurized or if insufficient pressure occurs during flight maneuvers. From a review of the past design data in Table 7-4, a very approximate value of shell mass, equivalent to about 32 percent of the empty mass, can be developed. On this basis, an estimated empty mass would be 30,901 kilograms (68,125 pounds) for an airship of Phase I size. It should be noted,

TABLE 7-4A

SUMMARY OF METALCLAD AIRSHIP DESIGNS
(METRIC UNITS)

Identity		ZMC-2	FRITSCHE	FRITSCHE MC50	FRITSCHE MC-72	FRITSCHE MC-72.6	UPSON MC-70-6	BURGESS	UPSON*	UPSON*	UPSON*	ZMC-12*	MC-38-4001011
Year		1929	1929	1931	1931	1931	1935	1937	1937	1937	1937	1939	1975
Reference		ref. 7-2,12,13	ref. 7-13	ref. 7-12	ref. 7-12	ref. 7-12	ref. 7-2	ref. 7-14				ref. 7-15	ref. 7-16
Displacement Volume	m^3	7152.8	-	141,584.2	205,297.1	205,580.3	198,217.9	209,544.7	-	-		36,528.7	130,257.5
Gas Volume	m^3	5720.0	71,924.8	138,752.5	200,483.2	200,483.2	-	-	28,316.8	42,475.3	56,633.7	33,697.0	107,604.0
Length	m	45.543	143.866	-	-	218.846	239.268	188.366	91.440	106.680	121.92	101.194	177.775
Diameter	m	16.054	32.004	-	-	43.190	41.453	47.092	27.127	30.480	32.918	26.822	38.100
Max Design Velocity	m/acc	27.715	44.714	36.210	37.551	33.528	37.490	38.557	35.326	37.094	38.892	-	46.939
Mass (Empty)	kg	4134.5	40,505.8	78,925.1	112,944.5	117,026.8	-	41,095.5	-	-	-	21,999.2	63,328.3
Mass of Shell	kg	1283.7	12,666.6	-	-	37,466.7**	-	13,789.2	4,535.9	6803.9	9525.4	7,030.7**	-
Mass of Hull Framing	kg	814.2	-	-	-	-	-	13,789.2	-	-	-	-	-
Gross Lift	N	$5.45x10^4$	$6.71x10^5$	$1.29x10^6$	$1.84x10^6$	-	-	$1.89x10^6$	$2.76x10^5$	$4.14x10^5$	$5.52x10^5$	$3.28x10^5$	$1.08x10^6$
Useful Lift	N	$1.39x10^4$	$2.74x10^5$	$5.12x10^5$	$7.47x10^5$	$7.07x10^5$	-	-	$1.07x10^5$	$1.78x10^5$	$2.40x10^5$	$1.13x10^5$	-
Aerodynamic Design Moment	Newton-m	-	-	-	-	-	$1.23x10^7$	$9.7x10^6$	-	-	-	-	$1.18x10^7$
Static Design Moment	Newton-m	-	-	-	-	-	$8.1x10^5$	-	-	-	-	-	-
Shell: t min.	mm	0.241	-	-	-	-	0.330	-	-	-	-	-	0.241
t max.	mm	0.241	-	-	-	-	0.432	-	-	-	-	-	0.508
t avg.	mm	0.241	0.406	-	-	0.533**	0.381	0.203	0.269	0.307	0.351	0.378**	0.330
Shell Surface Area	m	1805.66	11,148.36	-	-	25,083.8^{2}**	-	21,925.12	5,760.00	7,525.15	9290.30	6,642.57	16,453.13
Ballonet Volume	%	25						15					
Ballonet Volume	m^3	1432.8						1699.0					
Ballonet Mass	kg	353.8						2268.0					
Ballonet Area	ft^2							5,574.18					
Horsepower	kilo watt	$.33x10^3$	$2.98x10^3$	$2.46x10^3$	$3.34x10^3$	$3.73x10^3$		$2.31x10^3$	$.97x10^3$	$1.45x10^3$	$1.94x10^3$	$1.61x10^3$	$3.46x10^3$

*Personal papers by Ralph H. Upson, marked RHU/JA 6/14/37.
**Estimated values

TABLE 7-4B

SUMMARY OF METALCLAD AIRSHIP DESIGNS
(ENGLISH UNITS)

Identity		ZMC-2	FRITSCHE	FRITSCHE MC-50	FRITSCHE MC-72	FRITSCHE MC-72.6	UPSON MC-70-6	BURGESS	UPSON	UPSON*	UPSON*	ZMC-12*	MC-38-4001011
Year		1929	1929	1931	1931	1931	1935	1937	1937	1937	1937	1939	1975
Ref.		ref. 7-2,12,13	ref. 7-13	ref. 7-12	ref. 7-12	ref. 7-12	ref. 7-2	ref. 7-14				ref. 7-15	ref. 7-16
Displacement Volume,	$ft.^3$	$252.6x10^3$		$5.0x10^6$	$7.25x10^6$	$7.26x10^6$	$7.x10^6$	$7.4x10^6$				$1.29x10^6$	$4.6x10^6$
Gas Volume,	$ft.^3$	$202x10^3$	$2.54x10^6$	$4.9x10^6$	$7.08x10^6$	$7.08x10^6$			$1.x10^6$	$1.5x10^6$	$2.x10^6$	$1.19x10^6$	$3.8x10^6$
Length	ft.	149.42	472.			718.0	785.	618	300.	350.	400.	332.	583.25
Diameter	ft.	52.67	105.			141.7	136.	154.5	89.	100.	108.	88.	125.
Max. Design Velocity,	fps	90.93	146.7	118.8	123.2	110.0	123.	126.5	115.9	121.7	127.6		154.
Mass Empty,	lbs	9115.	89,300	174,000	249,000	258000		90,600+				48,500	139,615
Mass of Shell,	lbs.	2830	27,925			82,600**		30,400	10,000.	15,000	21000	15,500*	
Mass of Hull Framing,	lbs.	1795						30,400					
Gross Lift	lbs.	12,242	150,800	289,000	417,000			425,175	62000	93000	124000	73,800	243,710
Useful Lift	lbs.	3127	61,500	115,000	168,000	159,000			24000	40000	54000	25,300	
Aerodynamic Design Moment,	ft. lbs.	- -					$9.1x10^6$	$7.15x10^6$					$8.71x10^6$
Static Design Moment,	ft. lbs.	-					$.6x10^6$						
Shell: t min.	in.	.0095					.013						.0095
t max.	in.	.0095					.017						.020
t avg.	in.	.0095	.016			.0210**	.015	.008	.0106	.0121	.0138	.0149*	.013
Shell Surface Area,	$ft.^2$	19,436	120,000			270,000**		236,000	62,000.	81,000.	100,000.	71,500	177,100
Ballonet Volume,	%	25.						15					
Ballonet Volume,	$ft.^3$	50,600						60,000					
Ballonet Mass,	lbs.	780						5,000.					
Ballonet Area,	$ft.^2$							60,000.					
Horsepower		440	4000	3300	4,480	5000		3,100	1300	1950	2600	2160	4634

*Personal papers by Ralph H. Upson, marked RHU/JA 6/14/37.
**Estimated values

however, that this mass would not be completely correct for the Phase I design because:

1. No loading platform, hoisting system or load distribution systems are included in the past loads upon which this is based,
2. A ballonet system is included in the past designs but no gas envelope compartmentation was made, and
3. An additional static moment needs to be considered in determining the shell thickness, particularly in the area of the loading platform.

However, this does give a value to compare to the next conceptual design approach taken; that of using a sandwich panel for the shell.

7.5.2 SEMI-MONOCOQUE RIGID STRUCTURE

In general, this approach is based on the design of a shell that will be sufficiently stiff to withstand the aerodynamic and static forces without the use of longerons and/or internal pressure. Transverse frames with radial spokes, thereby having the appearance of a bicycle wheel, will be used to distribute the buoyant gas lift, and to support the airship's tetrahedron plate. This plate, in turn, is supporting the load-lift hoisting system, etc.

A review of the past literature shows that the general moment equation was

$$M = 1.354\ CqLV^{2/3} \quad (N\text{-}m) \qquad 7\text{-}3a$$

in metric units, or

$$M = CqLV^{2/3} \quad (ft\text{-}lbs) \qquad 7\text{-}3b$$

in English units,

where

V is the displacement volume, m^3 ($ft.^3$)
L is the overall length, meters (feet)
q is the aerodynamic pressure of 1224.6 N/m^2 (25.576 lb/ft^2)

for standard air at sea level, and C is a shape coefficient. Burgess (ref. 7-14) gives C values of .008 for the L-30 type and the Shenandoah derivative, .010 for the Los Angeles and .020 for the Akron and Macon; with the values including a factor of safety of 3. Klinkoff (ref. 7-17) uses a C of .02 and Burgess (ref. 7-18) in a later paper uses a general C of .0175. On this basis a value of C of .018 was assumed for this study; the resulting aerodynamic moments are shown in Table 7-5.

According to Brewer (ref. 7-19) of the Goodyear Aerospace Corporation, the critical bending moments based on a reanalysis of historical test data give the new formulation

$$M = 1.354\ CBM\frac{U}{V}\ q\ V \quad (N\text{-}m) \qquad 7\text{-}4a$$

in metric units, or

$$M = CBM\frac{U}{V}\ q\ V \quad (ft\text{-}lbs) \qquad 7\text{-}4b$$

in English units,

where U is the design gust velocity, m/sec (fps)

v is the airship velocity, m/sec (fps) and

CBM is a bending moment coefficient, given as

$$CBM = 0.11 + \frac{3D}{80L} \qquad 7\text{-}5$$

where D is the diameter, m (ft), and L is the length, m (ft.).

Based on the Goodyear moment formulations, with a design gust velocity of 10.67 meters/second (35 feet/second), geometrical data from the design team aerodynamics group, and a maximum velocity of 44.71 meters/second (146.67 feet/second), aerodynamic moments were obtained which were about 7.5 percent greater than those calculated by Eq. 7-3. These higher moments were used in determining the structure and sandwich skin thickness.

Since this was a conceptual design performed within a very limited time, static moments were estimated on the general basis that the center of buoyancy and the center of the net payload coincided. Distributing the net payload over a length equal to the loading platform plus 3.048 meters (10 feet) on each end, due to location of hoisting mechanisms, and equating the lift and downward forces gave the maximum static moment estimates as shown in Table 7-5.

The shell's sandwich panel was designed with a factor of safety of 1.5 based on the total maximum moment over the loading area and on the maximum aerodynamic moment outside of this area. This very conservative approach was taken because of its simplicity and because of time limitations.

The design approach for determining the sandwich panel component thicknesses basically followed the approach taken by Brewer (ref. 7-19).

Initially, Alclad faces with a foam core were assumed. It should be noted, however, that the use of the stainless steel face sheets should be seriously considered in a detailed design situation. The strength/density relations of

TABLE 7-5

SUMMARY OF MOMENT VALUES FOR THE DESIGN TEAM AIRSHIP CONFIGURATIONS

	PHASE I		PHASE II	
	N-m x 10^{-6}	ft-lbs x 10^{-6}	N-m x 10^{-6}	ft-16 x 10^{-6}
Maximum Aerodynamic Moment:				
m/C = 0.018	7.98	5.89	27.46	20.27
Per Ref. 7-17	8.60	6.35	29.41	21.79
Estimated Maximum Static Moment	1.72	1.27	6.01	4.44
Total Maximum Moment	10.32	7.62	35.53	26.23
Airship's Hull Design Moments				
Over Loading Area	15.51	11.45	53.29	39.34
Beyond Loading Area	12.92	9.54	44.28	32.69

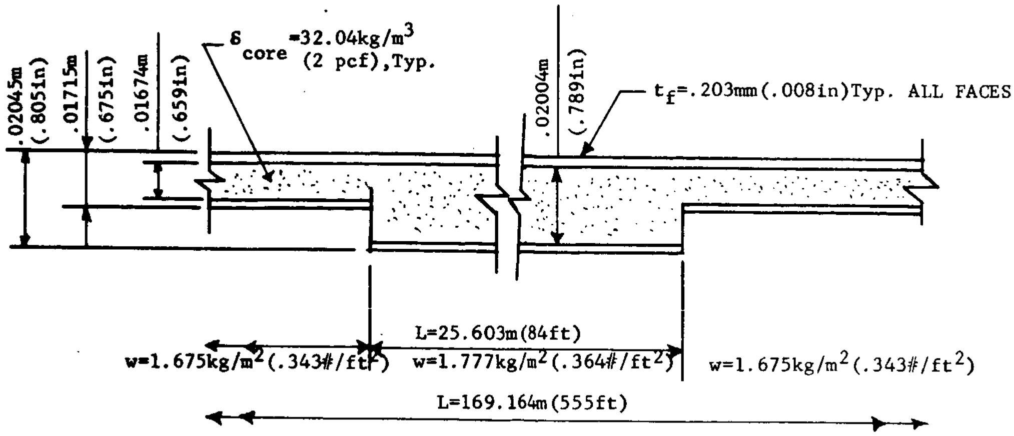
stainless steel to aluminum are such (ref. 7-20) that if very thin stainless steel sheets, perhaps in the order of .127 n/m (.005 in.), can be obtained that with a small weight penalty, stainless steel would prove to be feasible. The advantages of corrosion resistance, weldability and higher modulus of elasticity could more than compensate for the weight penalty. Additionally, since a foam core exists to separate the faces, the use of stainless steel for the exterior face and aluminum for the interior face may be very attractive for minimizing the penalties and maximizing the advantages. Further investigations along these lines certainly seems justified. However, using Alclad faces and considering optimum conditions, where the weight of the core would equal the combined weight of the faces, the sandwich panel cross sections shown in Fig. 7-7 and Fig. 7-8 were determined. It should be noted that the Phase I sandwich cross section outside of the loading area is not at optimum. The consideration of 203 mm (.008 in.) minimum Alclad face thickness, from an availability viewpoint, involved a minor additional weight penalty of about .107 kilograms/m2 (.022 pounds/ft2) which would require face sheets about .152 mm (.006 in.) thick.

The transverse frames, in addition to performing the load transfer functions previously discussed also provide a convenient physical mechanism for joining the transverse edges of the sandwich panels as will be discussed in Paragraph 7.7. Two typical transverse frames were considered for each airship; one at the center of the loading platform and one outside of the loading platform area.

The transverse frames within the loading area were based on supporting the tetrahedral plate uniformly loaded with the net payload; those outside of the loading area were based on transfer of the lifting gas load. Spacing of the transverse frames was critical only in the sense of providing rather closely spaced supports to the tetrahedral plate in order to reduce the moments induced into this plate in supporting the net payload; and in providing a reasonable division of the airships' envelope for compartmentation by vertical diaphrams, as discussed in Paragraph 7.4.2. The transverse frame rims were considered to be of aluminum. For this design the connecting cables, spaced at every 10 degrees, were considered to be stainless steel wires. However, in a detailed design, the use of Kevlar strands, coated to prevent abrasion due to contact with the vertical diaphrams, should be seriously considered. The transverse frames developed under the above conditions are shown in Fig. 7-9 and Fig. 7-10 for Phases I and II respectively. The mass of the frames for Phase I is 1284 kilograms (2830 pounds) and 7430 kilograms (16380 pounds) for Phase II.

The addition of the above transverse frame masses to the previous sandwich shell masses gives a total structural hull mass of 31,767 kilograms (70,035 pounds) for Phase I and 99,838 kilograms (220,105 pounds) for Phase II.

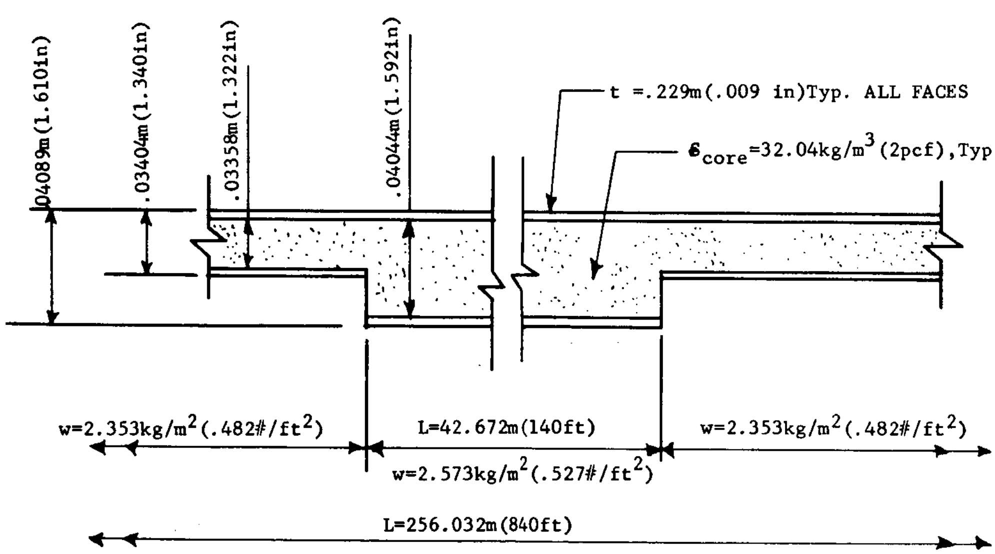
Since the above structural hull was designed without taking advantage of the internal pressure to reduce the compressive stresses, and since the design is



TOTAL SANDWICH PANEL HULL MASS, INCLUDING ADHESIVES=30,484kg(67,205 lbs)

FIGURE 7-7

PHASE I - HULL SANDWICH
PANEL CROSS SECTION

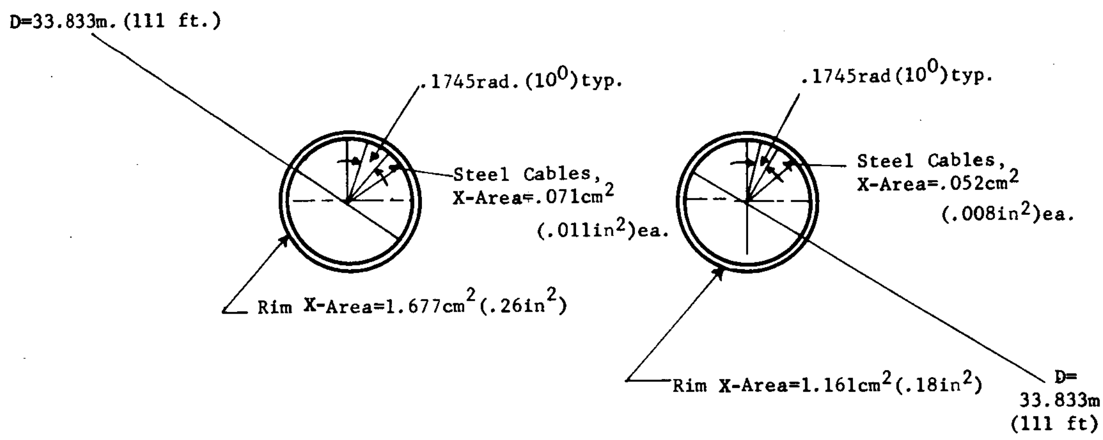


TOTAL SANDWICH PANEL HULL MASS, INCLUDING ADHESIVES=92,409kg(203,727 lbs)

FIGURE 7-8

PHASE II - HULL SANDWICH
PANEL CROSS SECTION

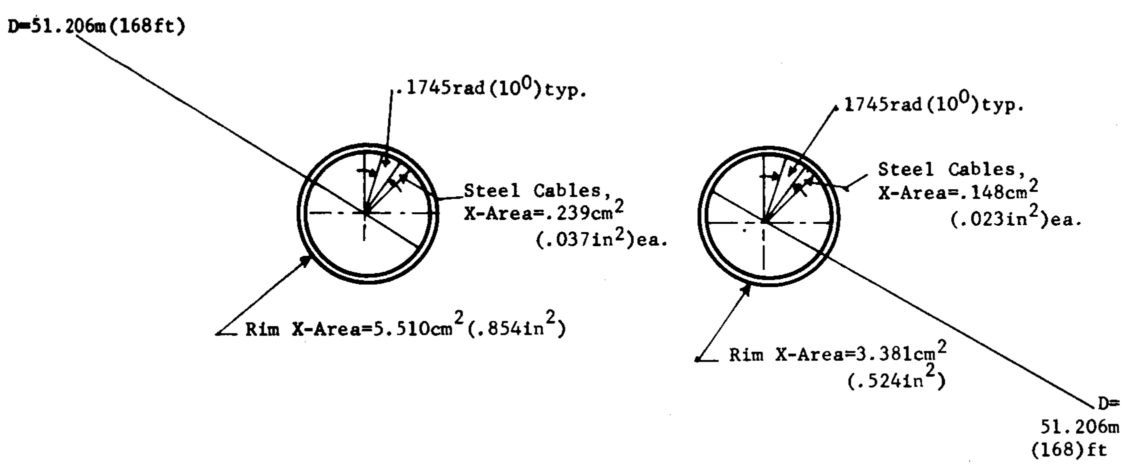
based on the compressive loading of a sandwich shell cylinder, lifting gas pressurization can add to the reserve structural strength. Preliminary indications are that at about .14 meters (5.5 in.) of water pressure all of the compressive stresses would be eliminated in both the Phase I and the Phase II airships. With Alclad faces on the sandwich panels, having a tensile yield of 3.45 x 10^8 Newtons/m^2 (50,000 pounds/$in.^2$), and with a factor of safety on yielding of 1.67, the maximum



TYPICAL @ LOADING AREA
7 FRAMES REQ'D @ 88kg(194 lbs)
EACH @ 4.572m(15ft) SPACING

TYPICAL OUTSIDE LOADING AREA
15 FRAMES REQ'D @ 44.5kg(98 lbs)
EACH @ 9.571m(31.4ft) SPACING

FIGURE 7-9
PHASE I TRANSVERSE FRAMES



TYPICAL @ LOADING AREA
8 FRAMES REQ'D @ 462.2kg(1019 lbs)
EACH @ 7.315m(24ft) SPACING

TYPICAL OUTSIDE LOADING AREA
18 FRAMES REQ'D @ 207.3kg(457 lbs)
EACH @ 11.328m(37.33ft) SPACING

FIGURE 7-10
PHASE II TRANSVERSE FRAMES

allowable tensile stress would be 2.07 x 10^8 Newtons/m^2 (30,000 pounds/in.^{2}). Based on transverse shell stresses, the Phase I airship could be safely pressurized to a total of 0.44 meters (12.15 in.) of water pressure. Since these include a factor of safety, in an emergency condition the pressure could be increased considerably without fear of catastrophic failure. Under normal flight conditions, if the internal pressure is kept to about 0.14 meters (5.5 in.) of water pressure, the Phase I airship could experience an instantaneous change in altitude of about 305 meters (1000 feet), the Phase II of about 152 meters (500 feet), and still remain within the allowable material stresses. This capability seriously recommends this type of airship hull construction. A review of the literature on past airship failures appears to indicate that the airships could have survived the

TABLE 7-6

AIRSHIP MASS AND
EFFICIENCY RATIO SUMMARIES

	PHASE I		PHASE II	
	kg.	lbs.	kg.	lbs.
MASS (EMPTY)				
Airship Hull w/Transverse Frames	31,910	70,350	99,838	220,105
Diaphram & Ballonet System	577	1,272	1,757	3,874
Loading Platform	1,197	2,640	5,606	12,360
Tetrahedron Ship Plate	1,719	3,789	5,568	12,275
Hoisting System	2,821	6,220	10,072	22,205
Tail Assembly	3,009	6,634	9,234	20,358
Flight Deck, Crew Quarters, etc.	558	1,230	771	1,700
Engines, Props., & Mounts	1,741	3,838	2,946	6,495
Thrusters	605	1,334	907	2,000
Fuel Tanks	69	153	276	608
Pumps & Actuators	810	1,785	2,756	6,075
Instruments & Elec. Power System	1,691	3,728	3,315	7,309
Total Mass (EMPTY)	46,707	102,973	143,047	315,364
USEFUL LIFT				
Fuel	3,200	7,056	15,175	33,456
Crew, Food, etc.	558	1,230	771	1,700
Specified Net Payload	22,680	50,000	90,718	200,000
Unspecified Additional Payload	4,872	10,741	19,722	43,480
Total Useful Lift	31,310	69,027	126,386	278,636
Total Operational Mass	78,017	172,000	269,433	594,000
Gross Lift	78,017	172,000	269,433	594,000
Unit Empty Mass	.471kg/m^3	.0294pcf	.421kg/m^3	.0263pcf
Useful Lift/Gross Lift (%)	40.1	40.1	46.9	46.9

weather conditions encountered if they could have successfully resisted, by aerodynamic power or airship structural strength, rapid altitude changes during weather front encounters. The relatively heavy structural frameworks used in the rigid airships R100 and R101, built by Great Britain, were not successful and ended in catastrophic failure. Since these airships were of the standard rigid configuration, pressurization of the hull could not be achieved to relieve or assist in resisting the induced compressive forces.

A mass summary, including all estimated airship components is shown in Table 7-6. The resulting unit empty masses and useful lift/gross lift ratios indicate this to be a highly efficient approach to take for final detailed calculations.

7.6 WEIGHT AND BALANCE STATEMENT

The weight of each airship component had to be accounted for to make sure that the total airship weight did not exceed the lift. In addition, the location of each component had to be determined to insure that the airship would be balanced.

With the location and weight of each component, the center of gravity of the airship could be determined. For the Phase I airship, the center of gravity was located 84.58 meters (277.5 feet) from the bow and 5.94 meters (19.5 feet) below the centerline. In the Phase II airship, the distance from the bow was 128.0 meters (420 feet) and 11.2 meters (36.8 feet) below the centerline. Tables 7-7 and 7-8 contain a summary of the weight, location, and moments for various airship components for Phase I and Phase II, respectively.

TABLE 7-7A

PHASE 1 WEIGHT AND BALANCE SUMMARY
(METRIC UNITS)

UNIT/COMPONENT	WEIGHT	HORIZ. ARM	MOMENT	VERT. ARM	MOMENT
	NEWTONS	METERS	NEWTON-METERS	METERS	NEWTON-METERS
AIRSHIP HULL-Sandwich Skin, Adhesive, Cables & Transverse Frames	311,531	84.6	26,349,931	0	0
HELIUM	130,239	84.6	11,015,915	0	0
DIAPHRAGM AND BALLONET SYSTEM	5,658	84.6	478,577	0	0
LOADING PLATFORM	11,743	79.2	930,633	-24.1	- 194,359
SHIP PLATE (TETRAHEDRON)	16,854	79.2	1,335,670	-12.5	- 210,625
HOISTING SYSTEM	27,668	79.2	2,192,629	-12.5	- 345.761
ENGINES	6,806	112.8	767,529	0	0
ENGINE MOUNTS	5,783	112.8	652,284	0	0
FUEL	31,387	84.6	2,654,746	-12.8	- 401,799
FUEL TANKS	681	84.6	57,564	-12.8	- 8,712
PUMPS AND ACTUATORS	7,940	158.5	1,258,470	- 2.5	- 20,086
TAIL ASSEMBLY	29,510	162.3	4,790,468	0	0
THRUSTORS, ETC.	5,934	84.6	501,903	0	0
FLIGHT DECK, CREW QUARTERS, ETC.	10,943	15.2	166.766	- 9.1	- 100,059
INSTRUMENTS ELECTRICAL POWER SYSTEM	16,583	42.4	702,574	-12.2	- 202,180
CONTROLS AND CABLES	4,484	126.9	568,942	- 2.5	- 11,343
NET PAYLOAD	222,411	79.2	17,625,633	-14.8	-3,220,068
ADDITIONAL PAYLOAD	49,180	79.2	3,897,380	-12.5	- 614,587
TOTALS	895,334	-	75,947,615	-	-5,329,579
LIFT	895,334	84.6	-75,729,174	0	0

TABLE 7-7B

PHASE I WEIGHT AND BALANCE SUMMARY
(ENGLISH UNITS)

UNIT/COMPONENT	WEIGHT (LB)	HORIZ. ARM (FT)	MOMENT (FT-LB)	VERT. ARM (FT)	MOMENT (FT-LB)
AIRSHIP HULL-Sandwich Skin, Adhesive, Cables & Transverse Frames	70,035	277.5	19,434,712	0	0
HELIUM (2.77x10^6 ft^3)	29,279	277.5	8,124,922	0	0
DIAPHRAGM & BALLONET SYSTEM	1,272	277.5	352,930	0	0
LOADING PLATFORM	2,640	260	686,400	-54.3	-143,352
SHIP PLATE (TETRAHEDRON)	3,789	260	985,140	-41.0	-155,349
HOISTING SYSTEM	6,220	260	1,617,200	-41.0	-255,020
ENGINE MOUNTS	1,300	370	481,100	0	0
ENGINES (3)	1,530	370	566,100	0	0
FUEL	7,056	277.5	1,958,040	-42.0	-296,352
FUEL TANKS	153	277.5	42,457	-42.0	- 6,426
PUMPS & ACTUATORS	1,785	520.0	928,200	- 8.3	- 14,815
TAIL ASSEMBLY	6,634	532.6	3,533,268	0	0
THRUSTORS, ETC.	1,334	277.5	370,185	0	0
FLIGHT DECK, CREW QUARTERS, ETC.	2,460	50.0	123,000	-30.0	- 73,800
INSTRUMENTS	3,728	739	518,192	-40.0	-149,120
ELECTRIC POWER SYSTEM CONTROLS & CABLES	1,008	416.3	419,630	- 8.3	- 8,366
NET PAYLOAD	50,000	260.	13,000,000	-47.5	-2,375,000
ADDITIONAL PAYLOAD	11,056	260.	2,874,560	-41.0	-453,296
LIFT	201,279	277.5	-55,854,922	0	0
TOTALS	201,279	-	56,016,086	-	-3,930,896

TABLE 7-8A

PHASE II WEIGHT AND BALANCE SUMMARY
(METRIC UNITS)

UNIT/COMPONENT	WEIGHT	HORIZ. ARM	MOMENT	VERT. ARM	MOMENT
	NEWTONS	METERS	NEWTON-METERS	METERS	NEWTON-NETERS
AIRSHIP HULL-Sandwich Skin, Adhesive, Cables & Transverse Frames	979,076	128	125,337,370	0	0
HELIUM	451,370	128	57,782,575	0	0
DIAPHRAGM AND BALLONET SYSTEM	17,232	128	2,206,024	0	0
LOADING PLATFORM	54,980	120	6,602,616	-25.0	- 1,374,149
SHIP PLATE (TETRAHEDRON)	54,602	120	6,557,210	-20.6	- 1,123,381
HOISTING SYSTEM	98,773	120	11,861,739	-20.6	- 2,032,150
ENGINES	11,788	154	1,810,830	-10.2	- 120,722
ENGINE MOUNTS	9,631	154	1,479,414	-10.2	- 98,628
FUEL	148,820	128	19,051,303	-25.3	- 3,764,900
FUEL TANKS	2,705	128	346,222	-25.3	- 68,420
PUMPS AND ACTUATORS	27,023	220	5,955,057	- 3.8	- 102,957
TAIL ASSEMBLY	90,557	224	20,287,280	0	0
THRUSTORS, ETC.	8,896	128	1,138,887	0	0
FLIGHT DECK, CREW QUARTERS, ETC.	15,124	11	161,342	- 9.1	- 138,293
INSTRUMENTS ELECTRICAL POWER SYSTEM	32,512	122	3,963,869	-25.0	- 812,593
CONTROLS AND CABLES	7,473	64	478,333	- 3.8	- 28,472
NET PAYLOAD	889,644	120	106,838,454	-22.7	-20,201,687
ADDITIONAL PAYLOAD	193,409	120	23,226,680	-25.0	- 4,833,979
TOTALS	3,093,614	-	396,032,036	-	-34,700,331
LIFT	3,093,614	128	-396,032,036	0	0

TABLE 7-8B

PHASE II WEIGHT AND BALANCE SUMMARY
(ENGLISH UNITS)

UNIT/COMPONENT	WEIGHT	HORIZ. ARM	MOMENT	VERT. ARM	MOMENT
	(LB)	(FT)	(LB-FT)	(FT)	(LB-FT)
AIRSHIP HULL-Sandwich Skin, Adhesive, Cables & Transverse Frames	220,105	420	92,444,100	0	0
HELIUM (9.6 x 10^6 ft^3)	101,472	420	42,618,240	0	0
DIAPHRAGM & BALLONET SYSTEM	3,874	420	1,627,080	0	0
LOADING PLATFORM	12,360	394	4,869,840	-87.0	- 1,013,520
SHIP PLATE (TETRAHEDRON)	12,275	394	4,836,350	-67.5	- 828,563
HOISTING SYSTEM	22,205	394	8,748,770	-67.5	- 1,498,837
ENGINE MOUNTS	2,165	504	1,091,160	-33.6	- 72,744
ENGINES	2,650	504	1,335,600	-33.6	- 89,040
FUEL	33,456	420	14,051,520	-83.0	- 2,776,848
FUEL TANKS	608	420	255,360	-83.0	- 50,464
PUMPS AND ACTUATORS	6,075	723	4,392,225	-12.5	- 75,937
TAIL ASSEMBLY	20,358	735	14,963,130	0	0
THRUSTORS, ETC.	2,000	420	840,000	0	0
FLIGHT DECK, CREW QUARTERS, ETC.	3,400	35	119,000	-30	- 102,000
INSTRUMENTS	7,309	400	2,923,600	-82.0	- 599,338
ELECTRIC POWER SYSTEM CONTROLS AND CABLES	1,680	210	352,800	-12.5	- 21,000
NET PAYLOAD	200,000	394	78,800,000	-74.5	-14,900,000
ADDITIONAL PAYLOAD	43,480	394	17,131,120	-82.0	- 3,565,360
LIFT	695,472	420	-292,098,240	0	0
TOTALS	695,472	-	291,399,895	-	-25,593,651

7.7 MATERIALS

7.7.1 INTRODUCTION

In the past decade, marked improvements have been made in the materials technology associated with airships. For example, a cotton structural fabric with neoprene film between the structural fabric and the bias ply fabric, with a strength of 1.75 x 10^4 Newtons/meter (100 pounds/inch) can be replaced with materials containing high tenacity. Dacron yielding a strength of 2.63 x 10^4 Newtons/meter (150 pounds/inch). The current state of the art, with Dacron, Mylar, and Tedlar offers strengths of 3.94 x 10^4 Newtons/meter (275 pounds/inch). With Kevlon replacing Dacron, even lower weights and higher strengths are achievable (ref. 7-21).

The parameters considered in the airship material selection process were strength, weight, cost, modulus, creep, fatigue, durability, permeability, and availability. Other factors considered were stability under ultraviolet light, moisture absorptivity, flammability, and wear resistance.

In general, composite materials, which are a mixture of two or more materials that differ in form and/or material composition, were used. Composites usually have properties better than those of the individual components and offer these advantages at lower weight.

Two types of composites were employed. A sandwich composite was used for the airship shell and a laminate composite, which consists of layers of single constituents bonded as superimposed layers, was used for the ballonet-diaphram material.

In a laminar composite, as in a sandwich composite, each layer performs a distinct and separate function. The layers are selected to provide improved overall properties: strength, protection against corrosion, wearability, permeability, and durability, for example.

7.7.2 HULL, RUDDERS, AND ELEVATORS

Reference 7-20 points out that the thin-walled shell is the basic structural element of the modern aircraft, spacecraft, missile and launch vehicle. When the thin-walled shell is stiffened by a number of reinforcing elements, a "semi-monocoque" results.

A sandwich construction, according to ref. 7-20, is a special laminate consisting of a thick core of weak, lightweight material sandwiched between two layers of strong material. This type of construction offers

1) a high strength/weight ratio;
2) resistance to vibration;
3) resistance to heat transfer;
4) ease of fabrication, and
5) high speed production, ref. 7-22.

Sandwich structures are highly resistant to fatigue failure because the bonded surface is continuous. It also has a large value of moment of inertia, which means a lower stress for the same bending moment.

The sandwich structure can be compared to the I-beam. The facings serve the purpose of the flanges, the foam core acts as the web, supporting the facings and allowing them to act as a unit. The foam core, like the web, carries the shear stresses and also supports the facings, preventing buckling or crimping and allowing uniform stress-compression or tension. The adhesive transmits and carries shear loads between the facings and the core.

The sandwich composite is more efficient than an I-beam. The combination of high strength facings and a low density core provides a much higher section modulus per unit density than any other known construction method (ref. 7-22).

The airship's operating environment determined the selection of the face sheet and core materials. Facing materials could include 2024 and 7075 Alclad aluminum and Kevlar-epoxy composites. Titanium, stainless steel and composites containing graphite or glass fiber are other alternatives. For the Phase I and II ships, 2024 Alclad aluminum was selected. The aluminum facing material would be 0.203 mm (.008 in.) thick in the Phase I shell and 0.229 mm (.009 in.) thick in the Phase II airship shell. The Alclading, of course, increases corrosion resistance.

The material for the core would be urethane foam having a density of 32 kilograms/m^3 (2 pounds/ft^3). Reference 7-22 gives the following properties for this density urethane foam: compressive strength 241,316 Newtons/m^2 (35 pounds/in.^{2}), tensile strength 303,369 Newtons/m^2 (44 pounds/in.^{2}) shear strength 193,053 Newtons/m^2 (28 pounds/in.^{2}), and thermal conductivity at 23.9°C (75°F), 0.016 Joules/sec·m·°K (0.0092 to 0.014 $\frac{Btu}{hr ft °F}$).

As previously mentioned, materials other than 2024 aluminum could be used as a facing material. Glass reinforced plastics offer the advantage that they can be built up to any desired thickness and they offer excellent insulation.

Kevlar 49/epoxy would also be an excellent facing material. It has a fatigue strength of 9.3×10^8 Newtons/m^2 (1.35×10^3 pounds/in.^{2}) at 10^7 cycles strength at 10^3 cycles of 1.17×10^9 Newtons/m^2 (1.7×10^5 pounds/in.^{2}). On the other hand, 2024 aluminum shows a fatigue strength of 2.758×10^8 Newtons/m^2 (40×10^3 pounds/in.^{2}) and a strength of 4.413×10^8 Newtons/m^2 (64×10^3 pounds/in.^{2}) at 10^3 cycles (ref. 7-23). Reference 7-23 has also shown that a sandwich panel using Kevlar 49 as the shell fabric reinforcing material gave good impact resistance, significantly better than graphite composites.

7.7.3 Transverse Rim Frames

The rim frames serve two purposes: (1) to stiffen the shell, and (2) to aid in fastening the panels of the shell together. A cross-sectional view of the rim frame is shown in Fig. 7-11.

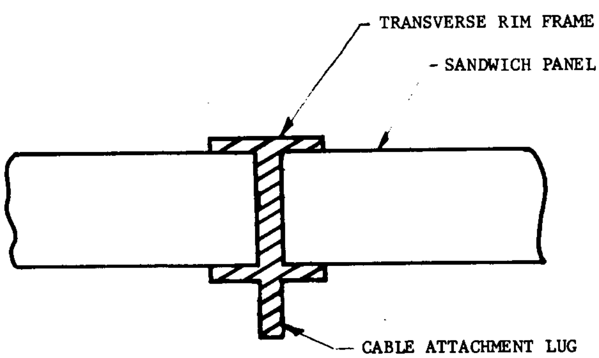


FIGURE 7-11

CROSS SECTION OF TRANSVERSE RIM FRAME

The rim frame would be extruded 2024 aluminum. This material has a tensile strength of 4.688×10^8 Newtons/m^2 (6.8×10^4 pounds/in.^{2}), a yield strength of 3.0336×10^8 N/m^2 (4.4×10^4 pounds/in.^{2}) and an elongation at 23.88°C (75°F) of 22 percent. An alternate material, which could also be extruded, would be 7075 aluminum with a tensile strength of 5.654×10^8 Newtons/m^2 (8.2×10^4 pounds/in.^{2}), a yield strength of 4.964×10^8 Newtons/m^2 (7.2×10^4 pounds/in.^{2}), and an elongation of 11 percent.

7.7.4 Cables

The cables attach to the transverse rim frame and hold the frame in a circular shape. In both airship designs, 36 cables are used on each frame.

Because of its high strength/weight ratio, high modulus, favorable resistance to corrosion, non-conductivity and excellent fatigue and creep properties, Kevlar was selected for the cable material. Both Kevlar 29 and Kevlar 49 yarns can be braided, stranded or twisted on standard textile machinery. Strength data on typical rope construction are given in Table VI of ref. 7-24. This table shows that at one-fifth the weight, the strength of Kevlar rope is equal to or better than steel.

Regarding cost, the selling price of Kevlar is comparable at equal breaking strength with nylon or polyester rope.

7.7.5 Ballonet

As previously mentioned in this report, the ballonets serve to create gas cells. Both the Phase I ship and the Phase II ship would each have seven cells.

Possible ballonet materials would include laminate composites of (1) Kevlar, Mylar and metallized Tedlar and (2) Dacron, nylon and Tedlar. The advantage of the Kevlar fabric over the Dacron fabric is its higher strength/weight ratio. Both fabrics, when woven in a triaxial weave, offer higher strength and lower permeability than previously-used materials (ref. 7-25).

The materials contained in the laminate composite ballonets for the Phase I and II airships are sketched in Fig. 7-12. Table 7-9 lists properties for the film and adhesive components of this laminate.

The Tedlar film provides, on both sides of the diaphragm material, a tough, durable, abrasive resistant surface and also ultraviolet protection for the inner constituents. Tedlar has proven itself with respect to mechanical properties. It filters out 98 percent or more of the incident UV radiation. Tests have revealed (ref. 7-21) that the Tedlar polyvinylidene fluoride film (laminated) has about twice the abrasion resistance of elastomeric coatings. The Tedlar film facing the helium gas, is metallized with aluminum. This reduces its permeability by a factor of 10.

The Kevlar fabric was selected because of Kevlar's high strength 2.068×10^9 Newtons/m^2 (3×10^6 pounds/in.^{2}) and high modulus 6.2×10^{10}-13.1×10^{10} Newtons/m^2 (9×10^6-19×10^6 pounds/in^2).

The strength/weight ratio of Kevlar exceeds that of Dacron by 100 percent (ref. 7-26). Kevlar also has far superior creep properties (ref. 7-24). The G. T. Sheldahl Company (ref. 7-26) has produced a laminate of Kevlar having a strength approximately equal to that of a high strength aluminum sheet having the same weight per unit area. Even higher strength/weight ratios are predicted with geometric optimization of the Kevlar fiber weave.

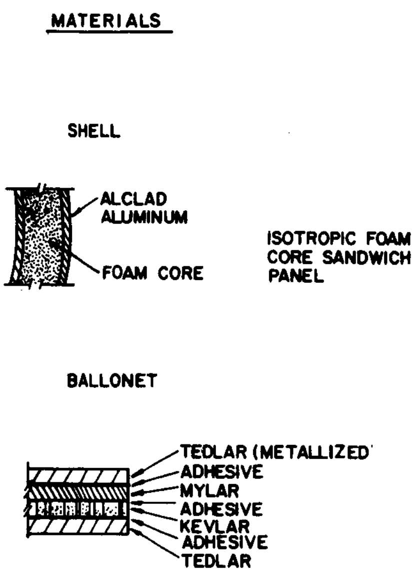


FIGURE 7-12

AIRSHIP SHELL AND BALLONET MATERIALS

The Mylar film was selected to insure a low helium permeability of the laminate. Mylar has a tensile strength of 1.7236×10^8 Newtons/m^2 (2.5×10^4 pounds/in.^{2}) and does not become brittle with age. It has excellent resistance to most chemicals and withstands temperatures ranging from -70°C (-94°F) to 150°C (302°F) (ref. 7-27). Moreover, it is available in thicknesses ranging from 3.63×10^{-3} mm (0.00015 in.) to 0.356 mm (0.014 in.) and widths from 0.00635 meters to 2.84 - 3.05 meters (1/4 in. to 112-120 in.) depending on gage and type. It can be bonded to itself or to practically any other material (ref. 7-27).

A polyester adhesive, specifically an aliphatic polyester resin would be used for bonding the above-mentioned films and fabric.

7.8 SUMMARY AND RECOMMENDATION

Concerns with the load/lift interface have been adequately summarized in Section 5.3. Suffice it to say here only that the upper tetrahedral grid and the cable hoist system serve to distribute the concentrated cargo reactions so that the hull structure is not subjected to destructive static shears and moments.

The drive of history and logic in the design of the structure of airships is toward incorporating the stiffening effect of internal pressure into the hull design and to use appropriate materials for that pressure rigid hull. This study has elected to minimize the internal stiffening in favor

TABLE 7-9

PROPERTIES OF FILM AND ADHESIVE COMPONENTS (REF. 7-19)

COMPONENT	DESCRIPTION	TENSILE STRENGTH @20°C (70°F)	DENSITY
Tedlar	Dupont polyvinylidene fluoride film, type 30, adherable both sides, "L" gloss, titanium dioxide pigment	55×10^6 N/m^2 (8000 psi)	1770 kg/m^3 (.064 lbs/in^3)
Mylar	Dupont type S, polyester film, 6.35×10^3 mm (0.25 mil) thick	138×10^6 N/m^2 (20,000 psi)	1390 kg/m^3 (.05 lbs/in^3)
Adhesive	Aliphatic polyester resin cured with di-isocyanate for hydrolytic stability	10×10^6 N/m^2 (1500 psi)	1240 kg/m^3 (.045 lbs/in^3)

of a pressure-stiffened, isotropic foam-filled, aluminum sandwich. The motive has been the obvious weight savings for a given hull strength.

A compromise between the rigid's gas cells and the nonrigid's ballonets has been devised for the lifting gas management system. At intervals along the hull at the planes of transverse stiffening double diaphragm, ballonets have been placed, providing the possibility of heated control both of lifting gas and ballonet air, trim management, compartmentation, surge resistance and added safety.

The placement of those weights contributing to the location of the center of gravity of the airship have been made. The center of gravity has been forced to a point just behind the center of buoyancy (c.b.). To keep the locations of the c.g. and c.b. in flight, trim is managed by exchange of water ballast in tanks incorporated into the upper tetrahedral grid. The effect of the payload in trim is negated during the loading operation ensuring that the c.g. of the cargo and loading grid is a constant.

The design of the hull structure and other systems components has been made using state of the art materials with the exception of some uses of Kevlar. The development of Kevlar cables, for instance, will require only an increase in the production capabilities of the producer. In the case of the hoists, present hoist weights must be reduced by design using lighter conventional materials. Future development should incorporate the use of any composite materials in the structure, ballonet or hoist system where their weight improvement implies their use despite higher cost.

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CHAPTER 8

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8.1 INTRODUCTION

Airships of the past have been characterized as slow responding and slow anticipatory vehicles; therefore, the control and stability problems were less severe than those encountered on heavier than air (HTA) vehicles. Large forces and moments, however, can act on the hull and fins of an airship due to atmospheric disturbances and gusting winds, thus complicating the problem. Although there is much information on HTA craft stability and control, this general area has been almost neglected in LTA design.

While stability is not a precise term, in the case of an airship in motion it can be thought of as a measure of the tendency to maintain a trimmed condition of flight and, if upset from this condition, the tendency to return to it. From an engineering viewpoint, stability can be classified as "positive" if the tendency is to return to the original heading; "neutral" if the tendency is to remain in the condition to which it has been perturbed; and "negative" if, following a perturbation, it continues to diverge.

In the design of any vehicle, the need for stability must be compromised with the need for controllability. That is, an airship with ultimate static stability would have such a positive tendency to remain in its trimmed flight condition that, like a freight train, it would be almost impossible to turn. On the other hand, the ultimately controllable airship would be so responsive to any changes, whether manually applied or arising from natural perturbations, that it would hold the desired heading for only the briefest time. The overly stable vehicle would excel on long cross-country flights at cruise conditions, but would pose serious problems during maneuvering. A highly controllable craft would require constant flight corrections with resultant oscillations about the desired heading and attitude.

Historically, most airships have been basically unstable craft, but for a combination of reasons, this is not necessarily a disadvantage. While modern airships will retain a basic simplicity, modern electronics and instrumentation will make them safe, reliable, sophisticated vehicles of the space age.

There are several basic vehicle and flight conditions which affect airship stability and any discussion must begin with their clarification. These are weight, center of gravity (c.g.), center of buoyancy (c.b.), center of pressure (c.p.), center of rotation (c.r.), power settings, cruise speed, flight mode (ascent, cruise, hover, descent, etc.), and vehicle configuration (flaps, fins, etc.). In view of the fact that any of these can vary the degree of stability, the details of each must be specified before stability and control data can have real significance.

8.2 INSTRUMENTATION AND CONTROL SYSTEM

The instrumentation and control system on an airship will be very much like the systems used on modern airliners. They will carry all the basic instruments required by federal regulations and those additional instruments which will improve the efficiency of the crew. A number of instruments special to airships will be required which are not found on heavier than air aircraft. Due to the complex interaction of the various controls, a computer-based control system will be used. The control signals will be transmitted electronically.

8.2.1 INSTRUMENTATION AND AVIONICS

8.2.1.1 FAA REQUIRED EQUIPMENT

All aircraft flying in the United States are subject to the Federal Aviation Regulations (Part 91, General Operating and Flight Rules). These regulations specify a number of instruments, communication, and safety equipment which must be carried by the various classifications of aircraft. At the present time, there is no special classification for airships. Airships will therefore be required to carry the same equipment as other aircraft flying under the same conditions.

All aircraft must carry an air traffic control radar beacon transponder which transmits an identifying code and the barometric altitude of the aircraft whenever it is interrogated by the air traffic control radar. When flying under visual flight rules, all aircraft must carry the following equipment: an airspeed indicator, an altimeter, a magnetic direction finder, a complete set of engine performance instruments for each engine, and a fuel gauge which indicates the quantity of fuel remaining in each tank. For night flying the addition of position lights, anticollision lights, and a landing light is required.

Any aircraft flying under instrument flight rules must also carry a two-way radio and whatever radio navigation equipment is appropriate to the ground facilities to be used. A gyroscopic rate-of-turn indicator, a slip-skid indicator, a sensitive altimeter adjustable for barometric pressure, a clock with a sweep hand, a gyroscopic bank and pitch indicator, a gyroscopic direction indicator, and a generator of sufficient capacity to supply all the electrical equipment are also required. Some variances may be granted in the altitude indicating instruments due to the different characteristics of airships as compared to the conventional airplanes.

To aid search and rescue teams in finding downed aircraft, an emergency locater transmitter is required on all aircraft, which will automatically start transmitting a homing signal in case of a crash or emergency landing in a remote location. Additional safety equipment including a flight recorder and cockpit voice recorder, is required on common carrier and passenger aircraft.

8.2.1.2. NONREQUIRED FLIGHT INSTRUMENTS

In order to improve the service and reliability of the airship and ease the work of the crew, some additional standard aircraft equipment will be included on the airship. Automatic direction finders, distance measuring equipment, an area navigation system, a rate-of-climb indicator, and a drift meter will aid in the navigation of the airship. A radio altimeter will give more accurate and reliable height above ground data, which will be necessary for low altitude flight and hovering. A weather radar system will allow the airship crew to spot severe weather systems and fly around them or pick the best path through a weather front.

8.2.1.3 SPECIALIZED AIRSHIP INSTRUMENTS

A number of instruments peculiar to airships will be required. The proper pressure must be maintained in the gas cells and ballonets in order to keep the airship trimmed properly and to pressurize the hull to the proper prestress level. This will require pressure indicators for each of the gas cells and ballonets. There will be a large number of strain gauges placed throughout the airship to measure strains in all the critical structural members. This will allow the pilot and autopilot to avoid maneuvers which might overstress the hull or other structural members of the airship. A visible display of the outputs of these strain gages will warn the pilot if forces due to wind gusts or turbulent weather are exceeding the desired limits.

The lift of the airship depends on the temperature of the lift gas in the gas cells, and the air in the ballonets relative to the ambient air outside the airship. Temperature sensors will be necessary to measure these relative temperatures and help monitor the lifting capability of the airship as conditions change. The lift of the airship can also be controlled by dumping or shifting a disposable ballast. Indicators will be necessary to inform the pilot of the remaining quantity of this ballast in each ballast storage compartment. Some indication of the amount and location of all nondisposable ballast will also be required.

The extreme size of the airships makes it difficult for the pilot to observe directly the full ship relative to the surroundings when landing or hovering. A closed circuit television system will aid the pilot in observing position and clearances during these operations. This will be of particular importance when loading or unloading a single large item which must be picked up or set down at a particular spot. The loading supervisor will also make use of this system to monitor his operations.

8.2.2 DIGITAL COMPUTER CONTROL SYSTEM

The primary control system will be centered around a real time digital flight control computer as shown in Fig. 8-1. All pilot control signals are fed into the computer along with the signals from the flight instruments and structural sensors. The computer then generates signals to drive all the control actuators and feedback signals to the artificial feel units on the pilot controls. The actuators in turn control the movement of the aerodynamic surfaces, the operation of the thrustors, the engines, and the gas management system. In translating the forces exerted by the pilot on the controls into changes in the movements of the airship, the computer will select the most efficient combinations of aerodynamic control, thrustors control, and ballast or ballonet trim control for the particular flight conditions at that instant.

The pilot may select one of several possible operating modes for the control system. The normal flight mode will have the characteristics of a straight manual fly-by-wire control system with the pilot directly controlling the airships altitude, attitude, and velocity. In the autopilot mode the computer will have complete control of the airship and will maintain the course, speed, and altitude settings as set by the pilot. In rough weather, the autopilot may be switched to maintain altitude and course heading. The manual hover mode will allow the pilot to indicate changes in horizontal position rather than attitude with his control stick and control altitude with the thrust of the side engines, which will be rotated to a vertical position. The automatic hover mode will hold a fixed altitude while the pilot controls the position in the horizontal plane and varies the attitude of the airship with his control manipulations.

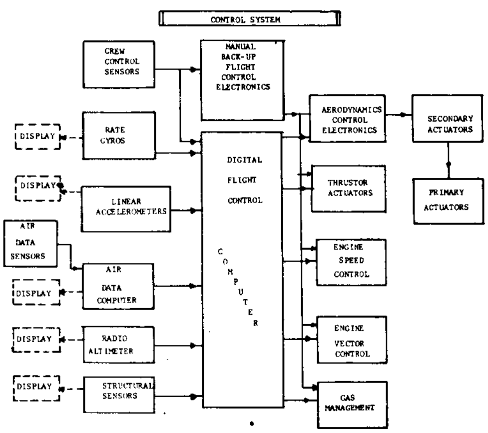

FIGURE 8-1

REAL-TIME DIGITAL
FLIGHT CONTROL COMPUTER

8.2.2.1 NORMAL FLIGHT MODE

When the control-system mode selector switch is in the normal flight position, the rudder pedals and stick will act to control the altitude of the airship as they do on conventional aircraft. The computer will generate control signals calling for forces on the aerodynamic surfaces which are proportional to the forces applied by the pilot. It will also generate feedback signals to the artificial feel units on the controls so that they respond in a proportional manner.

When the control system is in the normal flight mode, the side engies will be positioned for straight forward thrust. When the system is switched to normal flight mode from the hover mode, the side engines will automatically start to rotate from vertical to horizontal at a rate determined by a vector rate control.

8.2.2.2 AUTOPILOT MODE

The autopilot mode of the control system will give the computer complete control of the airship flight. The computer will generate the control signals to the aerodynamic surfaces, the engines, the gas management system, the ballast system, and the thrusters (if necessary) required to maintain the airship at the altitude, course, and speed as set by the pilot. It will automatically adjust the trim and balance to provide the most efficient flight. If the pilot changes any of the course, altitude, or speed settings, the computer will provide a smooth transition from the old flight path to the new flight path.

In rough air conditions, the pilot can switch from a hold-course mode to a hold-altitude flight mode in order to minimize excessive maneuvering of the airship as it is moved around by the winds. In this case, the pilot must closely watch the situation and make the necessary changes if the airship gets too far off course. There will be an automatic alarm warning the pilot if the radio altimeter detects an altitude below a preset minimum.

8.2.2.3 MANUAL HOVER MODE

When the manual hover mode is selected, the computer will convert the rudder pedal and stick forces into thrustor commands. The side engines will be used in a vertical direction in this mode with the throttle controlling their thrust. The pitch of the airship may be selected by a control setting. The computer will then adjust the balance and trim of the airship to maintain that pitch with a minimum of difference in the fore and aft vertical thrust.

When first switching to a hover mode from a flight mode the side engines will rotate from horizontal to vertical at a rate determined by the engine vector control setting.

8.2.2.4 AUTOMATIC HOVER MODE

The computer will attempt to maintain a constant height above the ground as read by the radio altimeter when operating in the auto-hover mode. The thrust of the side engines will be used for the primary control with the thrustors providing secondary or fine control of the vertical height. All other operations in this mode will be the same as in the manual-hover mode.

In automatic hover mode, the control inputs may come from either the pilot's station or the loading supervisor's station. The computer will also aid the loading supervisor in the operation and coordination of the hoist system during load and unload operations.

8.2.3 Backup Systems

All signals to and from the computer are carried over a redundant set of signal cables. There will be duplicate cables running down each side of the airship. Even if one side of the hull sustains severe damage, the cables on the other side will still provide complete control.

The critical flight instruments and communication systems will all have duplicate units. The electrical power for the airship can be supplied by generators on each of the main engines and from an auxiliary power unit. A set of batteries capable of starting any engine or the auxiliary power unit will provide additional backup for the electrical power system. As with the control cables the power distribution system will be duplicated down each side of the airship.

The computer will be highly reliable and easy to repair, but in the event that a failure occurs during flight, a complete set of backup electronic sensors and control drivers will provide manual mode backup for the computer control system.

8.3 NORMAL FLIGHT MODE

8.3.1 Flight Controls

Three types of control systems were considered:

1) Manual control by means of cables as was used in all previous airships;

2) Control of hydraulic actuators by means of cables as is presently used on several current commercial transport aircraft;

3) Control of hydraulic actuators by means of electrical signals, commonly referred to as fly-by-wire.

The first system was ruled out because of the extremely large aerodynamic forces that the pilot would be required to overcome, frictional forces associated with the pulleys, and cable stretch. The second system was ruled out because of cable stretch. frictional forces, and weight. The third system does not exhibit the problems of the other two and allows for a force feel system to be installed which can be designed to provide any desired force or "feel" to the pilot. Also, since the signal is electrical, the wires require no special routing and a separate set may be installed to provide a backup system with minimum weight penalty. This was the system chosen for use in both the Phase I and Phase II airships.

The primary flight controls for inflight maneuvering of the airship are rudders for directional control and elevators for longitudinal control. The rudders and elevators are radius nose surfaces attached to the aft portion of the fixed vertical and horizontal fins, and powered by hydraulic actuators located within the fins. Maximum streamwise deflections of $\delta r=(\pm 30^{\circ})$ for the rudder and $\delta e=(\pm 40^{\circ})$ for the elevator are available. The control surfaces have been split, because of the high hinge moments resulting from the large surface areas, so there are two on each fin. The split was made to give equal effectiveness from each surface. A surface position indicator installed on the cockpit instrument panel provides visual indication of control surface positions.

8.3.2 Hydraulic System

Four hydraulic systems provide the hydraulic power requirements for the airship with safety and reliability. Each of the primary control surfaces is powered from two independent, parallel systems by means of dual tandem actuators. Any single hydraulic channel is fully capable of performing the control function, thus insuring full control capability in the event of component or system failure. Fig. 8-2 is a schematic diagram of the hydraulic system for the Phase II airship. The Phase I system would be as shown in Fig. 8-2 if engines 2 and 4 were deleted. The engines are numbered consecutively beginning with the left front engine and going around the airship from bow to stern ending with the right front engine. The systems are completely independent and have no fluid interaction. The primary operating pressure source for the nos. 2 and 3 systems are engine driven pumps installed on the stern engine. Each pump normally supplies pressure at 2.067×10^6 Newtons/m^2 (3000 pounds/in.^{2}) to its respective system. The pressure source for systems 1 and 4 are electric pumps deriving their power from generators operating off the side-mounted engines. This was done to minimize the length of the hydraulic lines and thus the associated leakage and maintenance problems. Two power transfer units (PTU), which are essentially reversible hydraulic motor-driven pumps, are installed to enable pressurization of systems 2 and 3 from 1 and 4, respectively, and vice versa. The PTU's mechanically transmit power from one system to another without intersystem fluid transfer. Surface deflections can be commanded by either the pilot or autopilot with the command signal being transmitted by means of an electrical signal from the cockpit to the hydraulic system located in the stern of the airship.

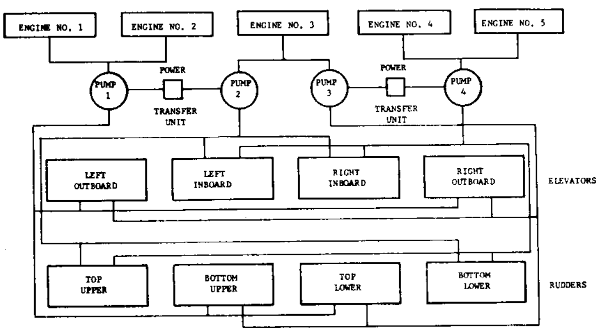

FIGURE 8-2

HYDRAULIC SYSTEM FOR THE PHASE II AIRSHIP

8.3.3 Trim Control

In the normal flight mode, trim can be accomplished by use of the elevators. Deflection of the control surfaces causes an increase in drag of the airship. In order to elminiate or decrease this trim drag, other types of trim capability have to be provided. Three types of trimming capability other than control surfaces are: ballonets, internal fluid transfer, and disposable ballast.

8.3.3.1 BALLONET TRIM

By adjusting the amount of air in the various ballonets, the trim of the airship may be altered without using the elevators. Fig. 8-3 shows that for the Phase II airship this would amount to a maximum moment of 1.56×10^6 Newton-meters (1.15×10^6 pound-feet). This moment is equivalent to about about 1.5° of elevator at a cruise of 26.8 m/s (60 miles/hour) or about 5° of elevator at 13.4 meter/sec (30 miles/hour). The Phase I airship would show similar values for reduction of elevator deflection by using ballonet trim.

8.3.3.2 INTERNAL FLUID TRANSFER

Trim in the airship may also be altered by the movement of fluid from forward to aft containers or vice versa. This change in position of fluid will give a moment which will reduce or even eliminate the elevator deflection required for trim. The fluid may be water ballast and/or fuel. The fuel tanks which supply the engines will be interconnected to provide transfer of fuel among the various tanks, thus allowing for the use of this fuel for trim management. Water ballast tanks are located in both the loading platform and the upper tetrahedron grid with interconnects such that water may be transferred from either level or within each system to assist with trim.

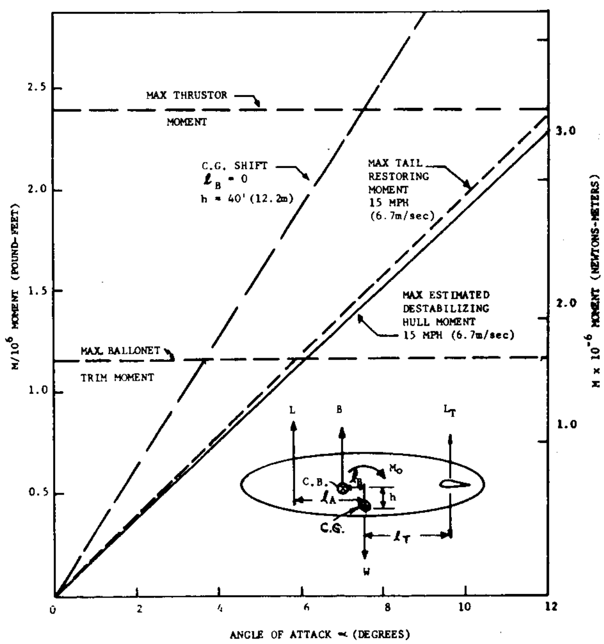

FIGURE 8-3

STABILITY MOMENTS

8.3.3.3 DISPOSABLE BALLAST

A third way of providing trim capability is by the use of disposable ballast. This could be achieved by use of disposable fluid such as water or compressed air or solids such as dirt, sand, gravel, etc. In addition to providing trim, it would also lighten the airship, thus reducing the amount of heaviness. This would allow the airship to fly at a reduced angle of attack which in turn would reduce the induced aerodynamic drag.

8.4 VERTICAL TAKEOFF AND LANDING

Both Phase I and Phase II airships are to be operated as VTOL aircraft. Since water recovery systems are not to be used, it will be necessary to take off "heavy" in the amount of at least one half the weight of fuel that will be planned to be expended during the mission. This would make the ship "light" in the amount of one half of the expended fuel at the end of the mission (ref. 8-1).

Vertical takeoff and landing is accomplished by rotating the side-mounted turboprop engines to a near vertical position. The vertical thrust from these engines will offset differences between gross weight and lift of the airship. The angle of the vectored engines will be determined by the thrust required to hold the ship against the wind during these operations.

8.5 HOVERING MODE

Hovering, or station-keeping ability, is one of the most important aspects of the airship operations. To accomplish many of the more profitable missions, the ability to remain in a stable position a short distance above the ground while loading or unloading cargo is necessary. Time required to transfer cargo to and from the airship must be minimized.

Hovering will be accomplished by supporting the weight of the airship and cargo by a combination of the buoyancy of the airship and thrust derived from the engine propeller slipstreams directed in vertical or near vertical positions. The fine or vernier control of position will be accomplished by the use of thrustors. Thrustors are high energy air jets commanded by the control computer system and the pilot. Holding against winds and supporting overloads will be done with the power of the main engines. Swivelling the main side-mounted engines through (90%), in conjunction with reversible props, will allow the thrust to be directed along desired directions to provide upward or downward forces.

The direction and power of the engines will provide the primary or course control of the airship. These engines will be of the turboshaft type driving large 7.62 meter (25 foot) diameter rotors. As discussed in Chapter 6, the engines have a normal rating of 932 kilowatts (1250 shp) and a weight of 240 kilograms (530 pounds). The three-bladed rotors are stiff in plane and gimballed. The blades are a high-twist design, with wide chord, suitable for both lifting and flight modes.

The thrustors are used for fine control of position and maneuvering and are of the compressed air jet type. Operation is electrical and a relatively fast response time is provided to mate with the slower main engine response. This should dampen small wind gust perturbations.

The airship will be brought into a load or unload position with its nose into the wind, using the tail engine to maintain zero ground speed against the prevailing head wind. The side engines will be rotated to a near vertical position and used to control the height of the airship.

The pilot would lower the airship to the desired working altitude and then switch to the automatic height control computer mode. Some control in the horizontal plane will be possible, but with wind shifts this will be more difficult. The only remaining operation is then to lower the cargo using the hoist system mounted in the cargo hold.

The vertical thrust will offset differences between gross weight and gross lift of the airship. The angle of the vectored engines will be determined by the thrust required to hold the ship against the wind with the small thrustors providing fast acting fine control for gust loads.

8.6 STABILITY

8.6.1 INTRODUCTION AND NOMENCLATURE

Most early stability investigations on airships were concerned with the "static" stability and, in particular, with the stability of two-dimensional craft since these were easier to treat theoretically. Theoretical treatments on dynamic stability have again been largely two-dimensional, without as yet any notable success. Data of wind tunnel model tests are scarce. For these reasons the treatment of stability and control here must be somewhat elementary. It is hoped, however, that the renewed interests in LTA technology will enable this to be rectified in the course of refined research on the subject.

Nomenclature

X,Y,Z	Airship body axes
$X_1Y_1Z_1$	Inertial axes
V	wind velocity
U	trim velocity of center of rotation (c.r.) along X axis
B	buoyancy force
L	hull lift force
D	drag force
T_L	tail thrust or propeller thrust
m	total of airship structural, gas and apparent mass
My	pitching moment
ρ	air density
α	angle of attack
Θ	pitch angle
β	angle of sideslip
Δ	perturbation of a parameter from the trim condition
q	pitch rate about Y-axis
r	Yaw rate about Z-axis
p	roll rate about X-axis
Y	airship lateral position with respect to initial position along Y-axis
h	distance of C.R. below centerline or airship
ℓ	total length of airship
ℓ_i	distance between C.R. and nose
ℓ_A	distance between center of buoyancy (c.b.) and center of pressure (c.p.)
ℓ_T	distance between c.b. and tail
W_{str}	weight of structure
S	aerodynamic reference area
$\bar{c}$	aerodynamic longitudinal reference length
Iyy	moment of inertia (pitching)
Izz	moment of inertia (yawing)
Ixx	moment of inertia (rolling)
Ixz	product of inertia
C_L	$\frac{L}{\frac{1}{2}\rho V^2 S}$ lift coefficient
C_D	$\frac{D}{\frac{1}{2}\rho V^2 S}$ drag coefficient
C_m	$\frac{M_y}{\frac{1}{2}\rho V^2 S}$ pitching moment coeff. about C.R.
C_n	$\frac{M_z}{\frac{1}{2}\rho V^2 S\bar{b}}$ yawing moment coeff, about C.R.
C_Y	$\frac{F_s}{\frac{1}{2}\rho V^2 S}$ side force coefficient
C_{m_q}	rotary damping coefficient due to pitching
C_{n_r}	rotary damping coefficient due to yawing
C_{ℓ_p}	rotary damping coefficient due to rolling

8.6.2 Static Stability

During steady flight conditions, airship stability in the state of equilibrium is governed by the aerostatic and aerodynamic effects in both longitudinal flight and curvilinear flight. These can be considered separately. In particular, the pitch mode stability in longitudinal flight is of primary concern.

8.6.2.1 PITCH MODE

The force elements which contribute to aerostatic and aerodynamic moments with respect to the center of buoyancy (c.b.) are shown in the schematic of Fig. 8-4. Summing the moments of all forces relative to c.b. gives the moment equation of pitch equilibrium.

$$M_o + (L\ell_A - Wh)\sin\alpha - L_T\ell_T\cos\alpha = 0 \quad (8\text{-}1)$$

where Mo is the zero-lift pitching moment, which may be equated to zero in most cases.

The contribution of the hull lifting moment to the stability of the airship is nearly always destabilizing, and the destabilizing effect is quite large, as one can see from Fig. 8-5 and the sample solid line plot of Fig. 8-3.

The theory accounting for the effects of the tail surfaces on the airship stability is rather complex. In the case of longitudinal stability the frictional lift and drag contributions are usually neglected. Using Munk's equation (ref. 8-2), with a correction factor (K_2 - K_1) which depends on the fineness ratio, one can express the variation of the pitching moment with respect to the angle of attack as function of volume and dynamic pressure, q, on the tail surfaces. Thus,

$$\frac{dM_T}{d\alpha} = \frac{\text{Volume}}{28.7} (K_2 - K_1)\, q \qquad (8-2)$$

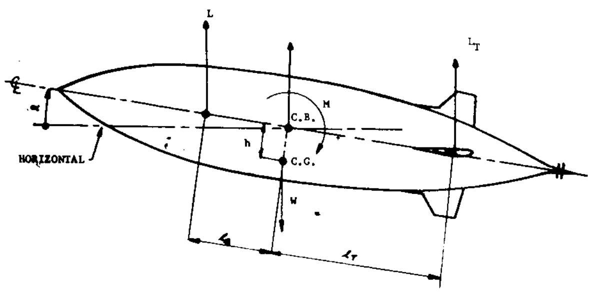

FIGURE 8-4

AIRSHIP IN LONGITUDINAL FLIGHT PITCH MODE

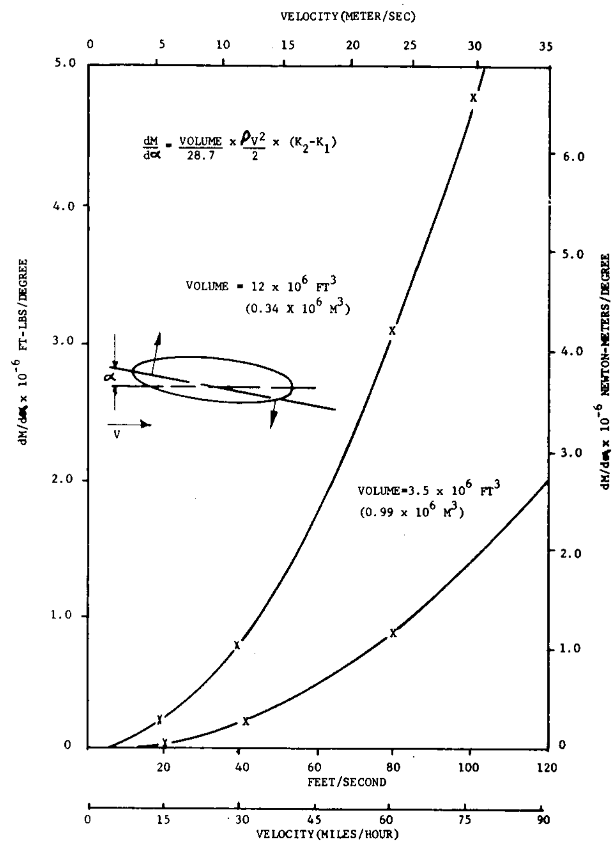

FIGURE 8-5

DESTABILIZING AIRSHIP HULL MOMENT DERIVATIVE

For tail control surfaces on both Phase I and Phase II vehicles, an airfoil section, NACA-0009 (ref. 8-3), was chosen. This representative airfoil is symmetrical in shape with respect to its chord with a maximum thickness of 9 percent of the chord and with a flat length about 30 percent of the length of the airfoil section. The flat serves as an elevator for the horizontal surface, and it serves as a rudder for the vertical surface. The horizontal and vertical control tail surface areas and their corresponding hinge moments for the Phase I and Phase II designs, respectively, are tabulated in Fig. 8-6.

Other stabilizing moments include the ballonet trim moment due to gas inflation or gas valving control, the thrustor moment as well as the moment change due to c.g. shift in both vertical and axial directions. However, such c.g. shifts in axial direction normally are small for an airship designed with compartmentalization of gas space; thus the resulting gas surge forward and aft is minimized. In Fig. 8-3, we have illustrated in dashed lines, various stabilizing moments for a sample flight speed of 6.7 meters per second (15 mph.) (for Phase II airship design). Plots for other flight speeds can be obtained in a similar fashion. Note that, in this figure, all moments in dashed lines are of stabilizing nature and they are additive. It should also be noted that the static trim adjustment varies with altitude and temperature.

8.6.2.2 ROLL AND YAW

No automatic control system is needed for roll stabilization since the large positive metacentric height (the c.g. is about 6.1 meters (20.01 ft.) and 11.3 meters (37.07 ft.) below the c.b. for the proposed Phase I and Phase II vehicles, respectively) provides

Surface (Exposed Planform)	Phase I m^2 (ft^2)	Phase II m^2 (ft^2)	Hinge Moments ($v = 44.7$ m/s = 100 MPH, $\delta = 30^{\circ}$) Phase I N · m (16-ft)	Phase II N·m (16-ft)
Horizontal	385 (4,149)	876 (9,434)		
Elevators	147 (1,577)	330 (3,585)	212,680 (156,844)	736,890 (543,432)
Vertical	279 (3,000)	632 (6,800)		
Rudders	111 (1,200)	253 (2,720)	161,030 (118,753)	535, 550(394,948)

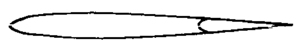

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FIGURE 8-6

TAIL SURFACE AREAS AND HINGE MOMENTS

sufficient inherent stability. As shown in Fig. 8-7 the roll motion in static mode is similar to that of a pendulum.

Since there is no aerostatic effect in yaw from fore and aft instability, stability and control in yaw is less critical, and hence less vertical stabilizer and rudder area may be needed. One might note that some blimps have been made without an upper rudder, and sometimes without an upper fin (especially for high-altitude airships).

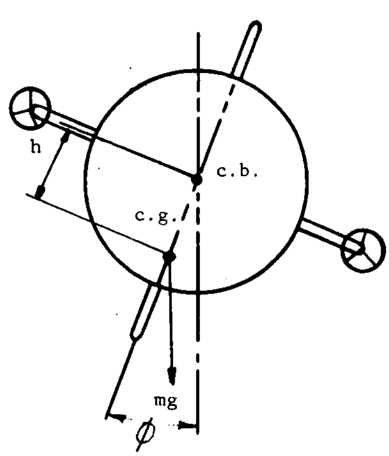

FIGURE 8-7

AIRSHIP IN ROLL EQUILIBRIUM

8.6.2.3 CURVILINEAR FLIGHT

When an airship is in steady curvilinear flight, the outward centrifugal force must be balanced by aerodynamic forces acting inward. This force cannot be provided if the airship remains aligned along a tangent to the curved flight path traced out by the c.g. It is generated as a side force on the body and fins by the airship taking up a yawed position across the flight path with a nose-in attitude. On deflecting the rudders to some fixed angle, the side load on the fins will swing the tail out and the resulting yaw gives an opposite side load on the body, which pushes the airship spiraling into a turn.

The radius of the turn decreases until the damping moment (yawing moment due to the rate of yaw) balances the static yawing moment. However, because the radius of turn is low, the airship settles into the turn with the nose aligned approximately with the flow, i.e., zero yaw. Amidships the flow has the nominal yaw angle, but the tail is swinging wide and experiences about twice the normal yaw angle (see Fig. 8-8).

Munk, ref. 8-2, has extended his analysis of the areodynamic forces on an airship moving in an ideal nonviscous and incompressible fluid to include steady curvilinear flight. It appears that the ship when flying in a curve or circle experiences almost the same resultant moment as when flying straight and under the same angle of pitch or yaw.

The entire transverse force on an airship, turning under an angle of yaw β, with the velocity V, and a radius R, is, according to Munk (ref. 8-2)

$$dF = dx[(K_2-K_1)\,\frac{dS}{dx}\,V^2\frac{\rho}{2}\,\sin 2\beta \qquad (8\text{-}3)$$
$$+ K'\,V\,\frac{\rho}{R}S\,\cos\beta + K'V^2\,\frac{\rho x}{R}\,\frac{dS}{dx}\,\cos\beta]$$

where

F = the transverse force

x = distance along the longitudinal axis of the airship measured from the aerodynamic center

S = cross-sectional area of the hull

K_1, K_2 = coefficients of additional mass of air transversely and longitudinally, respectively

K' = coefficient of additional mass of air due to rotation.

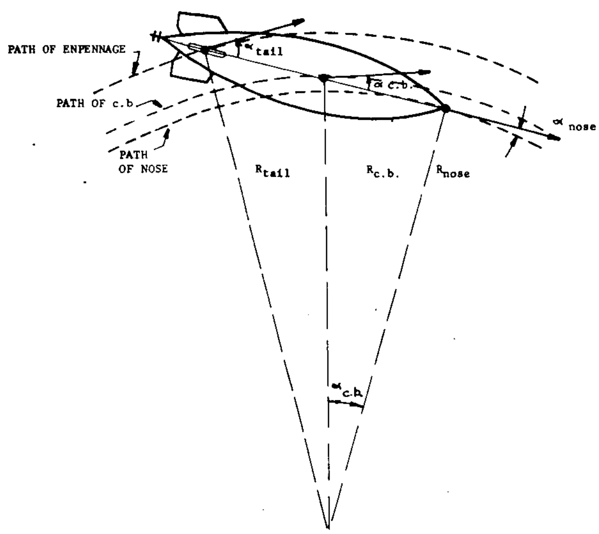

FIGURE 8-8

AIRSHIP IN CULVILINEAR FLIGHT

The first term of eq. (8-3) agrees with the moment of the ship flying straight having a yaw β. The direction of this transverse force is opposite at the two ends, and gives rise to an unstable moment. The ships in practice have the bow turned inward when they fly in a turn. Then the transverse force represented by the first term of (8-3) is directed inward near the bow and outward near the stern.

The sum of the second and third terms of (8-3) gives no resultant force or moment. The second term alone gives a transverse force, the magnitude and distribution being almost equal to the transverse component of the centrifugal force of the displaced air, but reversed.

Although the experimental determination of the areodynamic forces upon an airship in a steady turn is very difficult, some early reports of wind tunnel experiments are available. The well known wind tunnel oscillation test used for the study of airplane rotary derivatives should be with slight modifications, applicable to airships. In 1924, at the Luffschiffbau-Zeppelin Werft, Klemperer (ref. 8-4) tested a model of the airship LZ-126 (the U.S.S. Los Angeles) in the wind tunnel to study the steady turn conditions of the airship. In 1932, R. H. Smith of MIT tested several models of the U.S.S. Shenandoah (unpublished report). Around the same time, Troller (ref. 8-5) built a whirling arm laboratory at the Guggenheim Airship Institute at Akron, Ohio for exploring the conditions of curvilinear flight of airships.

Smith confirmed the usual theoretical assumption that the forces due to rotation are practically proportional to the curvature of turning path up to as sharp curve as can be flown by airships under full rudder. The proportionality factors (rotary derivatives), however, appear to be appreciably affected by, and not independent of, the simultaneously prevailing angle of yaw. The latter phenomenon appears more emphasized on Smith's tests than in Klemperer's.

8.6.3 Dynamic Stability

The formulations of equations of motion for dynamic stability of airships is comparable with that of airplane stability (ref. 8-6) even though the airship equations are far more complex. The additional complexity is due to the following:

(1) The principal sustaining force of airships comes from buoyancy, with a fraction of additional force available from dynamic lift.

(2) The equations of motion are about the center of rotation (c.r.) which takes into account the apparent additional mass and the apparent additional inertia of the external sheath of air surrounding the hull. These apparent mass and inertia effects are essentially reactive forces and moments caused by imparting an angular velocity and a linear and angular acceleration to the surrounding air. The acceleration stability derivatives not only occur explicitly in the dynamic equations but also occur implicitly by modifying certain of the stability derivatives.

8.6.3.1 PITCH MODE

First, consider an airship undergoing planar motion as illustrated in Fig. 8-9. The axes X,Y,Z are body-fixed axes, while X_1, Y_1, Z_1 are the inertial axes. Applying Newtonian laws of motion, realizing that the airship is a body with a plane of symmetry with respect to the X-Z plane (Y-axis is the principal axis, and the products of inertia I_{XY} and I_{YZ}

vanish), the differential equations of motion in the pitch mode caused by the input change of elevator angle $\Delta\delta_e$ can be derived, linearized, nondimensionalized, and expressed in the form

$$\begin{pmatrix} Us - Z_\alpha & -Us \\ -M_\alpha & s^2 - M_q s - M_\Theta \end{pmatrix} \begin{pmatrix} \Delta\alpha \\ \Delta\Theta \end{pmatrix} = \begin{pmatrix} Z_\delta \; \Delta\delta_e \\ M\delta \; \Delta\delta_e \end{pmatrix} \qquad (8\text{-}4)$$

where

$$Z_q = - PV^2 S \, (C_{D_0} + C_{L_\alpha})/2m$$

$$Z_\delta = T_L/M$$

$$M_\alpha = (\tfrac{1}{2}\rho V^2 S\bar{c} \; C_{m_\alpha})/I_{YY}$$

$$M_q = (\tfrac{1}{2}\rho V^2 S\bar{c}^2 C_{m_q})/2I_{YY}U$$

$$M_\theta = (W_{st}h)/I_{YY}$$

$$M_\delta = T_L(\ell T)\,I_{YY}$$

The detailed mathematical derivation is similar to that given in Perkins and Gage, ref. 8-6.

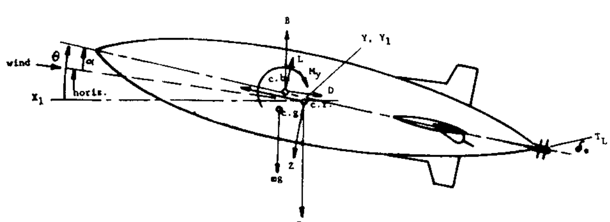

FIGURE 8-9

ASCENT WITH GYRO AXIS VERTICAL AND ELEVATOR DEFLECTED TRAILING EDGE DOWN

Equation (8-4) is a linearized two-degree-of-freedom system. For a given airship, the dimensional measurements, the mass and the moments of inertia and the aerodynamic stability derivatives are treated as given data. These data must be obtained from the structural designers and aerodynamic engineers by computations and wind tunnel model tests.

The transfer function of eq. (8-4) is in the form

$$\frac{\Theta\,(s)}{\theta_i\,(s)} = \frac{K_1(s + T_1)}{s^3 + T_{11}s^2 + T_{12}s + T_{13}} \qquad (8\text{-}5)$$

where K_1 is the gain constant and T_1, T_{ij} (i=1, j=1,2,3) are time constants of the system. Equation (8-5) is a typical three-pole, one-zero system. The root-locus method (ref. 8-7) may be used to study the characteristics and conditions for the stability of pitch.

8.6.3.2 YAW AND ROLL

If, while flying under equilibrium curvilinear flight, the rudder is rotated through the angle δr, as shown in Fig. 8-10, the airship will turn as indicated. The equations of motion for such a maneuver can be formulated, and based on ref. 8-6, are:

$$\begin{pmatrix} -\mu s^2 + L\beta & s^2 - L_p - L_\phi & -L_Y s \\ -Y_r s + Y_\beta & 0 & s^2 - Y\cdot s \\ s^2 - N_r s + N & -\mu s^2 - N_p s & -N_r s \end{pmatrix} \begin{pmatrix} \Delta\psi \\ \Delta\phi \\ \Delta Y \end{pmatrix} = \begin{pmatrix} L_\delta \Delta\delta_Y \\ Y_\delta \Delta\delta_Y \\ N_\delta \Delta\delta_Y \end{pmatrix} \qquad (8\text{-}6)$$

where

$$L_\beta = (\tfrac{1}{2}\rho V^2 S C_{Y_\beta} h)\,I_{XX}$$

$$L_p = (\tfrac{1}{2}\rho V^2 S\bar{b} \; C_{L_p})/2I_{XX}V$$

$$L_\phi = -(W_{st}h)/I_{XX}$$

$$L_s = -(T_L h)/I_{XX}$$

$$N_r = (\tfrac{1}{2}\rho V^2 S\bar{b}^2 C_{n_r})/2I_{ZZ}U$$

$$N_\beta = (\tfrac{1}{2}\rho V^2 S\bar{b} C_{n_\beta})/I_{ZZ}$$

$$N_\delta = T_L \ell T/I_{ZZ}$$

$$N_p = (\tfrac{1}{2}\rho V^2 S\bar{b}^2 C_{n_p})/2I_{ZZ}V$$

$$Y_r = (\tfrac{1}{2}\rho V^2 S\bar{b} C_{Y_r})/2mV$$

$$Y_\beta = (\tfrac{1}{2}\rho V^2 S C_{Y_\beta})/m$$

$$Y_\delta = -T_L/m$$

$$\mu = I_{XZ}/I_{XX}$$

Note that eq. (8-6) is a linearized three-degree-of-freedom system. The transfer function of yaw can be expressed as.

$$\frac{\psi(s)}{\psi_i(s)} = \frac{K_2(s^3+T_{21}s^2+T_{22}s+T_{23})}{s^5+T_{31}s^4+T_{32}s^3+T_{33}s^2+T_{34}s+T_{35}} \qquad (8\text{-}7)$$

where K_2 is the gain constant and T_{21}, T_{22}, . . ., T_{31}, T_{32}, . . ., T_{35} are the time constants, which in turn, depend on the given data of the airship to be designed. Again, the root-locus method may be used to investigate the characteristics and conditions of stability in yaw and roll.

8.6.4 Thrustor Control

Airship control can be conveniently divided into the following three main categories:

1. Aerodynamic control surfaces
2. Side vectoring devices
3. Lift thrusting devices

Although free stream control surfaces (fins) can be used to provide yawing, rolling, and pitching moments as well as lift, drag, and side forces, their primary use has been to provide a yawing moment and directional control. The use of aerodynamic forces via the rudder is effective at the high speed range; however, its effectiveness rapidly drops off with reduced speed. The rudder normally becomes of little value for control well before ground maneuvering speeds are approached.

To insure more positive, faster responding control for both trimming and maneuvering, direct, vectorable thrust control will undoubtedly emerge as a practical control design. Direct, vectorable thrust control can provide active control throughout the entire flight envelope of the airship but will be especially useful for airship handling near the ground.

Thrust producing devices include propellers, control ports, jet vanes and swivelling nozzle rockets. These thrusting devices are contingent on a rigid hull; without this quality of structure, most thrustors would actually be hazardous. Some care must be exercised in their design and use, since ports on the sides of the airship might locally alter the air cushion. This could give an adverse roll and tend to give a side force in the opposite direction.

The effectiveness of any thrustor is dependent on the airflow available and its distance from the c.g. Even in ideal design situations, thrustor forces are expected to be small and would only provide secondary control. The conventional method of using jet vanes has the advantages of large control forces and a high response rate. The disadvantages are a continual thrust loss because of the vanes and severe material problems in high temperature. The desirable features of using the swivelling nozzles are that there are no losses in thrust or impulse and that the control characteristics are linear. It requires shielding against the hot high-pressure exhaust gases. Finally, the method of achieving thrust-vector control using rockets or turbojets involves the non-axisymmetric injection of secondary fluid within the nozzle. The injection of secondary fluid disrupts the supersonic nozzle flow, causing shocks resulting in a nonaxial exhaust momentum flux. Advantages of this system are its low weight and its lack of moving parts. Gimballing of the complete liquid-propellant rocket is feasible because the unit is reasonably small.

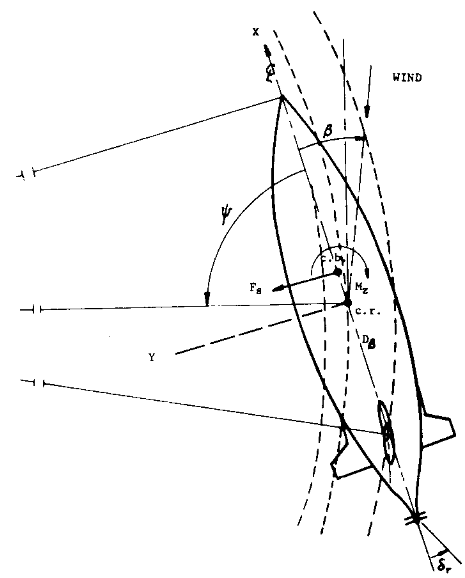

FIGURE 8-10

LEFT TURN WITH GYRO AXIS ALIGNED N-S AND RUDDER DEFLECTED

8.6.5 Flight Stability In Gusting Winds

Turbulence, whether encountered in cruise flight or on ground level maneuver, whether encountered as a pilot or as a passenger, can be a highly disconcerting, discomforting, and a potentially dangerous experience. Yet in a study of the history of airship flying qualities, a conspicuously small amount of attention has been paid, either theoretically or experimentally, to the effects of atmospheric turbulence on the pilot's capability to control the airship. Nevertheless, a considerable amount of knowledge has been accumulated in the past regarding the characteristics of atmospheric turbulence and ample evidence is available from pilot commentary collected during operational use and during flight test programs.

The adverse responses due to flying an airship in heavy turbulence include the physiological effects on pilots and passengers, fatigue damage to structural elements, and the possibility of extreme load damage to some vital part of the airframe structure.

The system concept of the control of the airship in the presence of atmospheric disturbances can be illustrated with the aid of Fig. 8-11. The response $\bar{r}$ of the closed loop, pilot-airship system to command inputs $\bar{C}$ and to turbulence $\bar{g}$ may be expressed in general using transform notation as

$$\bar{r}(s) = \bar{Y}_{pilot}\,\bar{Y}_{ship}E(s)+\bar{Y}_{turb}\bar{g}(s) \quad (8\text{-}8)$$

or in terms of the closed loop pilot-airship transfer function

$$\bar{r}(s) = \frac{\bar{Y}_{pilot}\,\bar{Y}_{ship}}{1+\bar{Y}_{pilot}\bar{Y}_{ship}}\bar{C}(s) + \frac{\bar{Y}_{turb}}{1+\bar{Y}_{pilot}\,\bar{Y}_{ship}}\bar{g}(s) \quad (8\text{-}9)$$

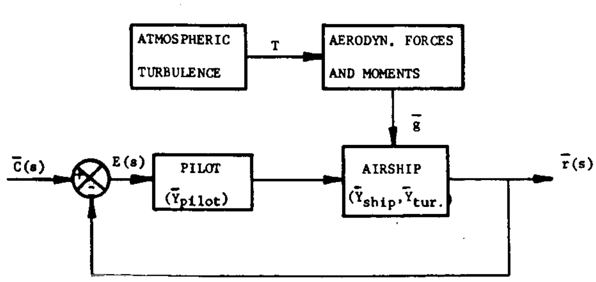

FIGURE 8-11

AIRSHIP CONTROL SYSTEM

It is required to minimize the error E between the airship's response and command input

$$E(s) = \frac{1}{1+\bar{Y}_{pilot}\bar{Y}_{ship}}\bar{C}(s) - \frac{\bar{Y}_{turb}}{1+\bar{Y}_{pilot}\bar{Y}_{ship}}\bar{g}(s) \quad (8\text{-}10)$$

The nondeterministic nature of turbulence makes it necessary to refer to statistical measures for the definition of the time or spatial variation of the turbulence field. Mathematical tools and techniques such as Fourier transforms and random process theory, and particularly the correlation function and power spectral density analysis, lend themselves to a description of turbulence suitable for airship dynamic response study. Fig. 8-12 shows the flow chart of a power spectral gust design procedure for HTA craft proposed by the FAA (ref. 8-8 and 8-9). High-speed HTA craft respond very rapidly to disturbances in the pitch mold. Unlike HTA craft, airships are characterized as relatively low speed, large volume, buoyancy-control vehicles. The airship's response to disturbances will be so slow that the vehicle could conceivably fail structurally before the human pilot or autopilot could react to the motion at all.

The stability and control problem of airships is probably the least understood and paradoxically the least investigated facet of LTA design. If a comprehensive study of the complex problem of an airship in gusts is to be attempted, then it would be useful to divide the task into the following areas of investigation:

1. The kinematics of interaction between the airship and "gusts".
2. The resulting aerodynamic forces and moments acting on the airship.
3. The dynamic response and the induced stresses on an airship caused by these forces and moments.
4. The method of controls and manuevers to achieve stability and acceptable flight quality.

Stability and maneuverability are not always compatible. For example, an airship could be made completely stable by making the tail fins large enough, but, aside from weight considerations, the primary reason for not doing so is to obtain improved maneuverability by using

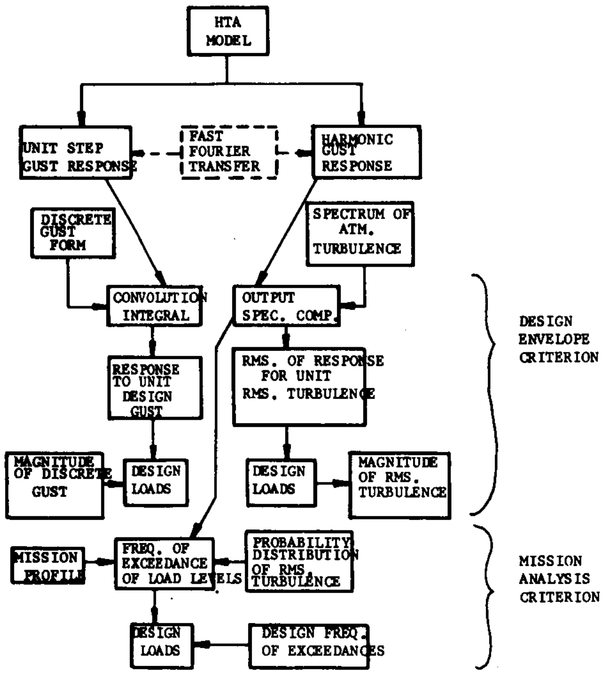

FIGURE 8-12

POWER SPECTRAL GUST DESIGN PROCEDURE FOR HTA PROPOSED BY FAA

this instability. The earliest aeronautical experimenters had hoped to achieve "inherent" stability. Many pursued this goal and discovered how to set the incidence of the tailplane so as to achieve "longitudinal stability" with respect to the relative wind, and to use wing dihedral so as to achieve "lateral stability." It gradually became clear, however, that configurations with a large amount of such inherent stability were distressingly susceptible to being upset by gusts. When an airship is negotiating a turn, the turning maneuverability can be made easier because the instability allows the nose to swing into the turn. The trade-off is one of constant intervention of the human pilot, or by automatic control of flight path and attitude, plus a continual, if gradual undulating and fish-tailing motion. Stability is actually secured with the mechanism of "feedback," a principle by which cause and effect systems are modified to secure certain desirable properties. Information about the effect is fed back to the input and is used to modify the cause. It is conceivable that modern airships will require artificial stabilization, automatic attitude and speed control, and rapid thrust response for satisfactory flying qualities. An airborne digital computer can be used to input and regulate the pilot control commands. The information will be processed in real time, with signals continuously returned in a feedback loop for monitoring and control purposes.

Several very recent papers related to airship stability and control are ref. 8-10, 8-11, 8-12, and 8-13.

8.7 THERMODYNAMIC MANAGEMENT OF LIFT

In the most general terms, thermodynamic management of lift (TML) simply means the control of the application and withdrawal of heat to the lifting gas. It is fairly obvious that in most cases heating the gas is easier and can be accomplished much more quickly than cooling, particularly if the gas in its heated state is confined to a large volume at low pressure.

The following represents the two broad applications for which thermodynamic management of lift might be used:

1. Heating and cooling of the lifting gas in order to maintain airship trim, to avoid venting of lifting gas, and to eliminate partially the use of disposable ballast.
2. Preheating the lifting gas before take-off to eliminate the otherwise "dead air" ballonet volume to achieve maximum lift capability.

The methods of implementing TML are numerous, and much discussion on the subject has occurred in the literature, (ref. 8-14, 8-15, 8-16).

8.7.1 Normal Superheat

Any condition which causes the gas temperature T_G to differ from the ambient air temperature T_A can be broadly classified as superheat. Natural or normal superheat arising from solar radiation is considered positive since direct sunlight heats the gas resulting in the condition $T_G > T_A$. Negative superheat occurs anytime the gas temperature is less than the ambient air temperature. An airship in flight may suddenly run into cooler or warmer portions of the atmosphere. Under these conditions, the gas will not respond instantly, but due to its thermal inertia will require time to adjust its temperature back to thermal equilibrium with its surroundings.

It should be noted that a rapid descent will give rise to an adiabatic increase in the temperature of the lifting gas, while a high airspeed results in a rapid cooling effect, thereby reducing the total superheat lift. Uneven heating, resulting from the airship moving in and out of cloud cover, may result in trim and balance problems. From the foregoing considerations, it is seen that superheat may introduce unwanted or unexpected sinking or lift conditions. Most of the undesirable superheat effects occur during critical operations near the ground (such as obtaining unwanted lift upon removing the airship from a hanger on a sunny day), or on approach to the ground (having descended from cruising at cooler altitudes).

Superheat may, of course, be exploited to advantage, but in general, natural superheat often adds a degree of uncertainty to airship operations and frequently complicates the trim and ballast control. Therefore, methods to eliminate, modify, or exploit superheat are desirable. In the present study, it is expected that the relatively thick sandwich construction of the hull walls (a layer of insulating foam between an inner and outer metal skin), will provide an outstanding thermal barrier to heat transfer. In effect, the lifting gas in both the Phase I and Phase II airship is contained in a highly insulated hull with a reflective metallic surface. This would give the confined gas a large thermal inertia against rapid changes in superheat.

The fact that both Phase I and Phase II are pressure-rigid airships yields the added advantage that they are far less subject to the vagaries of superheat than were the Zeppelin type (non-pressure rigid) airships. For example, for purposes of calculation, assume that both Phase I and II operate under a nominal internal pressure which is 1.24×10^3 Newtons/m^2 (5 inches of water) above standard atmospheric pressure. If the vehicles begin to absorb superheat, then as the temperature of the lifting gas begins to rise, the internal gas pressure can be allowed to increase to 3.73×10^3 Newtons/m^2 (15 inches of water) above ambient. By allowing the airship's internal pressure to increase to its safe upper limit, the tempeterature increase due to superheat can be absorbed at constant gas volume; hence the gas density remains constant and no lift from superheat occurs. For the case discussed, the temperature can increase from 15°C (59°F) to 22°C (71.6°F); that is, superheat in the amount of a temperature increase $\Delta T = 7$°C (12.6°F) can be safely absorbed by these pressure-rigid airships without generating any lift. The advantage is obvious when one realizes the amount of lift produced by this much superheat on a conventional rigid (Zeppelin) airship would be 2.31×10^4 Newtons (2.6 tons) for Phase I and 8×10^4 Newtons (8.98 tons) for Phase II. The assumption is that a conventional rigid airship would absorb superheat through an isobaric expansion of the lifting gas.

8.7.2 HEAT TRANSFER MODEL TO DETERMINE SUPERHEAT

To determine an estimate of the change in helium temperature during airship exposure to the sun, the following heat transfer model was developed. The model is

$$q_R = q_c + q_{He} \qquad (8\text{-}11)$$

where

q_R = heat radiated from the sun to the airship

q_c = heat convected away from the hull

q_{He} = heat absorbed by the helium

If the temperature of the helium (T_{He}) is assumed to be equal to the hull skin temperature (T_s), then the difference between hull and air temperature becomes the superheat temperature (ΔT). That is

$$\Delta T = T_s - T_a = T_{He} - T_a \qquad (8\text{-}12)$$

The model can be solved for the superheat temperature to yield

$$T = \alpha G A_p \frac{\Delta \tau}{h A_c \Delta \tau + m c_p} \qquad (8\text{-}13$$

where

α = absortivity of the hull skin

G = solar constant at the ground = 3.419×10^6 joules/m^2·hr

A_p = projected area of the hull for radiation (assumed to be 0.8 length x diameter)

h = convective heat transfer coefficient, assumed to be 2.05×10^4 Joules/m^2·hr °C (1 BTU/ft^2·hr·°F) for the stationary ship and calculated from $h = (k/L)(0.036 \, Pr^{1/3} Re^{0.8})$ when the ship is moving, based on a fully turbulent boundary layer on a flat plate, where

k = thermal conductivity of air

Re = Reynolds number, based on length (L) of the airship

Pr = Prandtl number

A_c = Area for convection (assumed to be 1/2 the wetted area of the hull

m = total mass of helium (assumed 95% pure)

c_p = heat capacity of helium

= 5.21×10^3 Joules/kg·°C (1.24 (BTU/lb·°F)

$\Delta\tau$ = time interval of exposure to sun.

To calculate the maximum temperature of the helium, equilibrium between the solar radiation absorbed and heat lost due to convection is assumed. The equilibrium superheat temperature is reached in the limit of very long exposure to the sun, and is calculated from ΔT as

$$\Delta T_{eq} = \lim_{\Delta\tau \to \infty} \left(\Delta T \right) = \frac{\alpha G A_p}{h A_c}$$

For both Phase I and II (ambient temperature = 10°C = 50°F) the equilibrium temperatures are tabulated in the table below for (a) motionless (static) conditions and (b) flight (dynamic) conditions.

	ΔT_{eq} for Motionless Conditions	ΔT_{eq} for Flight Conditions
Phase I	32.8°C(59°F)	5°C(9°F)
Phase II	32.8°C(59°F)	6.8°C(12.3°F)

In both cases, slightly more than 6 hours is needed to approach thermal equilibrium for the static case, while in flight (at cruise airspeed) equilibrium is essentially reached in 1 hour. These calculations are significant because large amounts of superheat can be expected to slowly build up in both airships at rest over a long period of time. While in flight, however, the equilibrium superheat temperature, which occurs in a little more than one hour, is still less than the 7°C (12.6°F) superheat which the airships can absorb by increasing their internal pressures at constant volume without generating any additional lift. The heat transfer model is very simplistic in nature, and it should be conservative in estimating the superheat temperatures.

Superheat on the ground may be minimized or controlled by

1. employing a highly reflective hull finish;
2. circulating air through the ballonets, which will be continually under pressure even when not in flight;
3. automatically pumping water on or off the airship for trim and balance when moored.

8.7.3 Artificial Superheat

8.7.3.1 The Hot Helium Concept

Thermodynamic management of the lifting gas by artificial heating would not be difficult to achieve while imposing little weight penalty. While a number of techniques exist for implementing this concept, the following represent a few of the more feasible possibilities:

1. Using heat from engine exhausts to maintain the temperature of the lifting gas above ambient.
2. Obtaining heat from electrical power on the ground
3. Maintaining heat in flight from onboard electrical generators or industrial propane burners.

Obviously, the details of the first method are highly dependent on the type of engines used, being easier to facilitate recovery of exhaust heat from diesel or gasoline piston engines which use radiators across which the helium could be circulated for heat exchange purposes. Heat recovery, like water recovery, from the exhaust of gas turbines is more difficult, however, and possibly impractical due to the large gas volumes in the exhaust. The energy recovery would necessitate very large and well designed heat exchangers because of the sensitivity of this type of engine to adverse back pressures.

Artificial superheat could be supplied directly to the lifting gas through electrical resistive heaters which would be located inside the airship hull itself. Preheating the helium by this method on the ground offers the possibility of taking off with extra cargo and/or fuel.

If supplementary heating of the lifting gas is employed, then relatively modest temperature increases for the large volumes would be sufficient for most maximum lift or "overload" missions. For the Phase II airship, for example, heating the helium at constant pressure from 15°C (59°F) to 25.4°C (77.7°F) just before takeoff will provide 1.18×10^5 Newtons (2.65×10^4 pounds) of additional lift. This would be sufficient to carry the design fuel capacity plus some additional reserve. The amount of energy required to heat the helium to 25.4°C (77.7°F) is only 3.3×10^9 Joules (3.13×10^6 Btu). Assuming that natural gas were used to provide the thermal energy (with a transfer efficiency of 50 percent), the cost of the heating based on 1975 prices (ref. 8-17) would be less than $10.

Under ISA conditions, it would be possible to heat the helium on the ground up to a maximum temperature of 75°C (167°F) before pressure height is reached. This helium temperature plus the volume increase would provide 6.8×10^5 Newtons (76.5 tons) of additional lift. It would probably be impractical to try to maintain this maximum helium temperature while in flight. Considering conduction through the multilayer hull and convective losses, a simple model from basic theory (ref. 8-18) predicts a heat loss of approximately 8.44×10^9 Joules (8×10^6 Btu/hour). Direct heating by propane burners would be possible, but extensive ducting and large blowers would be required.

The most feasible application of lifting gas heating, therefore, appears to be on the ground heating to temperatures which will compensate for a portion of the fuel and/or cargo load. Controlled cooling during the subsequent flight would allow a progressive loss of lift to balance the weight of the liquid fuel consumed.

8.7.3.2 THE HOT BALLONET CONCEPT

An alternative method of achieving artificial superheat is obtained by heating the contents of the ballonets, which, at takeoff conditions (I.S.A. at sea level), would normally be fully inflated with air. The ballonet air thus supplies no lift, serving only to pressurize the hull of the airship (by means of onboard fans or blowers supplemented by external airscoops during flight). By heating some portion of the ballonet air volume, additional lift will be generated. While this technique offers a relatively small amount of lift, an even greater advantage is realized in trim and ballast control. That is, the hot air in the ballonet can be thought of as a disposable fluid which can be dumped quickly and inexpensively to maintain airship trim. In view of the fact that costly helium should be vented only in extreme emergencies, hot air, as disposable ballast, will provide emergency lift control.

The simplest method of implementing such a system would be to heat a limited number of fore and aft ballonets (possibly as few as two) by industrial liquid propane gas burners. These units would be identical to the type now used by hot air balloonists and could be installed in much the same manner as is found on the manned thermal airship manufactured by Raven Industries, Inc., of Sioux Falls, South Dakota (ref. 8-19).

The rate of liquid propane consumption necessary to maintain the hot ballonnets at 100°C (212°F) is estimated to range from .05 kilograms/second (400 pounds/hour) to 0.18 kilograms/second (650 pounds/hour). These estimates are based on extrapolations from existing balloon fuel consumption rates (ref. 8-20). The lower value is probably the more accurate in view of the fact that the hot ballonets are surrounded by a stagnant dry gas; hence the rapid convective cooling experienced by hot air balloons in motion would not occur in the present case.

For the Phase II ship, as an example, assume a total volume of $2.83 \times 10^4 m^3$ (10^6 ft^3) divided equally between two ballonets located some distance fore and aft of the center of gravity. If heated to 100°C (212°F) these hot air volumes would supply a total lift of 7.7×10^4 Newtons (17,400 lbs). The exact shape of the ballonet volume would determine the weight penalty of such a system. However, it is possible to adjust the location, size, shape, and number of the other ballonets, such that incorporating two large hot air ballonets of the type under consideration may result in little or no increased weight.

Propane burners with very high heat to weight ratios are readily available in many different sizes. Typically, relatively small, lightweight units from the hot air balloon industry have outputs ranging from 5.86×10^5 watts (2×10^6 BTU/hour) to 3.22×10^6 watts (11×10^6 BTU/hour) (ref. 8-19).

A simple thermodynamic model was developed to investigate the heating effect that could be expected to occur from heat transfer from a distribution of hot air ballonets into the surrounding helium. For the worst possible case (for Phase II), it was assumed that the entire ballonet volume was divided into many (15) small hot air ballonets, 3.68×10^4 m^3 (1.3×10^5 ft^3) each, which were distributed down the length of the Phase II hull, separating it into 16 helium cells.

With the maximum ballonet temperature of 100°C (212°F) it was found that the internal temperature rise for the helium was $\Delta T_{He} \mp 16.7^{o}C$ ($30^{o}F$) and that half of the total temperature rise occurred in 30 minutes. With no additional heat being added, internal thermal equilibrium between the ballonet air and the stagnant helium was essentially reached in approximately 90 minutes.

It should be emphasized that while the hot air ballonet system will provide far less lift [hot air at $100^{o}C$ ($212^{o}F$) provides only about 1/4 the lift of helium at $15^{o}C$ ($59^{o}F$)] than heating the lifting gas itself, its main advantage rests with the fact that moderately rapid differential trim is possible. For example, by heating the contents of the forward ballonet while dumping the hot air contents of the after ballonet, a sizeable pitch moment would result to raise the bow of the ship. Pushing the hot air out by means of forced air blowers would still allow internal pressure to be maintained within the hull during all phases of the operation. Obviously, monitoring and maintaining internal temperatures, pressures, and trim will be routinely accomplished automatically under computer control.

8.8 SUMMARY

The ultimate success of future airships will, in large part, be based on advanced stability and control systems. Applying off-the-shelf modern aerospace technology to the airship of today will revolutionize rigid airship design, which has been dormant for over 40 years.

Some of the rigid airships of the 1920's and 1930's, despite minimal and rather primitive flight instrumentation, achieved a remarkable level of operational success. An airship of the 1970's, however, would truly be a product of the space age. Drawing heavily on advances in all areas of avionics, communications, air-weather forecasting, doppler radar, and computer applications, the operational safety and reliability of airships will be free of many of the limitations of the past. Fail-safe electronic redundancy, automatic computer control of the vehicle during all flight modes (including constant and automatic trim and control), will largely eliminate problems arising from faulty and inadequate instrumentation and pilot error. Improved meteorological information, including continual local weather updating from ground flight control centers, wide area input from weather satellites, and onboard radar for avoiding clear air turbulence and local storm activity, should minimize the problems previously associated with weather.

Thrust Vector Control (TVC) will give the modern airship a degree of static stability and control which was completely lacking in most airships of the past. Previous airships often behaved more like balloons at low speeds during which time fins and aerodynamic control surfaces were almost completely ineffective. Formerly, airships at near zero speeds were essentially without control except for discharge of ballast (or lifting gas) and manual restraint with ground handling ropes. By employing large, low speed, reversible propellers which can be swivelled through 90°, the modern airship, augmented by a gimballed stern propeller and thrust vector control system, will achieve outstanding control during the most critical hover mode near the ground.

Stabilizing surfaces will be retained for aerodynamic stability during flight and for assistance in weather vaning into the wind upon landing. In view of the propulsion and thrust control flexibility of the airship, the fin size can be greatly reduced, thus accepting a degree of directional instability for a savings in both weight and aerodynamic drag. It should be emphasized that while the present study favors fins of high aspect ratio, which are smaller and moved somewhat ahead of the traditional stabilizing surfaces of the older rigid airships, their exact shape, location, size, orientation, and number of surfaces should be thoroughly investigated and optimized with respect to stability, drag, lift, ground and hanger clearance, and structural weight.

Thermodynamic management of lift offers the possibility of increasing the total lift of a given airship. As a design philosophy, however, it could be regularly employed to achieve greater lift from otherwise undersized airships. Such vehicles would require greater structural strength than a conventional airship of equal size, but the advantages of the higher-lift, smaller craft would be

1. convenience of construction
2. convenience of ground handling and hangaring
3. reduction in helium volume.

While it is desirable to eliminate disposable ballast in the form of solids or liquids, it is probably impractical to do so at the present time.

The design philosophy during the present study has been to emphasize off-the-shelf technology of the 1970's. This has not in any way limited our considerations of more advanced concepts, and, it is felt that continued advances in the electronic and aerospace industries will contribute directly to LTA technology, particularly with respect to stability and control.

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CHAPTER 9

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9.1 INTRODUCTION

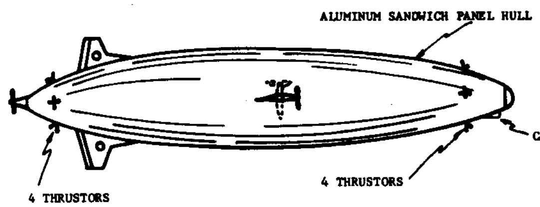
In this chapter the configuration of each phase will be summarized. A historical comparison will be made of the structural efficiency of both the Phase I and Phase II airships, assuming that both ships would be metalclads. An estimate of the construction cost of the Phase I and II airships will be made using two approaches, a historical approach and a building block approach based on current 747 aircraft technology.

9.2 AIRSHIP CONFIGURATION

9.2.1 CONFIGURATION SUMMARY

Phase I

The Phase I airship has a displacement volume of 9.9 x $10^4 m^3$ (3.5 x $10^6 ft^3$). Although this volume is more than twice the size of the largest nonrigid airship ever built, it is certainly conceivable that the Phase I ship could be a nonrigid. The final determination of the type (metalclad or nonrigid) would be made based on the mission requirements and economics. In general, for low speed missions, such as a passenger scenic cruise, a car suspended beneath the airship and supported by cables from a long, internal catenary curtain would be possible. For high speed cargo missions, where point loads of 2.27 x 10^4 kilogram (25 ton) are to be exchanged repeatedly, the metalclad is preferable because of the additional structural integrity. To have the capability for all missions, the metalclad was selected as the Phase I airship. The vehicle configuration and summary statistics are shown in Fig. 9-1.



SPECIFICATIONS:	
Shape	Classical
Displacement Volume	99,000 m^3 (3.5x10^6 ft^3)
Gas Volume	78,000 m^3 (2.77x10^6 ft^3)
Maximum Ballonet Volume	16,000 m^3 (.58x10^6 ft^3)
Cargo Capacity at Design Point	26.300 kg (29 tons)
Speed	
Cruise	35.8 m/sec (80 mph)
Maximum	44.7 m/sec (100 mph)
Range at Design Point	(600 miles)
Installed horsepower	
(2side engines and 1 stern engine)	2.8x10^3 KW (3750 hp)
Thrustor Capacity (8 total)	
Up	1.34x10^4 N (3000 lb)
Down	1.34x10^4 N (3000 lb)
Fore	1.79x10^4 N (4000 lb)
Aft	1.79x10^4 N (4000 lb)
Pressure height (Design)	1830 m (6000 ft)
Mass (Empty)	46,565 kg (102,658 lb)
Hull Structure	Aluminum Sandwich Panel
Ballonet Material	Kevlar backed Mylar and Tedlar film

FIGURE 9-1

PHASE I AIRSHIP CONFIGURATION SUMMARY

Empty mass as used here includes the mass of the complete airship--engines, instruments, controls--that is, everything necessary to operate the vehicle. The crew, food, fuel, ballast, payload, and lifting gas are excluded.

Phase II

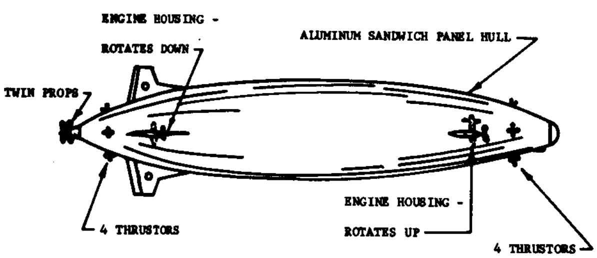
The Phase II airship has a total displacement volume of 3.40 x $10^5 m^3$ (12 x 10^6 ft^3), and is larger than any airship that has ever been built. The design is based on the metalclad construction described previously in Chapter 7. Fig. 9-2 summarizes the vehicle statistics and gives the overall vehicle configuration.

9.2.2 COMPARISON TO PAST AIRSHIPS

One approach that can be used as a measure of construction efficiency of an airship is a plot of density (empty) vs. displacement volume. The Goodyear Aerospace Corporation (ref. 9-1) generated a semi-log plot of past airships, and this curve is reproduced as Figure 9-3. Additional data points for other nonrigids, rigids, and metalclads, (refs. 9-2 through 9-7) have been added to the plot. In addition, a metalclad data point was obtained from personal papers of Ralph Upson, marked RHV/JA, 6/14/37.

As discussed in Ref. 9-1 some of these airships, such as the 'A' nonrigid and R100 and R101 rigids, were first tries of a type and were not considered typical. As a result, these were ignored by Goodyear in developing the "average line" indicated on the plot. This line goes from .881 kilogram/m^3 (.055 pound/ft^3) at a volume of 566.3m^3 (20,000 ft^3) to .449 kilogram/m^3 (.028 pound/ft^3) at a volume of 283,168m^3 (10 x $10^6 ft^3$).

The implications of Fig. 9-3 are interesting in developing a configuration concept with which to proceed for at least a preliminary design investigation. The average line implies that if a ship is efficiently designed for a specified air-displacement



SPECIFICATIONS:

SHAPE	CLASSICAL	
Displacement Volume	$3.40\times10^5 m^3$	(12×10^6 ft^3)
Gas Volume	$2.72\times10^5 m^3$	(9.6×10^6 ft^3)
Maximum Ballonet Volume	$5.66\times10^4 m^3$	(2×10^6 ft^3)
Cargo Capacity of design point	106×10^3kg	(117 tons)
Speed		
Cruise	26.8m/sec	(60 mph)
Maximum	44.7m/sec	(100 mph)
Range at Design Point	3,220 Km	(2000 miles)
Installed horsepower (4 side engines and 1 stern engine)	4.7×10^3 KW	(6250 hp)
Thrustor Capacity (8 total)		
Up	2.7×10^4 N	(6000 lb)
Down	2.7×10^4 N	(6000 lb)
Fore	3.6×10^4 N	(8000 lb)
Aft	3.6×10^4 N	(8000 lb)
Pressure height (Design)	1829 m	(6000 ft)
Mass (Empty)	(43,000 kg)	(315,364 lb)
Hull Structure	Aluminum Sandwich Panel	
Ballonet Material	Kevlar backed Mylar and Tedlar film	

FIGURE 9-2
PHASE II AIRSHIP CONFIGURATION SUMMARY

volume, it would be either a nonrigid, rigid, or a pressurized metalclad configuration. Efficiently designed, any configuration should result in approximately the same unit mass. Plots of the Phase I and Phase II proposed configurations using a sandwich shell construction indicate a structural efficiency improvement over conventional approaches as indicated by the average line in Figure 9-3.

9.3 AIRSHIP COSTS

In general, the estimation of construction/fabrication costs are difficult under the most ideal circumstances. Paraphrasing the cost estimation problems described at the Monterey, CA. LTA Conference in 1974, ref. 9-8, the problem of cost estimation of airships if further complicated by

1. A lack of recent experience with actual construction and operation of LTA cargo carrying airships or,
2. Effect of modern certification regulations and union work rules on the design, construction and operation of LTA cargo carrying airships or,
3. Inadequate information on the comparative economic conditions of the present compared to those under which the early airships were developed, and the
4. Inability to define the complexity of a modern airship structure relative to current airframe experience.

This same reference also expressed the attitude that the only real way to obtain true information on development, construction and operating costs is to build and fly a new airship. Perhaps as a result of the above perceptions, there has been a relative reluctance in the current literature to develop cost estimates, or at best to make very obscure cost development statements.

Since the Phase I and Phase II suggested configurations are, for the most part, conceptual as opposed to fully detailed designs, cost estimates are made on the basis of cost modeling, as described in the following paragraphs.

9.3.1 HISTORICAL MODELS

One approach to airship minimum life cost, including construction and operation cost, is to provide a minimum weight structure for the air displacement volume required to provide the operational lift and flight. This is, of course, similar to minimum cost approaches of the aerospace industries. That is, a minimum weight merit function is incorporated into the optimization process and is assumed to be a one-for-one replacement for a minimum cost merit function.

The historical data model connects the cost of year constructed to present cost based on some form of cost index. This model therefore assumes that the cost relations of dollars to volume have remained the same through the years. This requirement is assumed to have been achieved through technological advances so that a previously highly labor intensive industry would now be capital intensive.

9.3.1.1 COMPOSITE HISTORICAL MODEL

A historical data plot of air displacement volume vs $\$1975/m^3$ ($\$1975/ft^3$) is shown in Fig. 9-4. The data for this figure were

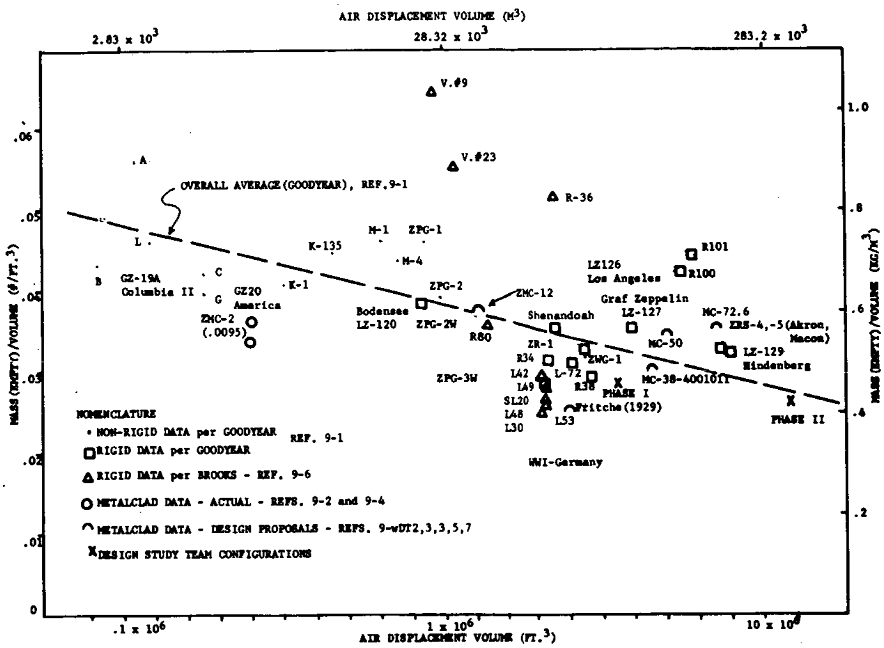


FIGURE 9-3

UNIT WEIGHT VS. TOTAL VOLUME

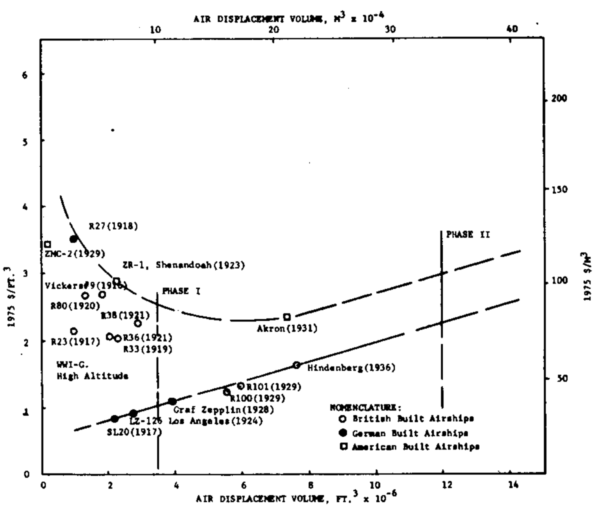


FIGURE 9-4

PAST RIGID AIRSHIP UNIT COSTS

developed from the data shown in Table 9-1A in SI units and in Table 9-1B in English units. The tables are not inclusive of all airships built, but do include those for which a constructed value could be obtained.

For those airships whose air displacement volume could not be located in a reference, an estimate was made on the basis that the gas volume represented 93.27 percent of the total air displacement volume. This represents an average value for those airships on which data were available. Construction costs, updated to 1972 British pounds (ref. 9-6), were converted to 1975 United States dollars by multiplying by 3.335, which converted 1972 pounds to 1972 dollars and accounted for an average 6 percent inflationary rate per year up to 1975.

Interestingly, the lower bound line shown in Fig. 9-4 is predominately developed from German-built airships, where as the upper bound line is predominately based on American-built airships. It should also be noted that although the Akron was built in this country, the builders, the Goodyear-Zeppelin Co., were staffed by experienced German airship engineers. Also, the ZP-1 Shenandoah, built in 1923 at the Naval Aircraft Factory in the United States, was a derivative of the German L-30 class of rigids used in WWI.

Based on this approach, the proposed configurations would have the cost ranges shown in Table 9-2.

Fig. 9-4 also displays a contradiction of the usual asumption that the larger the size, the lower the unit price. It thus appears that past difficulties of physically constructing large airships overcame the unit cost advantage of size on a per unit volume basis.

TABLE 9-1A

PAST AIRSHIP VOLUME, MASS (EMPTY) & COST SUMMARY (METRIC UNITS)

Airship	Year Flown (Ref 9-6)	Gas Volume M^3 (Refs 9-6, 9)	Air Displacement Volume M^3	Mass KG	Unit Empty Mass KG/M^3	1972 £ x 10^{-3} (Ref 9-6)	1975 \$ x 10^{-3}	1975 \$/M^3	1975 \$/KG
LZ 129, Hindenberg	1936	200,000	216,624	130,000(b,c)	.6000	3,730.	12,439.	57.42	19.69
ZRS-4, Akron	1931	193,970	209,545	111,000(b)	.5297	5,220	17,408.	83.07	32.27
R 100	1929	146,060	157,725	106,600(b,c)	.6759	2,110.	7,037.	44.62	13.58
R 101	1929	141,540	169,052	111,800(b)	.6613	2,350.	7,837.	46.36	14.42
ZMC-2 (Metalclad) (Refs. 9-2,4)	1929	5,720	7,153	4,134	.5780	260.	867.	121.21	43.14
LZ 127, Graf Zeppelin	1928	105,000	110,436	67,100(b,c)	.6076	1,300.	4,335.	39.26	13.29
LZ 126, Los Angeles	1924	70,000	79,287	41,005(a)	.5172	780.	2,601.	32.80	13.05
ZR-1, Shenandoah	1923	60,900	64,846	36,469(a)	.5624	1,980.	6,603.	101.83	37.25
R 38	1921	77,600	83,252	36,700(b,c)	.4408	1,970.	6,570.	78.92	36.83
R 36	1921	60,030	64,364±	53,400(b,c)	.8297	1,370.	4,569.	70.99	17.60
R 80	1920	35,680	38,256±	22,000(b,c)	.5751	1,060.	3,535.	92.40	33.06
R 33	1919	55,460	59,463±	36,900(b,c)	.6206	1,300.	4,335.	72.90	24.17
R 27 (23 x class)	1918	28,050	30,074±	25,000(b,c)	.8313	1,120.	3,735.	124.19	30.74
Vickers #23 (23 Class)	1917	28,250	30,288±	27,000(b,c)	.8915	685.	2,284.	75.41	17.40
SL 20	1917	56,000	60,041±	27,100(b,c)	.4514	550.	1,834.	30.55	13.92
L 53	1917	56,000	60,041±	25,000(b,c)	.4164	890.	2,968	49.43	24.43
L 48	1917	55,800	59,826±	25,750(b)	.4304	890.	2,968.	49.61	23.71
L 42	1917	55,500	59,505±	28,100(b)	.4722	890.	2,968.	49.88	21.73
Vickers #9	1916	25,200	27,018±	27,100(b,c)	1.0030	770.	2,568.	95.03	19.50
L 30	1916	55,000	58,969±	31,400(b)	.5325	890.	2,968.	50.33	19.45

(a) Ref 9-1 (b) Ref 9-6 (c) Ref 9-9

TABLE 9-1B

PAST AIRSHIP VOLUME, MASS (EMPTY) & COST SUMMARY (ENGLISH UNITS)

Airship	Year Flown (Ref 9-6)	Gas Volume Ft^3 (Refs 9-6,9)	Air Displacement Volume Ft^3	Mass LBS.	Unit Empty Mass Lbs/Ft^3	1972 £x 10^{-3} (Ref 9-6)	1975 \$ x 10^{-3}	1975 \$/Ft^3	1975 \$/lb
LZ 129, Hindenburg	1936	7,062,930	7,650,000(a)	286,600(c)	.0374	3,730.	12,439.	1.63	43.40
ZRS-4, Akron	1931	6,850,000(a,b)	7,400,000(a)	244,700	.0331	5,220.	17,408.	2.35	71.14
R 100	1929	5,158,000	5,570,000(a)	235,000	.0422	2,110.	7,037.	1.26	29.95
R 101	1929	4,998,400	5,970,000(a)	246,500	.0413	2,350.	7,837.	1.31	31.79
ZMC-2 (Metalclad) (Ref. 9-2,4)	1929	202,000	252,600	9,115	.0361	260.	867.	3.43	95.12
LZ 127, Graf Zeppelin	1928	3,708,000	3,900,000(a)	147,930	.0379	1,300.	4,335.	1.11	29.31
LZ 126, Los Angeles	1924	2,472,000	2,800,000(a)	90,400(a)	.0323	780.	2,601.	0.93	28.77
Zr-1, Shenandoah	1923	2,150,700	2,290,000(a)	80,400(a)	.0351	1,980.	6,603.	2.88	82.13
R 38	1921	2,740,400	2,940,000(a)	80,910	.0275	1,970.	6,570.	2.23	81.20
R 36	1921	2,119,900	2,273,000±	117,730	.0518	1,370	4,569.	2.01	38.81
R 80	1920	1,260,000	1,351,000±	48,500	.0359	1,060.	3,535.	2.62	72.88
R 33	1919	1,958,600	2,099,900±	81,350	.0387	1,300.	4,335.	2.06	53.29
R 27 (23 x Class)	1918	990,600	1,062,100±	55,120	.0519	1,120.	3,735.	3.52	67.77
Vickers #23 (23 Class)	1917	997,640	1,069,600±	59,530	.0557	685.	2,284.	2.14	38.37
SL 20	1917	1,977,620	2,120,300±	59,750	.0282	550.	1,834	0.87	30.70
L 53	1917	1,977,620	2,120,300±	55,120	.0260	890.	2,968.	1.40	53.85
L 48	1917	1,970,560	2,112,700±	56,770	.0269	890.	2,968.	1.40	52.28
L 42	1917	1,959,960	2,101,400±	61,950	.0295	890.	2,968.	1.41	47.91
Vickers #9	1916	889,930	954,100±	59,750	.0626	770.	2,568.	2.69	42.98
L 30	1916	1,942,310	2,082,500±	69,230	.0332	890.	2,968.	1.43	42.88

(a) Ref 9-1 (b) Ref 9-6 (c) Ref 9-9

TABLE 9-2

AIRSHIP COST ESTIMATES FROM COMPOSITE HISTORICAL MODEL

	1975 \$/M^3	(1975 \$/Ft^3)	Total 1975 \$ (in millions)
Phase I	35.31- 88.27	(1.00 - 2.50)	3.5 - 8.75
Phase II	79.46-105.94	(2.25 - 3.00)	7.9 - 10.5

9.3.1.2 GOODYEAR MODEL

The Goodyear Aerospace Corp., using their past cost records and cost estimates of proposed airships, developed a plot of air displacement volume vs. total dollars in a 1963 report (ref. 9-10) for both a fleet quantity and a prototype. This plot, updated to 1975 dollars, is shown in Fig. 9-5. An analysis of this figure yields the cost estimates shown in Table 9-3.

Fig. 9-5 also indicates a slightly reduced unit cost with size, as opposed to the previous plot of Fig. 9-4.

9.3.1.3 METALCLAD MODEL

In 1931 a paper by Fritsche (ref. 9-4) of the Detroit Aircraft Corp., estimated costs for a 33,980 m^3 (1.2×10^6 ft^3)

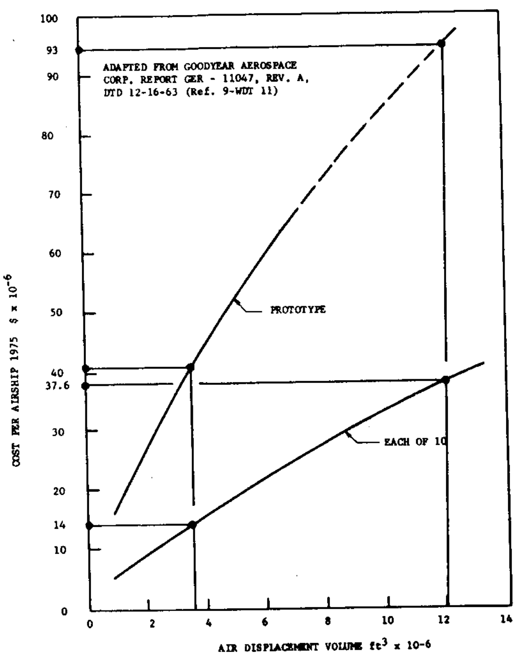


FIGURE 9-5

AIRSHIP CONSTRUCTION COST VS. DISPLACEMENT VOLUME

metalclad airship, the ZMC-12. This estimate was based on the ZMC-2 experience. The estimated 1931 cost of $24.49/kilogram ($54/pound), based on 6 airships being built, is equivalent in 1975 to about $69.85/kilogram ($154/pound). On this basis, the estimated Phase I and Phase II airship configurations would be $169.27/$m^3$ ($4.51/$ft^3$) and $143.02/$m^3$ ($4.05/$ft^3$), respectively.

9.3.2 BUILDING BLOCK MODEL

The building block method of cost estimation is based on the philosophy that the total construction process is a sum of the components. When the building block method is used to estimate the cost of an airship, several assumptions are made:

1. no penalties or advantages are incurred in the costs of assembling the "building blocks" into the total airship;
2. present technology can be applied directly to the construction of an airship without penalty or advantage due to the changes in size and scale;
3. the analogies drawn between airship building blocks and current construction practices are valid; and,
4. direct linear relations of cost hold when an analogy is drawn.

In the building block model of estimating both Phase I and Phase II airship costs, each vehicle was looked at as an assembly of six basic systems:

1. structure and hull;
2. propulsion;
3. controls;
4. buoyancy;
5. load and unload; and,
6. avionics.

In turn, each of the six systems was broken down, where feasible, into subsystems, and the subsystems into components. For example, the control system was broken into electronics, elevators and rudders. The individual components were then priced and a total for each subsystem and system then determined. In view of the fact that no rigid airship has been built since the 30's, modern technology has really never

TABLE 9-3

AIRSHIP COST ESTIMATES FROM GOODYEAR MODEL

Phase	Total Dollars Per Airship (millions)	Unit Cost $/$m^3$	($/ft.^{3})	Comments
I	$14.	141.26	(4.00)	Fleet of 10
	$40.	403.65	(11.43)	Prototypes
II	$37.6	110.53	(3.13)	Fleet of 10
	$93.	273.69	(7.75)	Prototypes

been applied to airship construction; therefore, an analogy was drawn between the largest commercial airplane, the 747, and the airship. The assumptions are

1. construction methods and techniques would not differ materially between the two vehicles;
2. the assembly of components, such as wiring, hydraulic systems, etc., are directly proportional;
3. there is a direct relation between cost per unit weight of a 747 airplane hull and structure and cost per unit weight of an airship hull and structure; and
4. that enough airships will be built so that the learning curve and prototype costs are absorbed in the same proportions as the 747 airplane.

When these additional assumptions were made, the approximate weight and cost of the 747 engines were deducted from the aircraft and a unit weight determined. This cost per unit weight was then applied directly to the estimated weight of the structure and hull of the airship.

After the cost of each of the systems had been determined, the systems costs were totalled and a cost estimate of approximately \$7,000,000 or about \$70/m^3 (\$2/ft^3) was obtained for the Phase I ship. The cost of the Phase II airship totaled \$21,000,000 or about \$62/m^3 (\$1.75/ft^3)

9.3.3 Cost Summary

The results of each of the historical cost models and the 747 building block model are given in Table 9-4. For the Phase I airship, the fleet cost ranged from \$35.31/m^3 (\$1.00/ft^3) to \$159.25/m^3 (\$4.51/ft^3). For the Phase II ship, the estimates ranged from \$61.80/m^3 (\$1.75/ft^3) to \$143.02/m^3 (\$4.05/ft^3).

Prototype construction costs were estimated from the Goodyear curve to be \$403.65/m^3 (\$11.43/ft^3) and \$273.69/m^3 (\$7.75/ft^3) for airships the size of Phase I and Phase II. No other prototype costs were determined.

9.4 SUMMARY

Estimates of the future construction costs of airships vary greatly and any model chosen is certainly open to criticism. Since any possible mission for the airship would be greatly dependent on the initial capital outlay for the vehicles, some value had to be chosen for the mission economics. As noted in Table 9-4, the construction cost for both airships was assumed to be \$176.55/m^3 (\$5.00/ft^3). This dollar figure should be conservative, based on all of the cost models used in this chapter.

Figure 9-6 is a size comparison of the Phase I and Phase II airships. As noted previously, the Phase II vehicle is larger than any airship that has ever been built. Photographs of models of each airship are shown in Fig. 9-7.

TABLE 9-4

UNIT COST SUMMARY

	ESTIMATED FLEET COST/SHIP			
	Phase I		Phase II	
	\$/M^3	(\$/ft^3)	\$/M^3	(\$/ft^3)
HISTORICAL MODELS				
Composite Historical Plot	35.31-88.27	(1.00-2.50)	79.46-105.94	(2.25-3.00)
Goodyear Report (ref. 9-10)	141.25	(4.00)	110.53	(3.13)
ZMC-12	159.25	(4.51)	143.02	(4.05)
BUILDING BLOCK MODEL				
747	70.63	(2.00)	61.80	(1.75)
FOR MISSION DATA				
Upper Limit Costs	176.55	(5.00)	176.55	(5.00)
ESTIMATED PROTOTYPE COST/SHIP				
Goodyear Report (ref. 9-10)	403.65	(11.43)	273.69	(7.75)

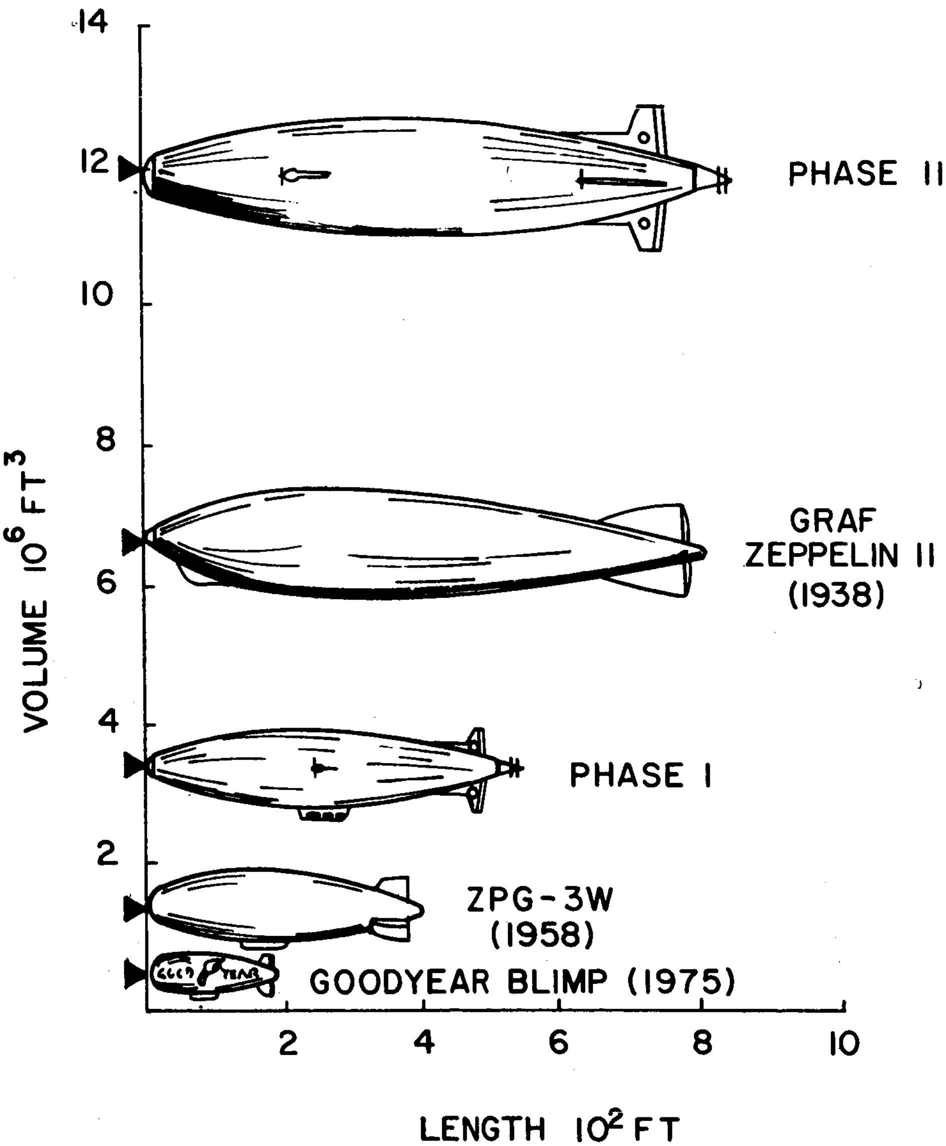


FIGURE 9-6
SIZE COMPARISON OF SELECTED AIRSHIPS

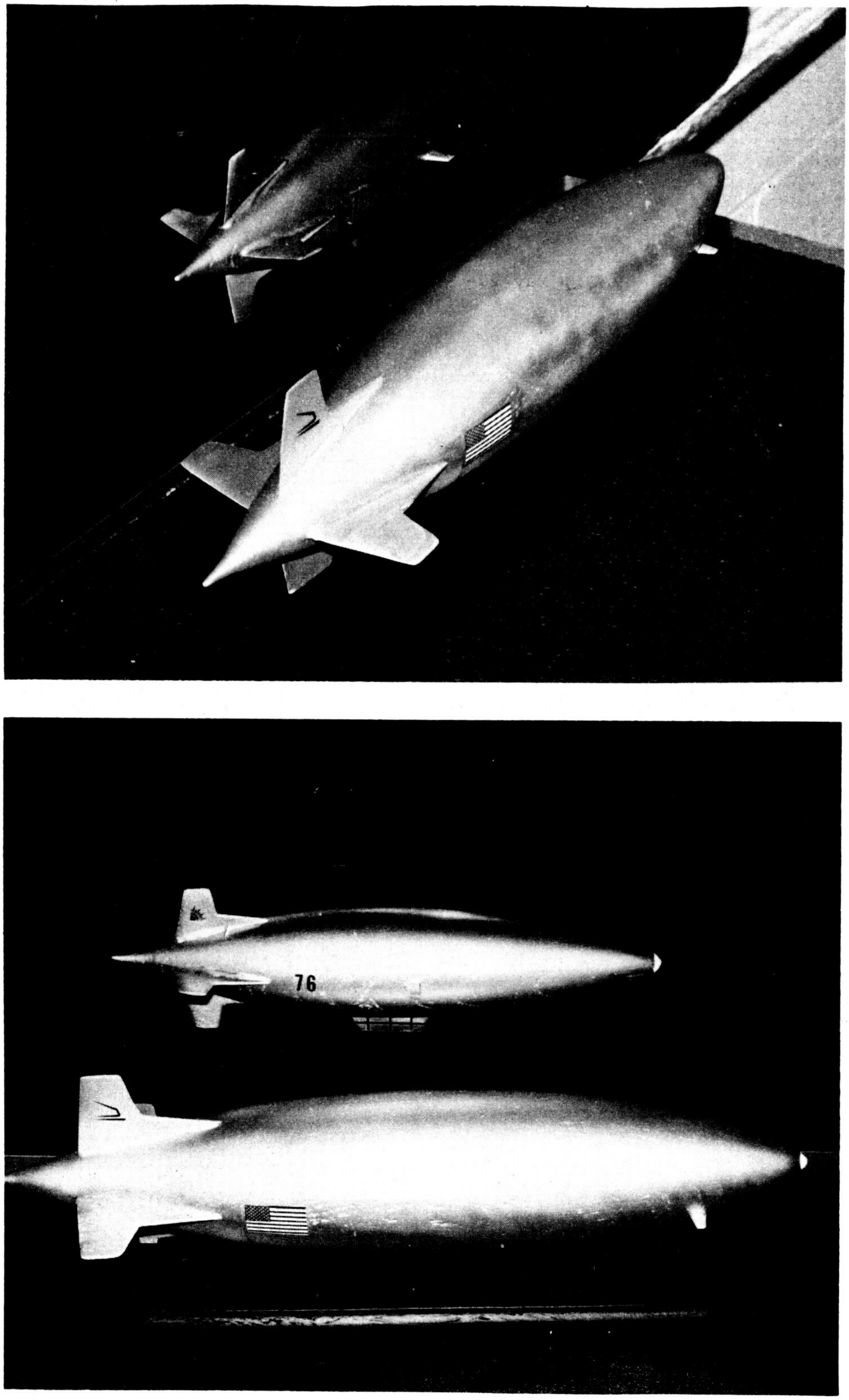


FIGURE 9-7
PHOTOGRAPHS OF MODELS OF THE PHASE I AND PHASE II AIRSHIPS

SELECTED REFERENCES

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CHAPTER 10

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10.1 PHASE I MISSIONS

10.1.1 INTRODUCTION

The hypothetical missions outlined in this chapter are by no means all inclusive but are intended to be representative of major ares of interest. Each mission was analyzed in sufficient detail to permit a thorough economic and operational appraisal. When important, social, legal, political, and environmental factors are discussed.

The specific missions outlined below are studied in detail.

PHASE I

1 - Heavy Loads - Apartment Modules,
2 - Commodities and Mail,
3 - Scenic Tour - Grand Canyon.

Two methods of economic analysis are utilized to evaluate the economic feasibility of some of the mission examples. A simple capital recovery (CR) model was utilized to rather quickly evaluate the economic feasibility of various missions. Then some of the missions were analyzed in greater detail utilizing the more rigorous present value (PV) model discussed in Chapter 2. The basic similarities and differences between the models are presented below:

1. The present value model derived the maximum feasbile airship costs as an output. The return on investment model specified a maximum airship cost $117.00/m^3 ($5.00/ft^3) as an input. The output of the return on investment model was the annual return on funds invested.

2. Both models assumed a cost of capital of eight percent which means that the airship transportation system would have to earn eight percent per year to be viable as an unsubsidized carrier in the private sector.

3. The CR model is not as accurate as the PV model in measuring the time value of money. However, both models lead to similar investment decisions when the initial cost of competing projects is the same and when projected revenues and expenditures do not vary substantially from year to year.

4. For the missions analyzed, both models yielded approximately the same investment decisions because the derived construction costs from the PV model were approximately the same as the assumed construction costs in the CR model for rates of return close in magnitude to the cost of capital.

5. The PV model is more flexible, precise, and comprehensive than the CR model.

10.1.2 HEAVY LOADS

10.1.2.1 OPERATIONS DESCRIPTION

Proponents of LTA transportation systems often emphasize the advantages of the vertical takeoff capability of airships. One article notes the following potential:

> Despite its potential, modular housing construction has been limited by two factors: (1) the difficulty of transporting and positioning large modules, and (2) the slow curing rate of normal concretes, leading to low output from the complex machines used to produce three dimensional structures. The latter problem has been solved at the Politechnical Institute in Kishinev by developing techniques that use quick-setting concretes. Special equipment has been designed and tested that yields six to eight times the productivity of the older methods.
>
> As a result the bottleneck is now transportation and installation of the modules. Modern construction management coordinates manufacture, transportation, and installation into a single production cycle. The use of dirigibles to transport and position building modules could smooth production flow by eliminating delays caused by poor roads or great distances between the module factory and construction site. (ref. 10-1)

One of the final statements in the same article is

> This would indicate that modular housing construction is a very promising potential market for Lighter Than Air.

Modular construction of housing units has for many years been an accepted procedure within the mobile home industry. However, the most serious restriction to this type of construction has been the allowable load widths and weights on the various states' highway systems, requiring special transportation vehicles and special permits. This has effectively limited construction materials to lightweight wood frames. The advantages that are inherent in modular construction are numerous and can be briefly stated as follows:

1. Central construction permits economy of scale with respect to purchase of raw materials and storage at a central location.

2. Construction location can be selected with reduced labor cost considerations due to travel.

3. Better quality control can be maintained because several units can be under construction simultaneously in the same location.

4. Ability to check all systems--electrical, plumbing, heating, and cooling--while in the central yard facilitates correction of problems.

5. Central construction will permit the use of semiskilled labor to a greater extent on repetitive work. Utilization of forms, jigs, and other tooling permits an assembly line process at reduced overall cost.

Modular construction was used to build a hotel at the San Antonio, Texas, Hemisfair. Habital, an apartment complex in Montreal, Canada, originally constructed for Expo '67, was also built using modules. This type of construction has the same advantages as outlined above when applied to single family modular housing units. Additional benefits are:

1. Construction can provide units at the final location without necessity to provide onsite concrete cure.

2. The usual problem of scheduling of various trades such as electricians, plumbers, carpenters, steel tiers, etc. is minimized.

3. Fewer pieces of heavy construction equipment are required at the site.

According to reference 10-2, a 32.5 m^2 (350 ft^2) floor space module weighing 22,226 kilograms (24.5 tons) requires a truck tractor and two truck trailers for transportation. One crane at each end of the trip is needed for loading, unloading, and positioning.

The amount and type of labor at the actual construction site are significantly reduced using a LTA transportation system. Cost of labor is directly influenced by the distance of the job site from nearest urban area, especially in states with strong trade unions where the travel time for craftsmen is usually paid portal to portal. When the distance to the site exceeds approximately 50 miles, cost of food and lodging may also have to be paid.

Numerous differences exist between modular construction techniques and traditional construction procedures. Modular construction utilizes forms, curing materials, paint and/or finishing in a factory that in traditional construction would require transportation to the site. For a typical project, the items creating differential costs between modular construction and conventional construction are outlined below:

1. Equipment not needed at site:
   a. mixers - concrete
   b. trucks - concrete or crane - concrete placing
   c. curing material
   d. form material

2. Men not required at site:
   a. plumbers
   b. concrete finishers
   c. electricians
   d. steel erectors
   e. rough carpenters
   f. finish carpenters
   g. heating and cooling technicians
   h. laborers
   i. equipment operators

NOTE: A few of the above would be required to resolve onsite problems.

3. Transportation not require to site:
   a. vehicles to move all materials and equipment listed in (1) above
   b. vehicles to move men listed in (2) above

An additional advantage of centralized modular construction is control of the work environment. This permits construction to be accomplished throughout the year without the additional construction costs due to delays caused by weather.

10.1.2.2 ECONOMICS

The economic analysis of the Phase I heavy cargo mission is presented below. One of the basic assumptions is that the use of airships would allow modularly constructed apartments to capture five percent of the total apartment market. It is further assumed that the assembly line techniques associated with modular construction would reduce construction costs by 15 percent. (See Appendix C for details.) These savings are assumed to be available for transportation costs. Theoretically, the cost of transportation could be, at a maximum, equal to the total construction costs savings.

In order to capture this large a share of the market, 16 airships and 6 terminals located in various sections of the country would be required. The airships could either belong to the construction companies involved or the service could be provided by a vendor operating the airship transportation system.

The economic analysis presented below is based on the PV model outlined in Chapter 2. The economic life of the airships and terminals is assumed to be 20 years. Projected annual revenues would be approximately $73,000,000. Maximum feasible costs of the airship per cubic meter were calculated at various internal rates of return between three percent and 20 percent. The results of these calculations are presented in Table 10-1. An historical projection of airship construction costs (see Chapter 9) indicates that the range of airship construction costs is between \$35.00 per m^3 and \$161 per m^3 (\$1.00 per ft^3 and \$4.50 per ft^3), depending on the method of analysis utilized. Thus it appears that this mission could earn an internal rate of return between 3 and 15 percent.

TABLE 10-1

MAXIMUM PHASE I AIRSHIP
COSTS AT VARIOUS INTERNAL RATES OF RETURN

Internal Rate of Return	Cost of Airship Per m^3	Per ft^3
.03	$385.00	$ 10.89
.08	202.00	5.73
.12	116.00	3.28
.15	71.00	2.01
.20	20.00	0.56

In addition to the PV analysis outlined above, the capital recovery (CR) method was also utilized to evaluate costs and revenues on an annual basis. The CR analysis made all of the same assumptions as the PV analysis, except that the cost of the airship was regarded as a given. In the CR analysis airship construction costs were assumed to be $177.00/m^3$ ($5.00/ft^3$). The basic data for this analysis are presented in Table 10-2. Projected annual revenues would exceed projected annual costs by approximately $21,300,000 annually. As noted earlier, any net positive revenue indicates a favorable investment opportunity when this method is utilized. Thus both the PV model and the CR model indicate that the movement of apartment modules by airship would be economically feasible.

10.1.2.3 LEGAL, POLITICAL, SOCIOLOGICAL, AND ENVIRONMENTAL

Legal

The same legal constraints outlined in Chapter 3 apply to the movement of modularly constructed housing units. However, it is likely that local and state regulations would be instituted to control the movement of externally attached heavy loads over heavily populated areas.

Political

This application might be opposed by the various building trade unions. Most housing construction utilizes craft methods, which are inherently less efficient than assembly line techniques. As noted previously, the mobile home industry is the only sector of the housing industry to apply factory methods to most aspects of housing construction. The use of airships would make it possible to extend assembly line techniques to an additional sector of the housing industry.

Sociological

The potential for reducing the cost of housing is a social benefit. If factory construction techniques could cut costs by more than the airship transportation costs, a cost reduction could be partially passed along to consumers.

Environmental

Transporting of manufactured units such as apartment modules by airship would have a continuing environmental impact at the

TABLE 10-2

PHASE I ECONOMIC DATA: HEAVY LOADS

	COSTS	
C. R. 16(1,746,500)	$27,944,000	(16 airships)
Crews, flight - 16(667,720)	10,683,520	(4 shifts - 6 men - 16 airships)
Fuel & maint. 16(480,000)	7,680,000	(4000 hours, 16 airships)
Crews, Ground	3,600,000	(3 shifts, 5 men 16 airships)
Crews, office	960,000	(2 shifts, 2 men, 16 office crews)
C. R.	231,000	(6 terminals)
Insurance	175,000	(1% of first cost)
	778,000	(1% of revenue)
Helium Cost 16(28,000)	448,000	(20% 1st cost of helium)
Total	$52,459,520	

REVENUE

Revenue at 5% of market and a construction cost savings of 15% gives $73,800,000 factory site and a temporary impact at the construction site. The manufacturing site would be located in an area zoned for industrial use or a rural area. The factory site would require heavy construction equipment, a concrete mixing plant, and sand and gravel storage as well as a large storage area for completed and partially completed apartment units.

The airship operation for this application would require a relatively small landing area with refueling and ballast management facilities. Engines will be designed to meet EPA emission and noise standards. In addition, the plant will not be located close to residential areas.

Fuel storage and waste handling will be in accordance with existing ordinances for the area. The loading procedure at the factory will not require airship landing. Modules will be attached to a hovering airship. In the hover mode, however, the airship may temporarily exceed EPA recommended noise levels. The rural or industrial area location of the factory will greatly reduce citizen exposure to noise. Employees working near the airship as it hovers will be required to wear ear protection. Some removal of vegetation and displacement of small forms of wildlife will occur during construction of terminal facilities.

The overall impact of the LTA terminal and operation on the environment will be mitigated in the design of the facility by generous use of open space, noise reducing screens of vegetation and/or walls.

Visual impact could be significant to the extent that it distracts motorists. However, increased familiarity with airships should reduce this problem. In time, the operation of an airship should cause no more distraction to motorists than other aircraft.

10.1.3 COMMODITIES AND MAIL

10.1.3.1 OPERATIONS DESCRIPTION, COMMODITIES

10.1.3.1.1 GENERAL

Conceptually, the Phase I commodity transportation system will provide service among eight major metropolitan areas. Although airships have door-to-door flight capability, ground facilities for loading and unloading are located only at terminals. Consequently, there will be an interface with other transportation modes at terminal locations. It is assumed that 1980 will be the first year of operation for the airship fleet, with an estimated lifetime of twenty years.

10.1.3.1.2 DEMAND

An assessment of the potential commodity market demand for an airship transportation system was made using data compiled by the Bureau of Transportation. Table 10-3 shows the 1967 data from which the 1980 data were extrapolated, assuming an annual increase in transportation traffic of 2.4 percent.

A weighted average distance of 611.55 kilometers (380 miles) was determined from the data in Table 10-1, and assuming potential demand to be .00125 of rail traffic and .0025 of truck traffic, 1980 annual demand was estimated to be 340.75 x 10^9 Kg-Km (233,393,091 ton-miles). An average flight of 611.55 kilometers (380 miles) would consume an actual flight time of 4.75 hours, and allowing one hour for loading, unloading, and refueling operations, each flight would consume a total of approximately 6 hours. Consequently, each airship would be capable of making 833 flights annually, and contribute 833 x 611.55 Km (380 miles x 22,679.6 Kg (25 tons) = 11.533 x 10^9 Kg-Km (7,913,500 ton-miles) so that the total number of airships in the system would be:

TABLE 10-3

U.S. COMMODITY TRAFFIC ACCORDING TO DISTANCE AND MODE*
(MILLIONS OF KILOGRAMS) [THOUSANDS OF TONS]

Distance (kilometers) [miles]	All Modes	Rail (1967)	Truck (1967)	Rail (1980)	Truck (1980
(402.336) [250]	(71,125) [78,402]	(29,304) [32,302]	(29,659) [32,694]	(39,886) [43,967]	(40,371) [44,501]
(482.8032-642.128256) [300-399]	(95,116) [104,847]	(38,712) [42,673]	(34,374) [38,374]	(52,692) [58,083]	(47,384) [52,232]
(643.7376-803.062656) [400-499]	(59,738) [65,850]	(33,393) [36,810]	(20,191) [22,257]	(45,453) [50,103]	(27,483) [30,295]
(804,672-963.997056) [500-599]	(48,699) [53,682]	(26,103) [28,774]	(15,145) [16,695]	(35,530) [39,165]	(20,615) [22,724]

*adapted from ref. 10-6

An upper limit on total flight hours is 30 x 5,000 = 150,000 hours. Each flight crew is assumed to fly 960 hours annually and hence 157 crews are required for the system.

10.1.3.1.3 OPERATIONAL COSTS

Operational costs refer to total costs of the system. Specifically, personnel costs include flight, terminal, and hangar crews. There are assumed to be eight cargo terminals and one hangar where temporary and periodic (scheduled) maintenance and overhaul take place. Since there are numerous airship hangars already in existence, it is assumed that these facilities may be rented or leased by the proposed system.

Flight personnel consist of a pilot, copilot/navigator, mechanic, and loading supervisor. Personnel at each terminal consist of two loaders/unloaders, one communications technician/mechanic, one supervisor, and one clerk. Personnel at the hangar consist of two mule operators, three security personnel, a mechanic, a structures technician, an electronics technician, a clerk, and a supervisor. Salaries of these personnel and other project costs are listed in Appendix B.

10.1.3.1.4 APPLICATION OF THE ECONOMIC MODEL

Since disaster insurance, spare parts, and salvage value of the fleet are all functions of initial fleet cost (A_0), these relations are established a priori as follows: disaster insurance is assumed to be 2 percent of the initial fleet cost (A_0), spare parts are assumed to be 1 percent of A_0, and fleet salvage value as 15 percent of A_0. The following terms result:

$$A_0 + .02A_0 + .01A_0 - .15A_0$$

The present value expressions of these sums differ, and the following terms are derived:

$A_3 = .02A_0$ = initial insurance payment (for 1 year)

$B_0 = (.02A_0/r)[1 - (1 + r)^{-(t-1)}]$

$C_8 = (.01A_0/r)[1 - e^{-rt}]$

$S_0 = .15\ A_0[1 + r]^{-t}$

Applying these definitional terms to the general model presented in Chapter 2 (eq. 2-2) results in:

$$A_o = \frac{(.99R/a)[1-e^{-at}]+\sum_1^3 Si(1+r)^{-t}-\sum_1^3 Ai-(1/r)}{1.02 + (.02/r)[1-(1+r)^{-(t-1)}]+(.01/r)\ \dfrac{\{B_1[1-(1+r)^{-(t-1)}]+\sum_0^7 Ci(1-e^{-rt})\}}{(1-e^{-rt})-.15\ (1+r)^{-t}}} \qquad (10\text{-}1)$$

Equation 10-1 is used to determine A_0, given parametric values of R, α, and t. R is equal to revenue, α is equal to the required internal rate of return, and t is equal to the useful life of the ship in years. For the parametric analysis, useful life was assumed to be 10 years and 20 years. The internal rate of return (α) was set at 3%, 8%, and 12%. Revenue (R) was determined by multiplying the rate per kilogram-kilometer (ton-mile) by the estimated demand of 3.41×10^{11} Kg-Km (2.33×10^{8} ton-miles).

The calculation results are given in Table 10-4.

10.1.3.1.5 INTERPRETATION OF RESULTS

As expected, the higher the revenue, the greater the maximum costs that can be incurred. For example, if revenue is based on .024¢/Kg-Km (35¢/ton-mile), a rate of return of eight percent may be obtained if construction costs of the airship do not exceed $79.48/m^3$ ($2.25/ft^3$) (assuming a 20-year lifetime).

Alternative prices per mass-distance may be considered from Table 10-4, by linear interpolation. For example, under t=20 years, a price of .02¢/Kg-Km (30¢/ton-mile) would allow construction costs to be $49.08/m^3$ ($1.39/ft^3$) at an 8% rate of return.

The table also indicates that commodities at the going rate of .01¢/Kg-Km (15¢/ton-mile) will not generate enough revenue. (See Chapter 9 for actual construction costs.) A mix of commodities and mail possibly doubling the revenue is needed to allow construction of Phase I ships. See section 10.1.3.2 for a discussion of the mail operation.

10.1.3.1.6 ENVIRONMENTAL CONCERNS

The environmental impact of an airship transportation system carrying a mixed cargo of mail and commodities would occur both at the terminal and along the routes flown. The terminals could be located either at new locations constructed specifically for airships or at the smaller existing airports on the outskirts of urban areas with separate facilities constructed for the airship operation.

This type of airship operation would require a cargo terminal, parking lot, refueling equipment, and an operations building. The refueling, maintenance, and general terminal operation would require sewage, water, and solid waste disposal procedures. The cleanup after refueling, routine maintenance and cargo handling could also require waste-water treatment facilities before introducing effluent into the storm sewer system.

The operations at the terminal area will require parking and manuever area for

TABLE 10-4

PHASE I REVENUE AND CONSTRUCTION COST PARAMETERS: COMMODITIES

Revenue Assumed	Internal Rates of Return Assumed $\alpha = .03$	$\alpha = .08$	$\alpha = .12$
(t = 10 year life)			
0.010¢/Kg-Km (15¢/ton-mile)	--	--	--
0.017¢/Kg-Km (25¢/ton-mile)	\$ 44.15/m^3* (\$1.25/ft^3)	\$ 14.48/m^3 (\$0.41/ft^3)	-- --
0.024¢/Kg-Km (35¢/ton-mile)	\$102.79/m^3 (\$2.91/ft^3)	(\$ 61.11/m^3) (\$1.73/ft^3)	(\$ 36.03/m^3) (\$1.02/ft^3)
(t = 20 year life)			
0.010¢/Kg-Km (15¢/ton-mile)	\$4.24/m^3 (\$0.12/ft^3)	-- --	-- --
0.017¢/Kg-Km (25¢/ton-mile)	\$95.73/m^3 (\$2.71/ft^3)	\$18.72/m^3 (\$0.53/ft^3)	-- --
0.024¢/Kg-Km (35¢/ton-mile)	\$186.86/m^3 (\$5.29/ft^3)	\$79.48/m^3 (\$2.25/ft^3)	\$28.26/m^3 (\$0.80/ft^3)

*Airship construction costs possible.

TABLE 10-5

PHASE I ECONOMIC DATA: MAIL SORTING AND TRANSPORTATION

COSTS	
Capital recovery for airship (3.5 x 10^6 ft^3 @ \$5/ft^3, 20 yrs, 8%)	\$1,746,500
Flight Crew (P, CP, FE @ 960 hrs/yr) (\$121,930/crew for 6 crews)	731,580
Fuel & Maintenance/yr	675,000
Ground Crew/yr (10 men at each end serving 6 ships/shifts, 3 shifts)	150,000
Ground Facilities (\$3.0 million first cost, 20 yrs, 8%)	300,000
C.R. for sorting machines (\$6 million first cost, 20 yrs, 8%)	598,800
Sorting crew/yr, 3 crews/day (\$20,000/man for 12 men/crew)	720,000
Helium cost (12% of F.C. leakage) (8% of F.C. interest)	28,000
Insurance (1% of F.C. & 1% of REV.)	288,390
	\$5,238,270
REVENUE	
Transportation @ \$0.09/lb, 18 tons of mail (6 tons of equip., 1 ton men)	\$2,920,000
Sorting (2 digits) @ \$0.09 lb, 18 tons of mail (6 tons of equip., 1 ton men)	2,920,000
TOTAL ANNUAL REVENUE	\$5,840,000

air and ground crew vehicles as well as trucks handling cargo. The operation of these vehicles will cause local concentration of engine emissions at peak operations periods and their operation will raise the noise level intermittently. Since the terminal will be located in areas zoned for industrial land uses, the above impacts should be acceptable.

The additional activity will induce economic growth in the immediate vicinity of terminals; however, this is anticipated to be small and to consist primarily of housing for employees and service industry personnel supporting the operation.

The additional water and electrical power required for the airship operation will impose an additional load on the community utilities system. Because the overall operation is comparatively small, the impact should be insignificant.

10.1.3.2 MAIL OPERATIONS

10.1.3.2.1 GENERAL REMARKS

Mail could be carried, for example, from Dallas, Texas, to Kansas City, Missouri, for .024¢/kilogram-kilometer (35¢/ton-mile). This is the current price being paid to airplanes based on competitive bids. This value was obtained by telephone from the U.S. Postal Service in Washington, D.C.

10.1.3.2.2 DEMAND

In 1970, a total of $461,000,000 was spent for the transportation of mail by scheduled air carriers. This represented 1.05×10^{12} kilogram-kilometers (7.15×10^{8} ton-miles) or about 0.0445¢/Kg-Km (65¢/ton-mile) (ref. 10-4).

Due to the recent fuel shortage, the number of night passenger flights has been reduced. These planes had previously carried large amounts of mail. The use of the airship to carry mail would fill in the gap left by the reduction in available airplane space.

10.1.3.2.3 OPERATIONAL COSTS

Details of the operational costs are shown in Table 10-5. Slightly different assumptions are made for mail than were made for commodities. The mail might be sorted by the last two digits of the zip code while in flight. This would require sorting machines and a sorting crew. The cargo would have to be reduced to 1.64×10^{4} kilograms (18 tons). An attachment for equipment and people as well as cargo would have to be added. The weight of the car would be offset by the removal of the loading/unloading platform and the hoist system. Utilizing the CR method of analysis, an annual cost/ship/year of approximately $5,250,000 would result and a revenue of approximately $5,850,000 would be generated.

10.1.3.2.4 APPLICATION OF THE PV ECONOMIC MODEL

The "mail only" or a mix of mail and commodities raise the revenue over that for commodities alone. Fig. 10-1 gives the results of the PV economic analysis (see Table 10-2) as applied to the mail commodity combination. Many combinations of revenue and rates of return are available for construction costs over $71/m^3$ ($2/ft^3$).

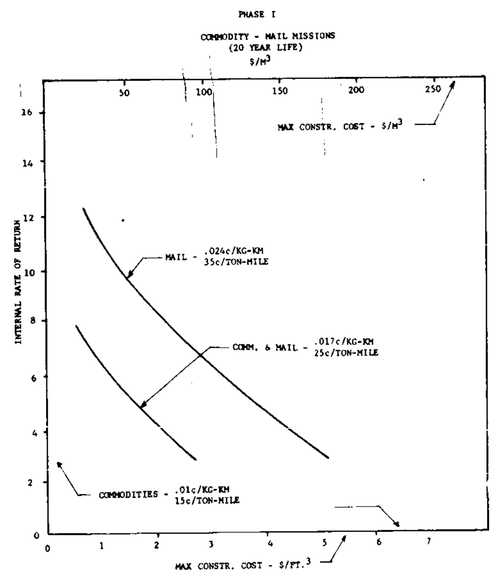

FIGURE 10-1

PHASE I COMMODITY - MAIL MISSIONS (20 YEAR LIFE) $/M^3

10.1.3.2.5 SOCIOLOGICAL CONCERNS

Definite social benefits could be derived from moving mail with an airship transportation system. Trucks are generally utilized to carry mail over short and medium distances. The economic analysis conducted for this mission indicates that airships could compete economically with trucks for the medium distance. For the longer range, of course, airplanes are much faster. Utilized in the medium range niche, the airship offers substantial advantages when compared to truck transport. The airship is not only faster than the truck, but also offers the possibility of sorting mail by the last two digits of the zip code in flight. Both of these advantages increase the speed with which the Postal Service can process the mail. Thus, it appears that the airship can increase the efficiency with which the mail is delivered without increasing costs.

10.1.4 SCENIC TOURS

10.1.4.1 OPERATIONS DESCRIPTION

The presence of man in our national parks and other public land areas is causing significant environmental damage. Methods of mitigating these adverse environmental impacts are being implemented in Yosemite and Yellowstone National Parks in the form of public transportation systems designed to reduce individual motor vehicle traffic. In some wilderness areas, it has become necessary to introduce strict regulations concerning disposal of waste by hikers.

Serious consideration is being given to restricting the number of visitors to the National Parks to protect the environment as noted in several statements in the third annual report of the council on environmental quality (ref. 10-5).

> Even with new urban recreation areas and with increased citizen use of National Parkways and National Historic Areas, the 'crown jewels'--the unique National Parks--will still be under demands that cannot be met without restricting their use.
>
> The danger is that we may not heed the very warning first sounded in the parks. If not heeded, there might follow another chapter in 'The Tragedy of the Commons.' As postulated in the late 19th century treatise, the multiplied individual use of a common pasture by village residents would eventually destroy the pasture for all. The 21st century chapter in 'The Tragedy of the Commons' would be the consequence of overusing the fragile areas, thus impairing forever the qualities for which they were originally preserved.

Utilization of the airship for scenic cruises or tours, especially over National Parks, could thus be beneficial from an environmental viewpoint. The automobile and pedestrian traffic inside our parks could be substantially reduced with simultaneous reductions in environmental damage, while still permitting the people of the nation to see and enjoy the scenic wonders of the areas. Airship terminals could be located well outside the parks, thus reducing the necessity for additional improvements to the transportation and other service facilities within the parks.

The Grand Canyon application was selected for a detailed economic analysis. The 1973 U.S. Statistical Abstract (ref. 10-4) indicates that 804,000 people stayed overnight at the Grand Canyon in 1971. Also, the number of people visiting national parks has been increasing 10 percent per year. The total number of people visiting national parks in 1970 was over 172,000,000. For the Grand Canyon tour it is assumed the airship would operate 300 days a year with an average of 600 passengers daily. The airship terminal would be located outside the park area, with parking, waiting rooms, restrooms, and operations offices provided.

A conceptual plan for a passenger pod is shown in Fig. 10-2. This pod is to be used with the Phase I airship and has a maximum capacity of 200 passengers. The structural configuration includes a double-deck arrangement. The floor area of the pod conforms to the cargo hold dimensions. The pod could be fastened to the airship on a semi-permanent basis by means of structural steel members located on the four corners of the roof.

The plan calls for two rows of seats around the perimeter of the pod on both levels. A refreshment bar is located in the top center portion of the cabin. Two primary exits would be located at the ends of each level of the airship. Depending upon the loading method, these doors must be carefully engineered to prevent passengers from opening them accidentally. Additional safety measures should be incorporated to assure that these doors are locked during flight. Emergency exits should be located on both sides of the pod for both levels. Exterior glass is tinted.

Additional studies should be made of the conceptual floor plan manufacturing. Human engineering studies should be conducted to assure minimum congestion in aisles, as well as comfortable viewing angles for all passengers. Another problem to be considered would be the methods of loading and unloading passengers. A method minimizing ballasting problems would allow disembarking passengers to exit on one side of the airship pod while passengers for the next flight are entering the opposite side.

10.1.4.2 ECONOMICS

In an effort to assess potential passenger demand and the elasticity of fares, the following people and firms were contacted by phone about current tours:

1. Superintendent of Grand Canyon National Park
2. Grand Canyon Airport
3. Grand Canyon Airlines
4. Grand Canyon Helicopter Tours

<u>Helicopter Tours</u>

The origin of this tour is Grand Canyon Airport, located four miles south of the south rim off Highway 64. Bell Jet Ranger Helicopters are used which have a capacity of four passengers. Currently, the service is operating three helicopters continuously ten hours per day, with a maximum of three trips per hour. Maximum capacity is around 120 passengers per day. Passengers may choose from among the following tours:

1. From airport, across the river and back.

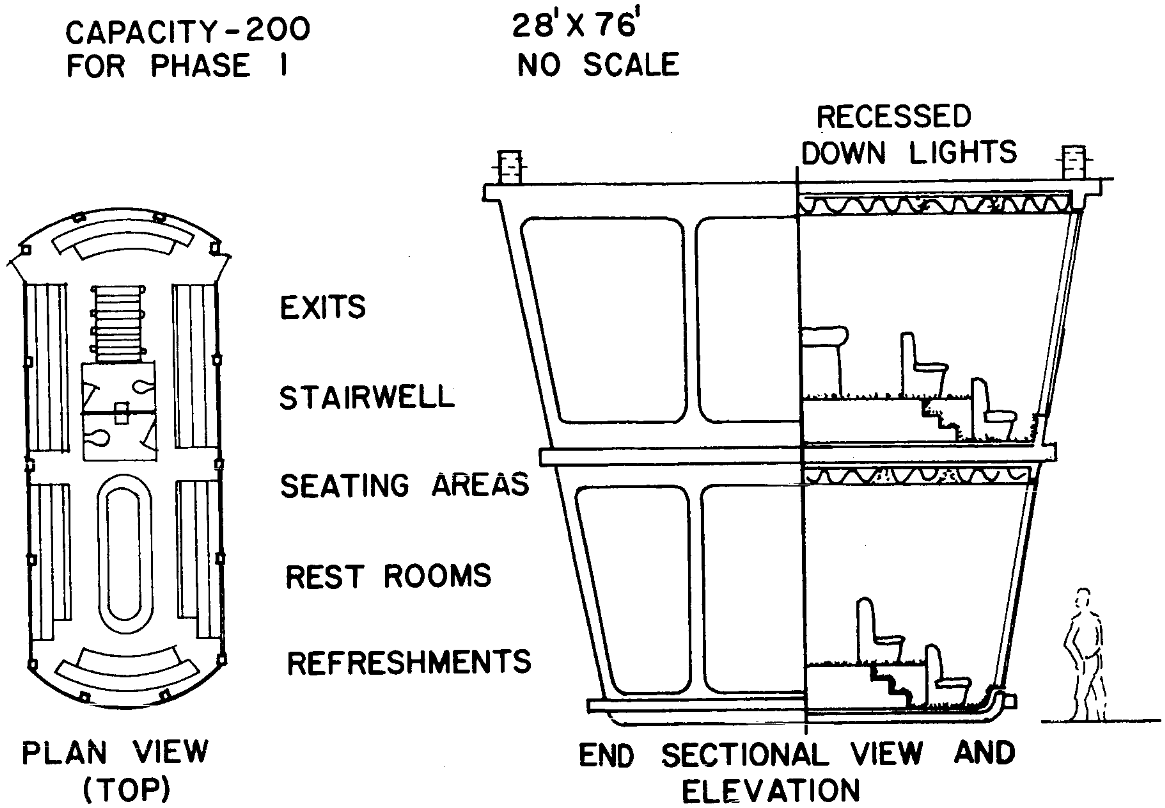

FIGURE 10-2

PASSENGER POD

20 minutes	52 Kilometers (32 miles)	$27.00

(children under 2 free)

2. From airport, over the north rim, Indian ruins and back.

30 minutes	67 kilometers (42 miles)	$45.00

3. From airport to the east side at junction of Little Colorado and Colorado Rivers and back.

45 minutes	113 kilometers (70 miles)	$73.00

Fixed Wing Aircraft Tours

Grand Canyon Airlines operates flights of 1 hour duration the year around. The basic information is as follows:

Flight time .... 1 hour

Distance Covered .... 209 kilometers (130 miles)

Number of Aircraft Operating .... 6 airplanes (twin Cessnas)

Passengers per flight 30

Passengers per day 210

Fare (1 hour) $25.50

Daily Revenue (approximate) $5,355.00

In addition, Scenic Airlines operates a shuttle service out of Las Vegas. The fare is $86.00 per person and offers an air tour as well as a ground tour connection. The tour lasts all day.

Mule Trips

Trips to the Canyon floor and back via mules are available daily. Price per person is $20.00 (minimum age is 12). An overnight mule trip is also available which includes two box lunches, a breakfast at Phantom Ranch, and sleeping quarters for 1 night. The price per person is $70.

In addition to the air tours listed, the Grand Canyon Airport, during a ten day period (June 20-30, 1975), had 6,008 passengers utilizing the airport as passengers in private aircraft. Seven thousand people visited the airport in June 1974.

Assuming a fare of $20.00 per passenger, a passenger pod with a capacity of 200 and an 85 percent occupancy factor, four flights per day for 300 days per year yield an annual revenue of $4,080,000 for the Grand Canyon tour. (See Table 10-6.) Annual costs associated with the tour would be approximately $3,600,000. Included in

TABLE 10-6

PHASE I ECONOMIC DATA: GRAND CANYON TOUR

ANNUAL COSTS

Capital recovery	=	$1,746,500	(airship 99,108.8 m^3 (3,500,000 ft.^{3}))
Crew, flight	=	667,720	(4 shifts, 6 men)
Fuel and maint.	=	270,000	(4 trips/day, 300 days/yr)
Crew, ground	=	225,000	(3 shifts, 5 men)
Crew, office	=	225,000	(3 shifts, 5 men)
Capital recovery	=	213,250	(mast, office, ramps)
Insurance	=	175,000	(1% of first cost)
		40,800	(1% of revenue)
Helium cost	=	28,000	(20% of first cost of Helium)
Total	=	$3,591,270	

REVENUE

200 passengers x 0.85 occupancy x 4 flights/day x 300 days/year x $20/flight

Total = $4,080,000

these costs is a capital recovery cost of almost $2,000,000, based on an investment of $20,500,000. The total investment is composed of $17,500,000 for the airship itself and $3,000,000 for the terminal and other support facilities. Both the airship and terminal are assumed to have a life of 20 years. Opportunity costs or the cost of capital were assumed to be 8 percent. Utilizing the capital recovery (CR) method of analysis, any project generating annual revenues greater than direct annual operating costs plus annual capital recovery costs represents a favorable investment opportunity. Based on an annual revenue of $448,000 in excess of direct expenses and capital recovery costs, the Grand Canyon tour appears to be economically feasible.

The Grand Canyon tour was also analyzed using the present value (PV) model. This model utilized the same estimates of direct costs as the CR model. Both models assumed an eight percent return (the minimum rate of return for feasible private sector operations. The maximum cost of the airship was calculated to be $189/m^3$ ($5.35/ft^3). This analysis suggests that the project will be economically feasible if the necessary airship can be built for a cost which is less than or equal to $189/m^3$ ($5.35/ft^3). Thus, both the CR and the PV models indicate that the Grand Canyon tour would be economically feasible.

10.1.4.3 LEGAL, SOCIOLOGICAL, AND ENVIRONMENTAL CONCERNS

Legal

The legal aspects of airship operations are discussed in Chapter 3. The primary legal concern focuses upon the routes flown by the airship. In all cases the airship will have to be certified by the FAA. Since the scenic cruise mission will operate within a single state, state and local regulations rather than CAB regulations would govern routes and rate structures. In general, separate FAA regulations do not exist for airship operations. The airship is generally required to comply with the same regulations which apply to the airplane.

Sociological

Airship tours of the Grand Canyon will have substantial sociological benefits. This proposed tour will bring a large number of people into closer contact with the Grand Canyon than the traditional methods of seeing the Canyon. The airship cruise will allow individuals to view a much larger portion of the Canyon than seen on fixed-wing and helicopter tours.

A major benefit associated with this tour would be a reduction of the automobile traffic in the park itself. Most national parks are currently faced with an overload of automobile traffic at peak tourist seasons. The airship would bring people into the park and allow a spectacular view of the park without increasing automobile traffic.

Environmental

The use of an airship to provide scenic trips over the Grand Canyon will have several positive environmental impacts. The use of the airship will actually provide one means of protecting the environment of the Grand Canyon while simultaneously providing a means for the citizens of the nation to enjoy its scenic beauty. The future plans for operation of our national parks anticipate a reduction in the permissible number of visitors at peak tourist seasons.

The airship operation would require development of a passenger terminal, parking lot, and airship handling facility outside the park. Some removal of vegetation and displacement of wildlife would occur. The refueling, maintenance, and general operation would require a local water source and waste water treatment unit. A site and approved procedure for solid waste disposal would also be required. The operation of passenger and crew automobiles as well as the airship would create localized degradation of the air quality; however, this is expected to be below discomfort and hazard levels even at peak periods. The amount of electrical power required for the terminal operation can be minimized by proper design.

The actual flight over the Grand Canyon would affect air quality, create noise, and have visual impact. The design of the engine emission and noise levels must be within established restrictions. These factors can be further controlled by varying altitude as necessary. Some economic growth can be expected in the area, consisting primarily of service industry for the airship operation and housing.

The use of airships would actually reduce present pollution levels in the park caused by automobiles.

10.2 PHASE II MISSIONS

10.2.1 Introduction

The Phase II airship will be designed to carry 9.09×10^4 Kg (100 tons) and to have a range of 3,219 Km (2,000 miles). These expanded load and range capabilities increase the mission possibilities for a lighter-than-air transportation system.

Specific mission possibilities for Phase II airships are analyzed in the remainder of this Chapter. Specific missions analyzed include:

1. Heavy Loads - Single Family Dwellings
2. Commodities and Mail
3. Public Service - Space Shuttle Casing.
4. Scenic Tour - West Coast

10.2.2 Heavy Loads

10.2.2.1 OPERATION DESCRIPTION

Prefabricated Bridge Units

Prefabricated construction procedures can be applied to the construction of highways, railroads, and similar structures. Modular bridge units, in particular, can be fabricated in a central location, and then transported and placed by airship. This would be especially beneficial when temporary construction roads can be eliminated at cost savings of $10,000 to $20,000 per mile. Environmental credits also accrue due to the elimination of the need to cross streams with ground vehicles, etc. Time is directly equated to economics in the construction industry and the ability to immediately move into the construction of structures without the necessity to construct access roads on new locations is important.

When it is necessary to modify existing highways with high traffic volume, a capability for quickly positioning prefabricated bridge units would be extremely beneficial. Costs to the traveling public required to detour around construction areas are real and substantial. These costs include time costs, additional stops required, and additional operating costs of the vehicle. Overall costs of environmental protection for the project would be reduced. The social costs associated with the project in terms of noise and air pollution imposed on residents in the adjacent areas would be reduced accordingly.

Modular Housing

Modular construction of housing is still in its infancy except for mobile homes; however, with rising costs of new home construction, more and more mobile homes are being purchased for residences by young couples, low income families, and retired individuals. Most cities have zoning laws and building codes that prevent the use of mobile homes except in special areas. These restrictions are primarily due to lightweight construction.

The reinforced concrete units that have been constructed in the locations mentioned previously overcome the objections that are raised to mobile homes and offer the potential for providing good homes at reasonable costs.

Presently, one restriction faced by the contractor prefabricating full-size single family homes in a factory is the necessity to transport the units by truck in half units requiring assembling at the site. The use of airships would provide the means to transport the entire house in one piece.

Present building code requirements in most communities are written in a manner that precludes modular construction in most instances. The reasoning or basis for these codes was that they would prohibit mobile homes which many people consider substandard and likely to deteriorate quickly. True modular construction is not the same as mobile home construction. In most cases, the construction standards for modularly constructed homes will exceed those of mobile homes. The increased structural strength associated with modular construction should allow builders of these homes to meet existing building codes.

10.2.2.2 ECONOMICS

The basic assumption underlying this economic analysis is that modular housing requiring airship transportation could account for 10 percent of new single family housing by 1990. It is assumed that it would be possible to charge a transportation fee equal to 10 percent of the construction costs savings.

An analysis of current housing trends and an estimate of potential demand are presented in Appendix C. Based on an estimated revenue of $25,938,000 annually and an airship life of 20 years, a present value analysis was utilized to derive maximum airship costs. These results, presented in Table 10-7, indicate that an airship built for $234.55 m^3 ($6.64 ft^3) or less would be economically viable for this application.

In addition to the present value (PV) analysis, a more general capital recovery (CR) analysis comparing annual costs and revenues was also completed. A fleet size of 4 airships costing $60,000,000 each is assumed. A 10 percent salvage value and an 8 percent cost of capital are assumed. Table 10-8 summarizes the analysis.

TABLE 10-7

MAXIMUM PAHSE II AIRSHIP COSTS AT VARIOUS INTERNAL RATES OF RETURN (20 YEAR LIFE)

Rate of Return	Maximum Costs m^3	Maximum Costs ft^3
0.08	$385.73	$ 10.92
0.10	234.55	6.64
0.12	162.83	4.61
0.15	126.10	3.57
0.20	83.36	2.36

10.2.2.3 SOCIOLOGICAL AND ENVIRONMENTAL CONCERNS

Sociological

Utilizing the Phase II airship to move and position bridges and bridge components would result in several direct and tangible social benefits. The overall environmental impact would be less than from methods currently in use. Since the erection of the bridge could be accomplished more rapidly, the area surrounding the construction site would be affected for a shorter period of time, which would mean less damage to the environment. Moving major components to the site by airship would reduce truck traffic to the site and reduce stress on the roadbed. Moving major components to the site by airship would also mean that the need for construction roads would be educed.

10.2.3 COMMODITIES AND MAIL

10.2.3.1 OPERATIONS DESCRIPTION COMMODITIES

TABLE 10-8

PHASE II ECONOMIC DATA: HEAVY LOADS*

Capital Recovery	$ 5,988,000	(One airship)
Crew, flight	667,720	(Two crews)
Fuel and maintenance	2,000,000	(4,000 hours)
Crew, ground	450,000	(1 shift-10 men)
Crew, office	225,000	(1 shift-5 men)
Capital Recovery	67,200	(Terminal, office, masts)
Insurance	600,000	(1% of first cost)
	210,000	(1% of revenue)
Helium Cost	115,200	(20% of first cost of helium)
Total Cost	$10,323,120	

Revenue @ 10% of market, 10% construction cost savings $21,000,000

* A complete economic analysis was not completed for single family modular houses; however, the basic information is included in the Appendix.

10.2.3.1.1 GENERAL

The Phase II commodity transportation system is assumed to begin operation in 1990. However, this is not meant to imply that Phase II airships could not be built before 1990, or that they would not be competitively viable before that time. Rather the decision is partially prompted by considering that flight crew and ground handling crew experience gained in Phase I operations might provide invaluable expertise in the larger airship operations.

The four terminals needed for this mission will be located in Los Angeles, Dallas, Kansas City, and New York. Thus, the airship would be capable of flying coast to coast with a single stopover. The same assumptions used for Phase I are also applied in Phase II.

10.2.3.1.2 DEMAND

Table 10-9 data were used to determine potential market demand in a manner analagous to Phase I. A weighted average distance of 1510 Km (938 miles) was derived, so each airshp could service 1510 kilometers (938 miles) x 9.09 x 10^4 kilograms (100 tons) = 1.373 x 10^8 Kg-Km (93,800 ton-miles) per flight. Since demand (1990, projected) is 3.3057 x 10^8 Kg (364,393 tons), an average distance of 1,510 kilometers (938 miles) determines an annual demand of 4.99 x 10^{11} Kg-Km (341,800,634 ton-miles).

Each airship can make 294 flights a year, thus servicing 4.026 x 10^{10} Kg-Km (27,577,200 ton-miles). Consequently, the total number of airships in the fleet is approximately 13. The total number of flight hours is 5000 hours x 13 airships = 65,000 hours, and assuming that each flight crew is limited to 960 flight hours annually, 68 crews are required.

10.2.3.1.3 OPERATIONAL COSTS

There are assumed to be four cargo terminals and one hangar where temporary and periodic (scheduled) maintenance and overhaul take place. Personnel at each terminal consist of four load/unload personnel, two communications/mechanics technicians, two electronics technicians, two clerks, operators, three supervisors, and three security personnel.

Flight personnel consist of a pilot, copilot, navigator, and mechanic/freight supervisor. Salaries and other costs are listed in detail in Appendix B.

10.2.3.1.4 APPLICATION OF THE ECONOMIC MODEL

Revenue and cost data associated with this mission are analyzed with the PV model. The general results are shown in Table 10-10.

10.2.3.1.5 INTERPRETATION OF RESULTS

The results in Table 10-10 are clearly better than for the Phase I system. Using the 0.010¢/Kg-Km ($0.15/ton-mile) assumption, if the Phase II airship can be built at a cost of $61.82 m³ ($1.75 ft³) or less, a rate of return of approximately six percent can be realized. The competitive viability of the Phase II airship for this mission is contingent upon realized revenues, as shown in Table 10-10. It would be unrealistic to assume that an airship mode could attract high-revenue traffic exclusively. Moreover, even though a 6 percent return is possible, airship operations must be treated as a new venture, and, as such, require a return on capital investment at least on the order of 20 percent.

From the foregoing analysis, it appears that even though the Phase II airship is superior to the Phase I airship for commodity transportation, competing modes of transportation are still competitively superior.

10.2.3.2.1 GENERAL REMARKS

Mail could be carried, for example, from Seattle, Washington to Los Angeles, California for .023¢ per kilogram-kilometer (35¢ per ton-mile). This is a representative price paid to airlines on competitive bids.

10.2.3.2.2 DEMAND

If there was not enough mail for a full load, the mail could be sorted in

TABLE 10-9

U. S. COMMODITY TRAFFIC ACCORDING TO DISTANCE AND MODE*
(MILLIONS OF KILOGRAMS) [THOUSANDS OF TONS]

Distance (kilometers)[miles]	All Modes	Rail (1967)	Truck (1967)	Rail (1980)	Truck (1980)
(965,6064-1285.865856) [600-799]	(95,186) [104,925]	(41,026) [45,223]	(21,322) [23,503]	(70,787) [78,029]	(36,789) [40,553]
(1287.4752-1607.734656) [800-999]	(75,521) [83,248]	(26,357) [29,054]	(10,649) [11,738]	(45,478) [50,131]	(18,373) [20,253]
(1609.344-1929.603456) [1000-1199]	(37,662) [41,515]	(14,123) [15,568]	(5,348 [5,895]	(24,369) [26,862]	(9,227) [10,171]
(1931.2128-2412.406656) [1200-1499]	(95,264) [105,011]	(12,479) [13,756]	(3,715) [4,095]	(21,532) [23,735]	(6,410) [7,066]

*adapted from ref. 10-3

TABLE 10-10

PHASE II - REVENUE AND CONSTRUCTION COST PARAMETERS: COMMODITIES

REVENUE	INTERNAL RATES OF RETURN a = .03	a = .08	a = .12
t = 10 year life			
0.010¢ KgKm ($0.15 ton mile)	$49.09 m3 ($1.39 ft3)	$31.44 m3 ($0.89 ft3)	$20.84 m3 ($0.59 ft3)
0.017¢ KgKm ($0.25 ton mile)	$107.03 m3 ($3.03 ft3)	$77.71 m3 ($2.20 ft3)	$60.05 m3 ($1.70 ft3)
0.024¢ KgKm ($0.35 ton mile)	$164.96 m3 ($4.67 ft3)	$123.63 m3 ($3.50 ft3)	$98.90 m3 ($2.80 ft3)
t = 20 year life			
0.010¢ KgKm ($0.15 ton mile)	$86.54 m3 ($2.45 ft3)	$40.97 ($1.16 ft3)	$19.43 m3 ($.55 ft3)
0.017¢ KgKm ($0.25 ton mile)	$176.62 ($5.00 ft3)	$100.67 m3 ($2.85 ft3)	$65.00 m3 ($1.84 ft3)
0.024¢ KgKm ($0.35 ton mile)	$266.67 ($7.55 ft3)	$160.36 m3 ($4.54 ft3)	$110.20 m3 ($3.12 ft3)

flight by the last 2 digits of the zip code. The total revenue for this type of load should be about the same as for a full load of mail.

10.2.3.2.3 OPERATIONAL COSTS

The costs and revenues are detailed in the economic model. The results are shown

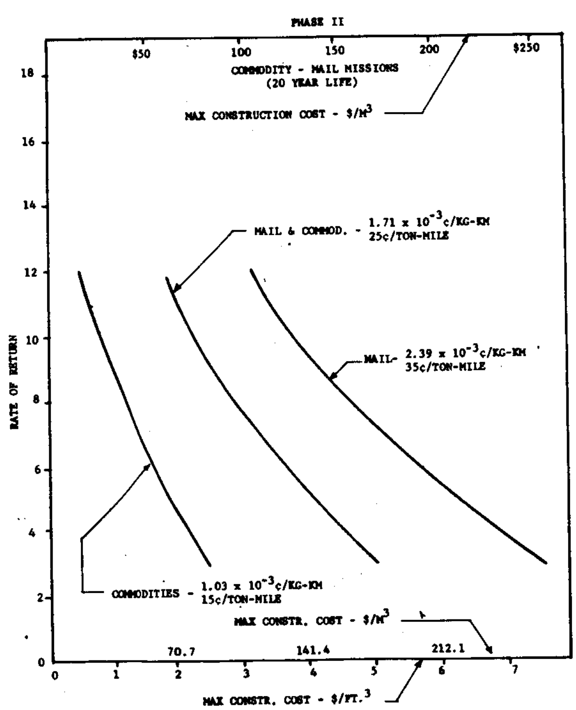

FIGURE 10-3

PHASE II COMMODITY - MAIL MISSIONS

in the curves for Phase II. If the mail was sorted in flight, this would require sorting machines and a sorting crew.

10.2.3.2.4 APPLICATION OF THE ECONOMIC MODEL

If the economic model is used for a cargo of mail only, the operation appears to be profitable.

For example, a maximum construction cost of $141.40 per m^3 ($4 per ft^3) for the airship would yield a rate of return of slightly less than 9.5%. (See fig. 10-3.) This rate of return suggests that the Phase II airship would be an economically competitive means of moving the mail.

10.2.4 PUBLIC SERVICE MISSION: RETRIEVAL OF SOLID FUEL ROCKET CASINGS

10.2.4.1 OPERATIONS DESCRIPTION

Over 1500 launchings are projected for the space shuttle during the 1980's. In standard launch procedures, rocket casings are jettisoned into the ocean after the fuel is expended. These boosters can be refurbished and reused if retrieved from the ocean. The casings are 45.4 meters (149 ft.) long, 3.71 m (12 ft. 2 in.) in diameter; and weigh 8.15×10^4 kilograms (89.9 tons) empty.

10.2.4.2 ECONOMICS

The following economic analysis is based upon the assumption that each retrieved casing would have a salvage value of $2.20/Kg ($1.00/lb). Thus the salvage value for each casing would be approximately $179,000. If 150 annual launchings are assumed, total yearly savings from retrieval of casings would be approximately $27,000,000.

TABLE 10-11

PHASE II ECONOMIC DATA:
ROCKET CASING RETRIEVAL

COSTS

Capital Recovery	2($5,988,000)	10,976,000.	(Two airships)
Crew, Flight	2(660,020)	1,335,440.	(Two crews, 8 shifts 6 men)
Fuel and maint.	2(2,000,000)	4,000,000.	(Two ships, 4000 hours)
Crew, Ground	2(450,000)	900,000.	(3 shifts, 10 men)
Crew, Office	2(225,000)	450,000.	(3 shifts, 5 men)
Capital Recovery	2(67,200)	134,400.	(Two terminals, masts, office)
Insurance	2(600,000)	1,200,000.	(1% of 1st cost)
		1,922,600.	(1% of Revenue)
Helium Cost	2(115,200)	230,400.	(20% of 1st cost of Helium)
	Total Cost	21,148,840.	

COST SAVINGS

1,500 total casings ÷ 10 year (program length)
x 170,600 lb. (casing weight) x $1.00 =
$26,900,000 year.

The capital recovery (CR) analysis assumes a fleet of two airships, costing $60,000,000 each. The airships are assumed to have a salvage value of 10 percent and a useful life of 20 years. Cost of capital is assumed to be 8 percent. The results of the CR analysis are presented in Table 10-11. The analysis indicates that this mission would be a cost effective use of the Phase II airships.

10.2.4.3 SOCIOLOGICAL AND ENVIRONMENTAL CONCERNS

Sociological

The overall social impact of utilizing the airship to retrieve rocket casings would be positive. Since a relatively large number of launchings can be expected annually, retrieval can be cost effective. The ability to recover and reuse these rocket casings will yeild direct and tangible resource savings without entailing any significant social costs.

Environmental

The public service mission described above will have minimal environmental impact. The airship will be able to leave and return to the launch site with routes entirely over water. The actual recovery operation will be handled from a hover mode without airship contact with the water. Emissions from engines will dissipate without detrimental effect.

10.2.5 SCENIC TOUR

10.2.5.1 OPERATIONS DESCRIPTION

A tour along the West Coast of the United States of about 1,609 Km (1,000 miles) could attract a large number of people. Three hundred passengers could fill each of 240 flights per year. The cruising speed would be 26.82 meter/sec (60 mph).

The passenger car would replace the load/unload platform and the hoisting mechanism. This would leave a net payload of 9.09×10^4 Kg (100 tons). The flight crew would consist of the pilot, copilot, navigator, purser, and 30 stewards.

There would be 50 staterooms, a coach area, lounges, etc. Two people would occupy a stateroom, and would each pay an additional $50 for this comfort. The coach tickets would be $125 each. Twenty trips per month would be made between Los Angeles and Seattle.

10.2.5.2 ECONOMICS

The assumptions used in the cost calculations were $17,500,000 airship cost, 20-year life, 10% salvage value, 8% interest. The flight crew was assumed to be a pilot, copilot, navigator, purser, and 30 stewards. Table 10-12 outlines projected costs and revenues.

TABLE 10-12
PHASE II ECONOMIC DATA: WEST COAST TOUR

COSTS		
Capital recovery	$ 5,988,000	(Airship)
Crew, flight	667,720	(4 shifts, 6 men)
Stewards	1,200,000	(30 @ $10/hour)
Fuel and maintenance	1,000,000	(4,000 hours/year)
Crew, Ground	450,000	(3 shifts, 10 men)
Crew, office	225,000	(3 shifts, 5 men)
Capital recovery	213,250	(Mast, office, ramps)
Insurance	600,000	(1% of first cost)
	108,000	(1% of revenue)
Helium cost	115,200	(20% of first cost of helium)
Total	$10,567,170	

REVENUE

300 people/flight x 240 flights/year x $150/person = 72,000 x $150 = $10,800,000

10.2.5.3 ENVIRONMENTAL CONCERNS

The cruise area for this mission would be parallel to the West Coast. The airship operation would require development of a passenger terminal, parking lot, and airship handling facility outside of the urban area. Some removal of vegetation and displacement of wildlife would occur. The refueling, maintenance, and general operation would require a local water source and a waste-water treatment unit. A site and approved procedure would be required for the disposal of solid wastes. The operation of passenger and crew automobiles as well as the airship would create localized degradation of the air quality; however, this is expected to be below discomfort and hazard levels even at peak periods. Electrical power will be required for the terminal operation but the amount can be minimized by proper design.

The actual flights would be parallel and adjacent to the coast. The airship would create a visual and noise impact; however, this should be acceptable for the short periods of time involved.

10.3 FUTURE MISSIONS

Potential future applications for LTA transportation systems are worldwide and extremely diverse. This section outlines some applications which may be feasible as experience is gained with airship operations and as the technology is developed.

Underdeveloped countries suffer continually because of lack of transportation systems. There is a correlation between the level of overall development in a nation and the development of its transportation system. Construction of transportation systems in these nations is usually a slow process requiring construction procedures progressing from the point of origin toward the final destination. The use of airships would permit initiating construction at several points along a route and moving heavy equipment quickly and easily. In addition, the airship would allow developing nations to utilize centralized modular construction of structures which would reduce cost and expedite construction. The airship would provide an economical means to move materials and equipment into remote settlements for construction of basic community improvements.

The concept of centralized construction or assembly of complete units that now are shipped as component parts to the final location and assembled there will no doubt be expanded beyond the 100 ton limit used for this study up to the 300 to 400 ton range. This would open a wide range of possibilities for new methods of construction in all fields, substantially changing the character of work methods. Generators and other large components for use in large electrical generating plants, whether nuclear or conventional power, are now constructed at the manufacturer's plant, assembled to test, disassembled, and shipped to the final location for reassembly. The time savings, cost reduction, and additional flexibility associated with the removal of transportation constraints would be very beneficial.

Keating, in his paper entitled, "The Transport of Nuclear Power Plant Components," (ref. 10-6) discusses the potential number of nuclear plants to be constructed by the year 2000. It is estimated that 700 new nuclear plants will be constructed in the 1981 to 2000 period with 50 to 20 percent located inland. These plants will have major component units ranging in size from 18 tons to 1000 tons.

In a telephone conversation, Mr. Lyle Lafauer, Project Engineer for the Pacific Gas and Electric Company, Diablo Canyon Nuclear Power Plant construction project, stated that at that project major component units weighing from 88 to 400 tons were involved, requiring a special roadway, 192 wheel transporter, and a specially constructed gantry crane for offloading from barge to land. Mr. Lafauer also stated that his information indicates over 1000 nuclear plants are anticipated in the U.S. by 2000 with only 55 now in operation and 60 under construction. Twenty-six foreign nations are planning for an additional 212 nuclear plants during the same time frame.

Although this report did not deal with military applications, the potential for movement of equipment, housing, etc., would be an immediately feasible application at any time that such use were deemed advisable. In addition, surveillance-type missions for special operations, such as maneuvers, etc. would be very practical.

The use of airships as vehicles for surveillance in our wilderness areas, during disasters, and during major forest fires, etc. is a very feasible application. The flexibility of an airship providing a stable hovering platform for long durations would be beneficial in such applications. Goodyear has also examined the feasibility of a small airship for police use.

Helicopters have recently become popular for agricultural purposes (planting and spraying) due to their ability to maneuver in a STOL or VTOL mode. The airshp would have a definite potential in this area and be superior due to greater load capabilities and flight duration.

Emergency missions utilizing the high load capacity and VTOL mode capability of the airship in times of national and international disaster are definitely feasible. This application is difficult to address in economic terms; however, nations spend millions yearly in disaster relief. Hospital ships would fall in this category as well as being considered separately when aid to underdeveloped countries is the topic. A disaster mission might take the form of one of the following:

1. Series of Explosions (Texas City 1948)
2. Earthquake
3. Flood
4. Wind Storm
5. Atomic attack

When disaster occurs, facilities such as those listed below are disrupted:

1. Telephone lines
2. Electric lines
3. Natural gas mains
4. Water mains
5. Sanitary sewers
6. All ground transportation systems
7. Air transportation requiring fixed runways

An airship could serve as a command headquarters over the disaster area. It could provide a base for security operations to prevent looting. It could provide transportation for:

1. Food and portable kitchens
2. Water and portable purifiers
3. Fuel of all kinds
4. Medical supplies
5. Clothing and blankets
6. Portable hospitals
7. Portable shelters

This list of possible applications is not intended to be exhaustive or all-inclusive, but rather to briefly touch on a few of the many potential areas where the airship can fulfill a need. In ref. 10-7, a paper prepared by Mr. Horsburgh, he outlines many additional areas of potential airship applications:

> Lighter-than-air vessel operations are of immediate relevance to geological and mineral exploration, forestry management and logging; agricultural services; crop fertilization spraying; stock supervision, pollution observation and assessment; mariculture and fisheries; offshore oil rig servicing; scheduled bulk transportation of routine cargos, of fragile perishables, and livestock; unscheduled, incidental deliveries and pipeline inspections. . . .
>
> Humanitarian uses of lighter-than air vessels would include all forms of tempest, aircraft and highway accidents, policing and general public safety. Special hospital facilities and operating equipment could be assembled aloft, as in any field hospital, and emergency food distribution, human and livestock, are obvious benefits, while educational travel and exploration, and tourism (for the revelation of territorial and natural wonders and wildlife sanctuaries to which public should not have access) are among the more pleasurable operations required of lighter-than-air vessels.

The use of LTA's for commuter traffic in today's market is uneconomical; however, the constraints governing this conclusion, such as price of gasoline, availability and capacity of surface transportation facilities as well as levels of government subsidies, are changing continually. Rising costs of present transportation systems, including environmental costs, could dictate the use of an LTA transportation system in the future. The LTA system, because it does not require environmentally and sociologically damaging dedicated, fixed surface routes may become more attractive in the future.

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CHAPTER 11

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11.1 SUMMARY STATEMENT

An airship cargo transportation system for the carrying of large, heavy loads has been designed coneptually, using the techniques of systems engineering. Loads up to 9.1×10^4 Kg (100 tons) can be accommodated and are found economically feasible. A number of mission examples are given with economic analysis to illustrate the feasibility of the airship concept. These missions include examples ranging from public service and civil needs to long distance cargo hauling.

The design calls for implementation in stages designated as Phase I and Phase II. The Phase I stage calls for a fleet of rigid airships capable of carrying cargo loads of 1.27×10^4 Kg (25 tons) at a speed of 36 m/sec (80 mph) for a distance of 966 Km (600 miles). The hull volume for the Phase I airship is suggested to be $9.9 \times 10^4 m^3$ ($3.5 \times 10^6 ft^3$) and the lifting gas will be helium. The Phase II stage also calls for a fleet of rigid airships, carrying 9.1×10^4Kg (100 tons) at a speed of 27 m/sec (60 mph) for a distance of 3200 Km (2000 miles). The lifting gas will again be helium and the hull displacement will be $3.4 \times 10^5 m^3$ ($12 \times 10^6 ft^3$) for the Phase II airships.

Since the Phase II airships will be the largest ever built, the Phase I ships will be built first. Phase I will serve as a training base for construction techniques, ground handling, crew training, and load handling. Current technology should offer many engineering advances which were not available during the heyday of the airship. These advances include sophisticated communication electronics and navigation equipment, ground handling equipment, and exotic materials for construction. Also, innovative structural techniques should produce a more effective structure.

The load handling design calls for the cargo to be taken into a cargo hold inside the airship. Hoisting equipment would be part of load-unload mechanism and would travel with the airship to facilitate loading and unloading in remote areas.

The airships would have a stern-mounted propeller for propulsion as well as for a measure of boundary layer control and pressure drag minimization. Side-mounted engines would provide a hovering capability as well as thrust vector control.

In connection with the study, an airship attitude survey was conducted among members of Congress. Approximately forty percent of Congress responded to the questionnaire. The overwhelming majority of the respondents had a positive attitude about airships and their place in our nation's future. A majority of the respondents felt that a national investment in airships would be a worthwhile venture.

11.2 RECOMMENDATIONS FOR IMPLEMENTATION

The suggested sequence for the implementation of airships is shown in Fig. 11-1.

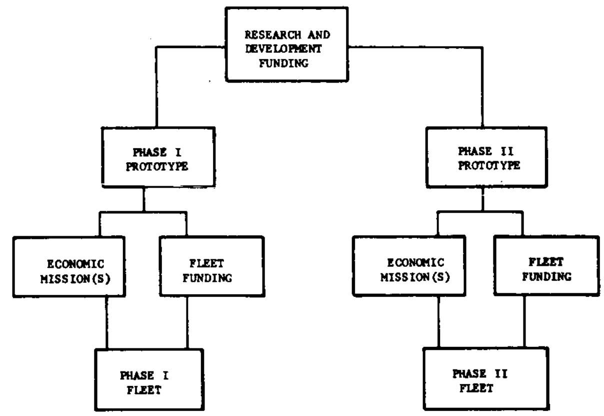

FIGURE 11-1
AIRSHIP IMPLEMENTATION

Distinct paths are noted for each size airship, but in reality, there may be an interdependence between the two.

Of the possible methods of R and D funding discussed in Chapter 3, the most feasible appears to be by government appropriation. A line-item in the budget of some governmental agency such as NASA would probably be best. The two airships could be developed simultaneously, or if the Phase I airship is to be used for testing and systems checkout, its development could precede the Phase II airship.

The prototype vehicles would be used for training of flight crews, ground crews, for flight qualification of equipment and vehicle certification. Assuming that feasibility is demonstrated in the prototype vehicles, a fleet could then be sized, depending on the missions deemed economic at that time. The Phase I fleets and the Phase II fleets could be developed independently; or, particular missions might require both ships to be built. Depending on the missions selected, the fleet funding could be private or governmental.

11.3 IDENTIFICATION OF NEEDED TECHNICAL ADVANCEMENT

The classical body of revolution shape is possibly not the best aerodynamic shape to be used for an airshape. Some recent studies have identified a "laminar" classical shape which is reputed to have less drag than the classical shape itself. This laminar shape supposedly retains a laminar boundary layer for a greater distance from the leading edge. Whether or not this is true is unclear at this time. Wind tunnel tests and/or potential-flow simulation of the shape could lead to some answers concerning questions of this nature. These types of analyses have been lacking thus far in the renewed study of airships.

Hoisting systems need to be designed to gain a reduction in weight with no loss in lifting capability. Possible ways of doing this would be to use aluminum instead of steel, use of composite materials and use of Kevlar cables for lifting.

Ground-handling equipment for these larger airships needs to be developed. This would involve use of a hydraulic, telescoping mast and larger, more mobile mules. A cable-arrest system similar to that used on aircraft carriers would also be a useful addition to ground-handling facilities.

An investigation of the trade-offs involved in using stainless steel as a hull material should be made. This is because of the potential of stainless steel as an outer skin material.

A significant amount of work remains to be done on the topic of materials technology. This involves the use of composite materials to reduce weight without any sacrifice in strength.

The thermodynamic management of the lifting gas and the air in the ballonets needs to be studied carefully. The amount of superheat and overpressure both could play significant roles in the lifting capability of the airships.

APPENDIX A
AIRSHIPS ATTITUDE SURVEY

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AIRSHIPS ATTITUDE SURVEY

Table A-1 is the survey form used to determine Congressional attitudes towards the lighter-than-air vehicle.

TABLE A-1

AIRSHIPS ATTITUDE SURVEY

Some corporations and governmental agencies are currently proposing that airships (lighter-than-air vehicles similar to blimps) be used to move both cargo and people. These proposals are based on the fact that the airship could handle much larger loads than airplanes and go directly to remote locations without airports or the necessity of elaborate site preparation.

The following questions ask you to express your opinions concerning the safety and economic feasibility of using airships for transportation. This is not an attempt to determine how much you know about airships, but what your opinions are about airships. No attempt will be made to identify any respondent by name.

Directions: Please circle the response which most closely represents your opinion.

1. I feel that airships could offer a practical means of moving extremely heavy cargoes.

1	2	3	4	5
Strongly Agree	Agree	Do Not Know	Disagree	Strongly Disagree

2. I would feel uncomfortable with a large airship flying over my community.

1	2	3	4	5
Strongly Agree	Agree	Do Not Know	Disagree	Strongly Disagree

3. I believe airships could compete economically with airplanes on specialized jobs such as carrying cargo to underdeveloped areas (jungles, arctic regions, etc.) which do not have airports.

1	2	3	4	5
Strongly Agree	Agree	Do Not Know	Disagree	Strongly Disagree

4. The airship is an outmoded form of transportation which should not be seriously considered for cargo or passenger transportation.

1	2	3	4	5
Strongly Agree	Agree	Do Not Know	Disagree	Strongly Disagree

5. I believe that modern technology could make the airship safe.

1	2	3	4	5
Strongly Agree	Agree	Do Not Know	Disagree	Strongly Disagree

6. Research and development funds to update airships for transportation purposes would be a good investment.

1	2	3	4	5
Strongly Agree	Agree	Do Not Know	Disagree	Strongly Disagree

7. I believe airships could be built safe enough for passenger transportation.

1	2	3	4	5
Strongly Agree	Agree	Do Not Know	Disagree	Strongly Disagree

8. The Hindenburg accident of 1937 demonstrates that airships are simply too dangerous to be used for civilian cargo or passenger transportation.

1	2	3	4	5
Strongly Agree	Agree	Do Not Know	Disagree	Strongly Disagree

TABLE A-1 (continued)

9. If modern technology can make the airship feasible, would you support Federal funding to make it a reality?

1	2	3	4	5
Definitely Would	Probably Would	Do Not Know	Probably Would Not	Definitely Would Not

Please check the section of the country that you represent.

____ EAST NORTH CENTRAL
Illinois, Indiana, Michigan, Ohio, Wisconsin

____ EAST SOUTH CENTRAL
Alabama, Kentucky, Tennessee, Mississippi

____ MIDDLE ATLANTIC
New Jersey, New York, Pennsylvania

____ MOUNTAIN
Arizona, Colorado, Idaho, Montana, New Mexico, Nevada, Utah, Wyoming

____ NEW ENGLAND
Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont

____ PACIFIC
California, Oregon, Washington

____ SOUTH ATLANTIC
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia

____ WEST NORTH CENTRAL
Iowa, Kansas, Missouri, Minnesota, Nebraska, North Dakota, South Dakota

____ WEST SOUTH CENTRAL
Arkansas, Louisiana, Oklahoma, Texas

____ ALASKA or HAWAII

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UNITED STATES SENATE

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APPENDIX B
COST DATA ON COMMODITY TRANSPORT

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COST DATA ON COMMODITY TRANSPORT

The following material is cost detail related to an airship fleet transporting commodities. Table B-1 and Table B-2 give the ground facility data for Phase I and Phase II respectively. Table B-3 gives crew costs for both Phases. Table B-4 and Table B-5 summarize the Phase I and Phase II cost data respectively.

TABLE B-1
PHASE I GROUND FACILITIES

HANGAR OPERATIONS	
Personnel at Hangar (annual costs)	
Mechanic (1)	$ 16,000
Structures (1)	16,000
Electronics (1)	16,000
Mule Operators (2 @ $10,000)	20,000
Clerk (1)	10,000
Supervisor (1)	20,000
Security (3 @ $8,000)	24,000
Administrative ($122,000 x .5)	61,000
Total Personnel Cost	$ 183,000
Other Costs (fixed)	
Mobile Mast	$ 500,000
Masts (stick) (4 @ $75,000)	300,000
Mules (2 @ $75,000)	150,000
Support vehicles and equipment	25,000
Total Other Cost (fixed)	$ 975,000
Other Costs (operating)	
Electricity	$ 12,000
Sewer and water $200/mo.	2,400
Telephone	2,000
Rent on hangar	120,000
Miscellaneous replacement equipment & supplies	25,000
Total Other Cost (operating)	$ 161,400
TERMINAL OPERATIONS	
Personnel at Terminal	
Load/unload (2 @ $10,000)	$ 20,000
Comm/Mech (1)	15,000
Supervisor	15,000
Clerk	10,000
Annual Cost for Each Crew	$ 60,000

Each 5-man crew contributes (49 weeks x 40 hours) =
1960 hours/year (364 days x 24 hours) ÷ 1960 =
5 crews x $60,000 = $300,000
(8 terminals) x $300,000 = $2,400,000
Administrative Costs (.5 x 2,400,000) = $1,200,000

Annual Cost for all Terminal Personnel $3,600,000

TABLE B-1 (CONTINUED)

Other Costs (fixed)	
Land - 1.4 x 10^5 m^2 (35 acres @ $1000 an acre)	$ 35,000
Building (operations room, radio, billing, etc.)	60,000
Mast (stick) (2 @ $75,000 each)	150,000
Electricity	10,000
Sewer and water	25,000
Maintenance (refueling, ballast handling)	10,000
Loading docks 15 m x 37 m (50 ft x 120 ft)	30,000
Access road, parking, etc.	100,000
Support vehicles	40,000
Total Other Costs (fixed)	$ 460,000
Total fixed cost for all terminals (8 x $460,000)	$3,680,000

Other Costs (operating)	
Electricity	$ 12,000
Sewer and water	5,000
Telephone	2,000
Miscellaneous replacement equipment and supplies	25,000
Total Each Terminal	$ 44,000
Total Other Operating Costs (8 terminals x $44,000)	$ 352,000

TABLE B-2

PHASE II GROUND FACILITIES

HANGAR OPERATIONS

Personnel at Hangar (annual cost)	
Mechanics (2)	$ 32,000
Structures (2)	32,000
Electronics (2)	32,000
Mule operators (4 @ $10,000)	40,000
Clerks (2)	20,000
Supervisors (3)	60,000
Security (3 @ $8,000)	24,000
Administrative ($240,000 x .5)	120,000
Total Personnel Cost	$ 360,000

Other Costs (fixed)	
Mobile Mast	$1,500,000
Masts, stick (2 @ $225,000)	450,000
Mules (5 @ $75,000)	375,000
Docking trolley	500,000
Support vehicles and equipment	50,000
Total Other Costs (fixed)	$2,875,000

Other Costs (operating)	
Electricity	$ 24,000
Sewer and water	3,600
Telephone	3,000
Rent on hangar	120,000
Miscellaneous replacement equipment and supplies	50,000

TABLE B-2 (CONTINUED)

Total Other Costs (operating)	$ 200,600

Personnel at Terminal	
Load/Unload (4 @ $10,000)	$ 40,000
Comm/Mech (2 @ $15,000)	30,000
Supervisor (2 @ $15,000)	30,000
Clerk (2 @ $10,000)	20,000
Annual Cost for Each Crew	$ 120,000

Each 10-man crew contributes (49 weeks x 40 hours) = 1960 hours/year (364 days x 24 hours ÷ 1960 = 5 crews. 5 crews x 120,000 = $600,000 (4 terminals) x $600,000 = $2,400,000 Administrative Costs (.5 x 2,400,000) = $1,200,000

Annual Cost for all Terminal Personnel	$3,600,000

Other Costs (fixed)		
Land - 3.03×10^5 m^2 (75 acres @ $1,000 an acre)	$ 75,000	
Building (operations room, radio, etc.)	60,000	
Masts (stick) (2 @ $225,000 each)	450,000	
Electricity	20,000	
Sewer and Water	25,000	
Maintenance (refueling, ballast handling)	30,000	
Loading docks 30 m x 37 m (100 ft x 120 ft)	60,000	
Access road, parking, etc.	100,000	
Support vehicles	80,000	
Total Other Costs (fixed)	$ 825,000	(except land)
Total ($825,000 x 4 terminals) =	$3,300,000	(except land)
Total Land Costs (75,000 x 4)	$ 300,000	
Total Other Costs (fixed) for 4 Terminals	$3,600,000	

Other Costs (operating)	
Electricity	$ 24,000
Sewer and Water	10,000
Telephone	3,000
Miscellaneous replacement equipment and supplies	50,000
Total Each Terminal	$ 85,000
Total Other Operating Costs (4 terminals x 87,000) =	$ 348,000

TABLE B-3

PHASE I AND PHASE II CREW COSTS

Flight Personnel

Total annual commodity demand is 340,747,452,100 kilogram-kilometers (233,393,091 ton-miles)

Average flight is 611.55 kilometers (380 miles) and takes 6 hours (allowing for load, unload, refuel, etc.).

TABLE B-3 (CONTINUED)

At a 5000 hour/year utilization rate, each airship will fly 833 flights annually, and since each average flight generates 611.55 x 22,679.6 = 13,869,709.38 kilogram-kilometers (380 x 25 = 9,500 ton-miles), each airship is capable of serving 13,869,709.38 x 833 = 1.16 x 10^{10} kilogram-kilometers a year (9500 x 833 = 7,913,500 ton-miles a year).

Total flights per year = 24,568

Total flight hours per year = 24,568 x 6 = 147,408 hours.

Assuming that flight personnel fly 960 hours annually, (5000/960) x 30 = 157 crews.

Salaries of Flight Personnel	Phase I	Phase II
Pilot	$ 45,965	$ 45,965
Co-pilot	45,965	
Flight engineer	30,000	30,000
Freight engineer	12,000	12,000
	$ 133,930	$ 87,965
Total flight personnel (157 x totals I & II)	$21,027,010	$13,810,505
Administrative costs (½ x flight personnel costs)	10,513,505	6,905,253
Total Costs	$31,540,515	$20,715,758

TABLE B-4

PHASE I COST SUMMARY

A_0 = Fleet Cost (parameter to be determined)	
A_1 = Cost of helium (no. ships x He volume x $50/1000 ft^3)	$ 4,155,000
A_2 = Cost of terminals	3,680,000
A_3 = Cost of hangar operations equipment	975,000
A_4 = Initial insurance payment = .02 A_0	
B_0 = Annual insurance payments = .02 A_0	
B_1 = Annual helium cost = .25 x $4,155,000	1,038,750
C_0 = Annual cost of hangar rent	120,000
C_1 = Annual cost of terminal personnel	2,400,000
C_2 = Annual cost of flight personnel	21,027,010
C_3 = Annual cost of hangar personnel	122,000
C_4 = Annual administrative costs	11,774,505
C_5 = Annual cost of terminal operations	352,000
C_6 = Annual cost of hangar operations	41,400
C_7 = Annual cost of fuel and oil	13,031,483
C_8 = Annual cost of spare parts = .01 A_0	
S_0 = Salvage value of airship fleet = .15 A_0	
S_1 = Salvage value of terminals, less land @ 20%	680,000
S_2 = Salvage value of land (= initial value)	280,000
S_3 = Salvage value of helium (= (1.2) x initial value)	4,986,000

TABLE B-5

PHASE II COST SUMMARY

A_0 = Fleet Cost (parameter to be determined)	
A_1 = Initial helium cost (no. ships x He volume x $50/1000 ft^3)	$ 7,488,000
A_2 = Terminal fixed costs	3,600,000
A_3 = Hangar fixed costs	2,875,000
A_4 = Initial insurance payment = .02 A_0	
B_0 = Annual insurance payment = .02 A_0	
B_1 = Annual helium cost = .25 x 7,488,000	1,872,000
C_0 = Annual hangar rent	120,000
C_1 = Annual cost of terminal personnel	2,400,000
C_2 = Annual cost of flight personnel	9,107,240
C_3 = Annual cost of hangar personnel	240,000
C_4 = Annual administrative cost	5,873,620
C_5 = Annual cost of terminal operations	348,000
C_6 = Annual cost of hangar operations	200,600
C_7 = Annual cost of fuel and oil	6,252,702
C_8 = Annual cost of spare parts = .01 A_0	
S_0 = Salvage value of airship fleet = .15 A_0	
S_1 = Salvage value of terminals, less land, @ 20%	660,000
S_2 = Salvage value of land (= initial value)	300,000
S_3 = Salvage value of helium (= (1.2) x initial value)	8,985,600

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APPENDIX C

HEAVY LOAD MARKET COMPUTATIONS FOR PHASE I AND PHASE II AIRSHIPS

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HEAVY LOAD MARKET COMPUTATIONS FOR PHASE I AND PHASE II AIRSHIPS

Phase I

Tables C-1 through C-5 contain data related to the potential market for a Phase I airship carrying modular apartment units.

The main savings over current building practices result from using modular construction when the airship is utilized for transport.

TABLE C-1
1972 UNITED STATES
APARTMENT CONSTRUCTION DATA
(ref. C-1)

Type of Unit	Floor Area m^2 / ft^2	Number of Units	Const. Cost Per Unit Dollars	Total Const. Cost Millions of Dollars
1. Bedroom	72 770	210,344	15,400	3,239
2. Bedroom	108 1,155	244,892	23,100	5,657
3. Bedroom	144 1,350	35,268	27,000	952
			Grand Total	9,848

TABLE C-2
NUMBER OF UNITS AT VARYING PERCENTAGES
OF TOTAL MARKET

Potential Market Attracted (Percent)	Total Const. Cost (Millions Dollars)	Number of Apart. Modules*	** No. of Airships Needed
5	492***(a)	64,822(b)	16(c)
10	985	129,660	32
15	1,477	194,559	49
20	1,970	259,187	65

*Modules are 6m x 6m -- $36m^2$ (18 ft - 4 in x 18 ft - 4 in -- 335 ft^2)
need: 2 modules for 1 bedroom apartment
3 modules for 2 bedroom apartment
4 modules for 3 bedroom apartment

**Based on 1 hour handling time/module and 4000 hours/year/airship.

***Example:

a) $9,848,000,000 (Table C-1) x .05 = $492,000,000

b) (210,344 (Table C-1) x 2) + (244,892(Table C-1) x 3) + (35,268 (Table C-1) x 4) = 1,296,436 modules and 1,296,436 x .05 = 65,822 modules

c) 64,822 modules x 1 hr/module x airship/4000 hr = 16 airships

TABLE C-3
TOTAL CONSTRUCTION COST SAVINGS ESTIMATED AT VARYING PERCENTAGES OF TOTAL MARKET AND COST SAVINGS

Percentage of Total Market	Const. Cost Reduction (Percent) Using Modular Construction			
	5	10	15	20
5	24.6*	49.2	73.8	98.4
10	49.2	98.5	147.8	197.0
15	73.9	147.7	221.6	295.4
20	98.5	197.0	295.5	394.0

*Table numbers are expressed in millions of dollars.

Example: $9,848,000,000 (Table C-1) x .05 x .05 = $24,000,000

TABLE C-4
TOTAL CONSTRUCTION COST SAVINGS AT VARYING PERCENTAGES OF MARKET BY TYPE OF APARTMENT

Type of Apartment	Total Const. Expenditure (Millions of Dollars)	Total Number of Units	Percent of Const. Costs Saved At Different Percentages of Market			
			5	10	15	20
One Bedroom	3,239	210,344	162* (10,517)	324 (21,039)	486 (31,558)	648 (42,078)
Two Bedroom	5,657	244,892	283 (12,251)	566 (24,502)	849 (36,753)	1,131 (48,961)
Three Bedroom	952	35,268	48 (1,778)	95 (3,519)	143 (5,296)	190 (7,037)

*Example: $3,239,000,000 x .05 = 162,000,000 Dollars Saved
210,344 units x .05 = 10,517 Units modular built and airship carried

TABLE C-5
TOTAL NUMBER OF APARTMENT MODULES TO BE HANDLED BY PHASE I AIRSHIPS

Modules	Total Modules at Varying Percentage of Market			
	5	10	15	20
One Bedroom (2 modules/unit)	21,034*	42,078	63,116	84,156
Two Bedroom (3 modules/unit)	36,753	73,506	110,259	146,883
Three bedroom (4 modules/unit)	7,112	14,076	21,184	28,148
Total Modules	64,903	129,660	194,559	259,187

TABLE C-5 (CONTINUED)

*Example:
10,517 units (Table C-4) x 2 modules/unit = 21,034

Phase II

In 1972, $20,960,000,000 was spent on new construction for streets, highways, and railroads (ref. C-1). It is assumed that 10 percent of this money i.e., $2,096,000,000, is spent on structural units adaptable to centralized off-site construction. These units could be carried to construction sites by an airship.

A conservative estimate of the cost savings would be about 10 percent or $209,600,000. The tabulation in Table C-6, however, presents cost savings over a range from 5 to 20 percent.

TABLE C-6
MARKET-AIRSHIP-COST DATA RELATED TO LARGE MODULAR STRUCTURES

Percent of Total Market	Cost Reduction Through Modular Const. (Millions-Dollars)	Number of Units (Ea.)	Airship Operational Time (Hours)	No. of Airships Required Ea.
5	10.5 (a)	300 (b)	1,200 (c)	1 (d)
10	21.0	600	2,400	1
15	31.4	897	3,588	1
20	42.0	1,200	4,800	1

Example: a) $209,600,000 x .05 = $10,500,000

b) Assuming an average modular unit cost of $35,000
$10,500,000/35,000 = 300 units

c) Assuming 4 hours of airship time/module, 300 x 4 = 1200 hrs

d) An airship can operate up to 5000 hrs/year; therefore, 1 is required.

The economics analysis assumes that the reduction in overhead and savings in time would be sufficient inducement for a customer to pay one-half of the savings to the airship transport system.

Modular units of the type carried are presented in the following.

Bridge Segments

Fig. C-1 shows a typical two lane bridge segment which could be carried by a Phase II airship.

Housing Modules

Number of housing starts per year are estimated at 2,000,000 (See Chapter 10) with an assumed value of $20,000 each. Using these values a potential market for centralized modular construction is analyzed. Phase II airships are used for delivery to the construction site. Tables C-7, C-8, and C-9 present data pertinent to this analysis.

TABLE C-7

POTENTIAL NUMBER OF MODULAR HOUSING UNITS AT VARYING PERCENTAGES OF TOTAL MARKET (PHASE II)

Percentage of Total Market	Number of Units
5	100,000
10	200,000
15	300,000
20	400,000

TABLE C-8

CONSTRUCTION COST SAVINGS FOR VARYING PERCENTAGES OF MARKET AT VARIOUS PERCENTAGE COST REDUCTIONS

No. of Units	Percentage Saving			
	5	10	15	20
100,000	100*	200	300	400
200,000	200	400	600	800
300,000	300	600	900	1,200
400,000	400	800	1,200	1,600

*Example: ($20,000/unit)x(100,000 units)x .05 = $100,000,000 cost savings

TABLE C-9

FLEET SIZE AT VARIOUS MARKET PERCENTAGES

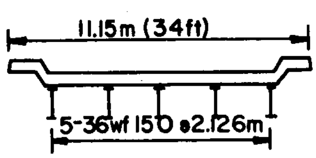
Percentage of Market	Number of Housing Units (Table C-7)	Fleet Size
5	100,000	100 (a)
10	200,000	200
15	300,000	300
20	400,000	400

Example:

(a) 100,000 units x 4 hr/unit = 400,000 hrs.

$$\frac{400{,}000 \text{ hrs}}{4000 \text{ hrs/airship}} = 100 \text{ airships}$$

Fig. C-2 illustrates the size and mass of a centrally constructed housing unit.

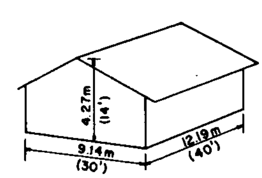


MASS:	kg	lbm
BEAMS	17,010	37,500
SLAB	63,031	138,958
BRACING (20 PERCENT OF BEAM MASS)	3,402	7,500
	83,443	183,958 (92 tons)

FIGURE C-1

MODULAR BRIDGE

111.5 m^2 (1,200 ft^2) FLOOR AREA HOUSE UTILIZING 10.2 cm (4 in) SLABS, LIGHTWEIGHT CONCRETE, AND STEEL RATED AT 9.8 kg/m^2 (2LBM/ft^2)



MASS	kg	lbm
SLAB	21,909	48,312
END WALL	12,050	26,572
SIDE WALL	11,685	25,766
ROOF	27,606	60,873
PARTITIONS	12,050	26,572
	85,300	188,095

NOTE: WINDOW AND DOOR OPENINGS WERE NOT CONSIDERED AS THE EQUIVALENT MATERIAL WOULD BE NEEDED FOR STRUCTURAL STABILITY ANYWAY.

FIGURE C-2

MODULAR HOUSE

SELECTED REFERENCES

C-1 Statistical Abstract of the United States, U. S. Dept. of Commerce, 1973.

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APPENDIX D

ADDITIONAL LTA VEHICLE APPLICATIONS

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ADDITIONAL LTA VEHICLE APPLICATIONS

In addition to the missions given in Chapter 10, there are several that the team analyzed. These do not appear economically feasible at this time. However, due to broad interest in these areas they are presented here.

"New Town" Applications

The present "new town" or resort town concept (a self-contained community removed a short distance from an urban area) is not proving feasible. Most of these towns have a substantial number of residents employed outside the town who require intercity transportation.

Airships could be used to provide transportation from these towns to a central terminal--an interface with other modes. The economic analysis should account for reduced air pollution and highway facilities, but these factors are very area dependent and hence not included in this general analysis.

Assumptions:

"New town"-40.23 kilometers (25 miles) from urban center, cost of auto transportation is .0932¢/kilometer (15¢/mile).

Monthly commuting:

80.46 kilometers x .0932¢/kilometer x 22 days = $165.00 revenue per passenger per month - @ 200 passenger/airship = $33,000 revenue/month.

This revenue is not adequate to support an airship system for commuter purposes--monthly costs alone are about $300,000. However, there are several positive factors that could be considered. They are as follows:

1. Traffic would be reduced on access roads due to the elimination of peak commuter loads. Structural strength could then be designed on the order of 40 to 50 percent less. Depending on the distances involved, the cost reduction at a rate of $15,534.28 - 31,068.56/kilometer ($25,000-50,000/mile) could be up to a maximum of $1,250,000 for 40.23 kilometers (25 miles).

2. Traffic accidents and traffic related injuries and deaths would also be reduced. The total U. S. transportation deaths in 1972 was 61,673 persons (ref. D-1). The highway toll was 56,600 while air travel deaths were 1,547. Passenger kilometers (miles) traveled were 3,628,850 (2,255,345) and 214,160 (133,101) for highway and air respectively. Hence, over 97 percent of the deaths occur on highways while 94 percent of the traffic moves in this manner. Use of airships could reduce this death toll.

3. Current pollution levels due to surface transport modes may also be reduced by the airship since it flies high enough for adequate dispersal of any engine emissions.

4. Airships could also be used to deliver commodities and remove waste materials. This would be a productive use during off-peak commuter hours.

An analysis of the waste removal potential follows:

Solid waste generated in this country averages between 1.18 and 1.81 kilograms (2.6 to 4 lbs) per person. Collection of solid waste costs about 5¢ per kilogram ($45 per ton) and represents 80 percent of the total disposal cost. (ref. D-2)

For estimating purposes assume solid waste is equal in mass to the commodities brought into a community. This would give a range of 431 kilograms (949 lbs) to 664 kilograms (460 lbs) per person per year. An airship could make 2 round trips per day assuming a 50 mile trip and 1 hour loading and 1 hour unloading time. The size community necessary to support one airship then is calculated as follows:

Assume an average of 1.5 Kg (3.3 lbm) of solid waste/day/person. This same number is assumed for commodities/day/person. Utilizing a Phase I ship carrying 22.7×10^3 Kg (25 tons), community size =

$$\frac{22.7 \times 10^3 \text{ Kg}}{1.5 \text{ Kg/person/day}} \times \frac{2 \text{ trips}}{\text{day}} = 30,200$$

The total monthly revenue available to each airship utilized as a combination commuter-commodity-waste carrier would be

commuter revenue	$33,000
commodity and waste revenue -assumes 2 round trips a day and 0.007¢/Kg-Km (10¢/ton-mile)	$39,500
Total Revenue/Month	$72,500

This is still much less than the $300,000 monthly cost of the Phase I airship. However, social and environmental considerations could motivate another look at this application in the future.

Commuter Applications-Phase II Airship

The present market for LTA commuter application appears uneconomical; however, this could change very quickly with changes in the availability and cost of fuel. Theoretically the Phase II airship can transport 750-1000 people per trip; however, the loading and unloading of this large a group would require extensive terminal facilities both at origin and destination. This type of application would require feeder systems.

With the existence of numerous local terminals 30-60 miles from a large central urban area and a central terminal interfacing the LTA system with the city distribution systems, it is reasonable to assume a demand up to the LTA passenger limit twice a day. The trip, including boarding and disembarking would take approximately one hour for the 48 kilometer (30 mile) trip and one and one-half hours for the 97 kilometer (60 mile) trip. The elasticity of fares for this type of service is difficult to predict due to the numerous variables involved. The existence of public transportation subsidies also makes direct determination of a reasonable fare difficult. Hence, use a cost of 9¢/kilometer (15¢/mile)--that needed to operate an automobile. Assuming one person per car the cost would be $9.00 for 48 kilometers (30 miles) and $18.00 for 97 kilometers (60 miles). This does not include the cost of parking. Using these numbers the revenue for airship commuter operation can be computed as follows:

48 kilometers (30 miles):
1,000 people x $9.00 per day x 264 days per year = $2,376,000

97 kilometers (60 miles):
1,000 people x $18.00 per day x 264 days per year = $4,752,000

The key to an economic operation will be usage during off-peak periods. This is true for any public transportation system and is not restricted to LTA operation. With the use of removable pods permitting passenger haul during peak commuting periods and cargo haul during off-peak, a dual usage system could be developed that is economically attractive.

The total monthly revenue available to each commuter-commodity Phase II airship would be

	48 Km trip (30 mile)	97 Km trip (60 mile)
commuter revenue	$2,376,000	$4,752,000
Commodity revenue -assumes 1 round trip a day and 1¢/Kg-Km (15¢/ton-mile)	270,000	540,000
Total Revenue/Year	$2,646,000	$5,292,000

These revenues are less than the $10,000,000/year cost of the Phase II airship.

Boeing-Vertol indicates that a West Coast commuter service using LTA vehicles of their design could be economically feasible at a fare of 6.7¢/kilometer (10.8 ¢/mile) if a 7.6 percent share of the San Francisco to Los Angeles and 6.5 percent of the Los Angeles to San Diego markets could be attracted. Pertinent data adapted from the reference are given in Table D-1.

A Commercial Mission for a Large Airship

An airship mission that may be very attractive economically is the transportation of heavy, large-volume, indivisible, unique payloads that cannot be moved by any other method. Environmental concern almost dictates that future petrochemical plants, large power generation installations and other "socially undesirable" construction activities be located far from population centers. Remoteness often means that these sites cannot be reached by water-borne transportation and even railroad and highway access is often difficult.

In the interest of efficiency, the trend in industrial plant design is for larger components and systems. However, if road or rail transportation is involved, the designer is size-restricted. An obvious alternative would appear to be "onsite" assembly, but experience has shown that field fabrication is undesirable because of the tooling, process control, and quality assurance tests required that are only possible in the factory. If transportation restrictions could be removed, the designers of petrochemical and power generation equipment could make a stepwise gain in economical operations. An example of the movement to larger size is the desire of the power industry to increase the size of nuclear power plants from 1,300 to 1,500 megawatts during the 1980's. (ref. D-4).

Reference D-4 also includes a table indicating that the nuclear power industry's need for moving large payloads will increase from 80 to 128 individual pieces in 1980 to 142 to 214 components in 1990. These items include nuclear reactor vessels and components associated with steam generation. Their weights range from 4.5×10^4 to 6.35×10^5 kilograms (50 to 700 tons) and the volumes include components with diameters of 7.6 meters (25 feet) and lengths of up to 21.3 meters (70 feet). Reference D-5 indicates that 2,000 loads in the 1.81×10^5 to 3.63×10^5 kilograms (200 to 400 ton) bracket are moved every year in England and western Europe at great cost.

TABLE D-1

PASSENGER TRAVEL MARKET

SAN FRANCISCO TO LOS ANGELES
AND LOS ANGELES TO SAN DIEGO

Fare - Cents/P-Km (Cents/P-mi)	3.7 (6.)		5.2 (8.4)		6.7 (10.8)		8.2 (13.2)	
Route	SF-LA	LA-SD	SF-LA	LA-SD	SF-LA	LA-SD	SF-LA	LA-SD
Market Share (%)	12.6	10.8	9.4	8.1	7.6	6.5	6.4	5.5
Load Factor (%)	72.6	98.0	54.0	69.8	43.6	56.0	36.9	47.4
Direct Operating Costs								
$/Hour	1045	1477	1515	2045	1786	2394	1984	2659
Cents/seat-Km (Cents/seat-mile)	1.1 (1.8)	1.6 (2.5)	1.6 (2.6)	2.1 (3.4)	1.9 (3.1)	2.5 (4.0)	2.1 (3.3)	2.7 (4.4)

ASSUMPTIONS:

- 500 seat LTA vehicle
- 5% reserve for profit
- Indirect Operating cost, 1.8¢/P-Km (3¢/P-mi)
- Total annual fleet flying hours
  15,885 for San Francisco to Los Angeles
  10,575 for Los Angeles to San Diego
- Number of LTA vehicles and annual utilization
  5 at 3,177 hours a year for San Francisco to Los Angeles
  3 at 3,525 hours a year for Los Angeles to San Diego
- Number of flights each way
  7 a day for San Francisco to Los Angeles
  16 a day for Los Angeles to San Diego

These missions would be specialized and would require careful scheduling and preparations. Moving fees of many thousands of dollars or even hundreds of thousands of dollars would be involved in the moving of single unique payloads. These admittedly costly airship operations are economically attractive when compared to the alternative of reinforcing bridges, building special roads or railroads to bypass tunnels, overpasses, or other obstructions. The speed of load movement would not be a factor; in fact, postponements awaiting favorable weather conditions could be expected.

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APPENDIX E

STUDY ORGANIZATION

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STUDY ORGANIZATION

Figure E-1 is an overall schedule of the study team activities. Figure E-2 shows the major organizational and activity steps.

Table E-1 gives the final team organization, team membership, and responsibility areas. Team members could be in more than one group.

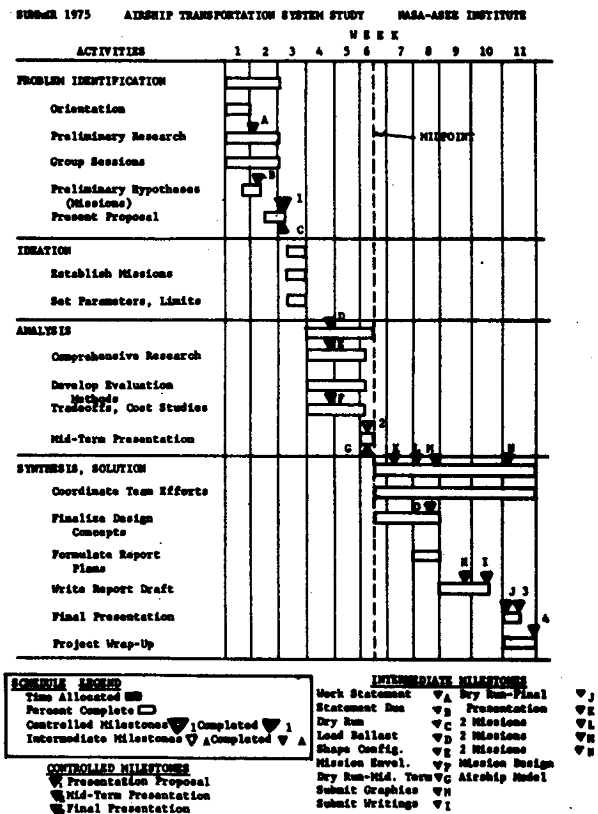

FIGURE E-1
SUMMER 1975
AIRSHIP TRANSPORTATION SYSTEM STUDY
NASA-ASEE INSTITUTE

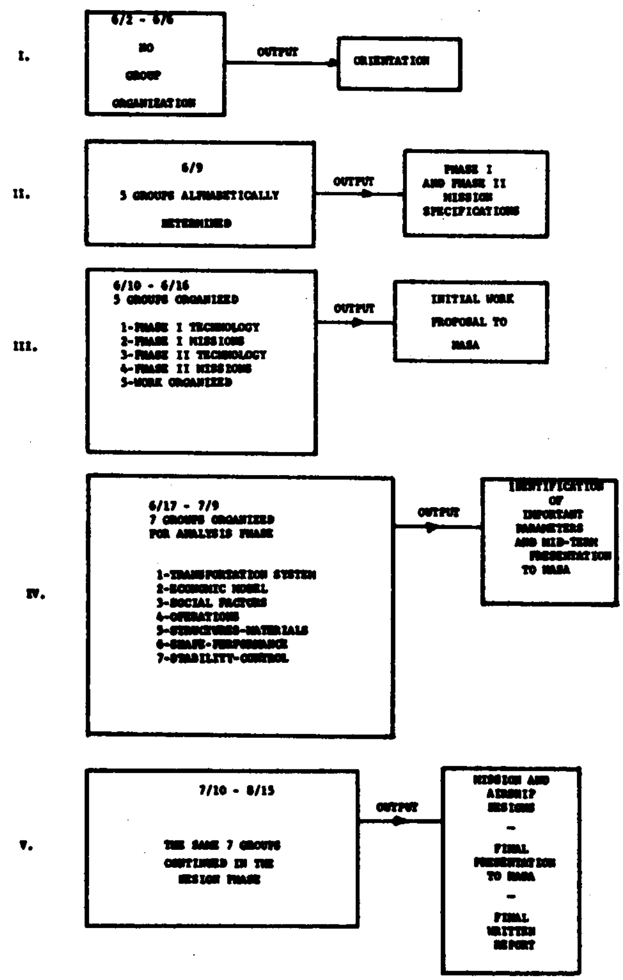

TABLE E-1
FINAL GROUP MEMBERSHIP

STUDY MANAGERS: D. TURNER
L. VAN POOLEN

FIGURE E-2
ORGANIZATION STEPS
OF AIRSHIP DESIGN TEAM

TABLE E-1

FINAL GROUP MEMBERSHIP

STUDY MANAGERS: D. Turner
L. Van Poolen

ECONOMIC-POLICY GROUP

Group 1: Overall Transportation System

- cargo lift
- cargo utilization factor
- finances
- history
- future programs
- test programs
- missions
- market locations
- implementation
- fleet size
- organization structure
- costs

Members: D. Gillanders, L. Hurley, A. Jones, J. Savage, R. Smith, E. Vento

Group 2: Economic Analysis Model

- costing system
- cost/benefit analysis
- energy accounting

Members: R. Smith, E. Vento

Group 3: Political-Social-Legislative-Environmental

- social benefits
- effects on people
- attitudes
- community
- politics
- psychology
- funding
- technology assessment
- regulations
- certification of ship, crew, system
- pollution
- costs

Members: W. Anthony, A. Jones, T. Mullins, C. Story

TECHNICAL GROUP

Group 4: Operations

- ground handling
- maintenance
- hangar
- crew
- flight
- crash survival procedures
- human engineering
- crew training and simulation of ship and controls
- gusts
- take off, landing
- weather
- airship utilization
- flight on ground
- de-icing
- costs
- safety at man-machine interface

Members: L. Hurley, T. Mullins, L. Pleimann, F. Toline

Group 5: Structure-Materials

- buoyancy gas
- structure type
- fabrication
- materials
- costs
- interface between load and lifting body
- load and unload system
- gust loads
- weight and balance system
- car
- structural efficiency

Members: F. Chen, L. Klotz, K. Marshek, L. Pleimann

TABLE E-1 (CONTINUED)

Group 6: Propulsion-Performance-Shape-Aerodynamics

- propulsion-engines-number, type, arrangement
- performance
- drag, lift
- boundary layer control
- celing
- speed
- hover capability
- fuel
- fineness ratio
- costs

Members: J. Gill, K. Marshek, C. Martin, E. Strother, D. Toline

Group 7: Stability-Control Systems

- control surface size
- pressure control
- flight stability
- buoyancy control
- flight instruments
- flight trajectory
- electrical-mechanical-hydraulic systems
- costs
- trim
- maneuverability (low speed)
- pilot-controls-airship dynamic interactions
- equations of motion
- sensor design
- heat transfer
- thrust control

Members: F. Chen, D. Gillanders, C. Martin, B. Strong

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APPENDIX F
INSTITUTE STAFF

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1975

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APPENDIX G

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