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AN ASSESSMENT OF LIGHTER THAN AIR TECHNOLOGY

The Report of the Multi-Agency Workshop on  
Lighter Than Air

Monterey, California  
September 9-13, 1974

by  
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Editor

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Report R74-6  
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MEMORANDUM

DATE: November 7, 1974  
TO : All Workshop Participants and Other Interested Parties  
FROM: J. Vittek

SUBJECT: Report Review and other Publication Deadlines

This document is a draft report of the Workshops' output - The Working Group Reports. It is for your review and comment which should be returned to me by January 1, 1975. With those comments and criticisms in hand, I will make any needed revisions, add sections on background, history, etc. and print significant comments or minority views if they exist. The revised final report will be issued in the spring of 1975.

With this draft report completed, I will turn my attention to the proceedings. A preliminary review indicates that there is more work to be done on the papers than expected, but I still plan to mail the papers in early 1975.

I am pleased to announce that the AIAA has approved its' LTA subcommittee's plan to hold a followup conference in Snowmass-at-Aspen, Colorado, July 15-17, 1975. Details will be in the December issue of Aeronautics and Astronautics. Hope to see you there! To help us improve that program, could you take a few minutes to complete and return the questionnaire on the reverse side of this page? It would be very helpful.

LTA Workshop Questionnaire

NAME: (optional) \_\_\_\_\_

AFFILIATION: \_\_\_\_\_

MAJOR INTEREST: ( ) User ( ) Manufacturer ( ) Other \_\_\_\_\_

1. What was the highlight of the LTA Workshop for you?
  
2. Which sessions were best and why?
  
3. Which sessions were poor and why?
  
4. How could the Workshop have been improved?
  
5. On a scale of 1 to 5, with 1 being poor and 5 excellent, how would you rate the following aspects of the Workshop?

Organization	1	2	3	4	5
Operation	1	2	3	4	5
Technical Content	1	2	3	4	5
Ratio of Social Time to Work	1	2	3	4	5
Site and Facilities	1	2	3	4	5
Opportunity to Express Views	1	2	3	4	5

6. Other Comments or General Remarks

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EXECUTIVE SUMMARY

(will be expanded to include other sections of final Report)

Summary of Working Group ReportsPolicy

The major issues addressed were:

1. Should the United States Government undertake development of a Lighter Than Air vehicle.
2. Should the United States sponsor research and technology efforts in the area of Lighter Than Air including the construction of an experimental LTA research vehicle?

Due to unknown economic risks, the group concluded that it was premature to stress government development of an LTA vehicle at this time. Rather, appropriate agencies, particularly NASA, should sponsor appropriate studies in LTA to better define the technical unknowns. Only after some of the general uncertainties are resolved did the group feel that it would be beneficial to construct an experimental LTA vehicle.

However, the working group did feel that a positive policy statement was needed, which is set out starting on page 3 of this report.

Market Analysis

The objectives of the group were to:

1. Identify possible missions and market opportunities for Lighter Than Air craft,
2. Evaluate relative value of mission/market applications,
3. Indicate primary areas for Lighter Than Air vehicle development and application.

The resulting mission/market matrix is on page 10. The following subsections summarize the types of missions and markets each type of LTA vehicle might serve in the future.

Tethered Balloons - These have a particular application as heavy lift devices in the ten to five hundred ton payload range. Most of

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the technology is available from current logging balloon and tethered aerostat systems. Numerous very short haul and stationary applications were identified such as spot-lifting industrial or mining equipment and surveillance platforms.

Heavy Lift VTOL - Several applications were identified for heavy lift and transport capabilities. Payloads would be up to 1000 tons, although speed and range need not be great. Detailed uses are outlined in Table II on page 15. Since several vehicle concepts have already been proposed and studied, the next step would be vehicle development, rather than further study.

Fully Buoyant Airships - Different sizes of fully buoyant airships can be used for different missions and applications. Many uses have been hypothesized and many missions suggested, but further market research is needed to define market potential for all sizes before prototype development is justified.

Hybrid Airships - Like fully buoyant craft, hybrids come in all sizes and could perform numerous tasks. However, even less is really known about hybrids than fully buoyant airships so further market analysis is even more important.

## Economics

The working group attempted to formulate costing techniques for LTA vehicles. Although costing and economic techniques developed for fixed wing aircraft and other transportation systems could be applied to LTA, there is no data base available to which these techniques could be applied. More information is needed on development and construction costs, operating costs and the like. And the only way to obtain that information is by building and flying a new airship.

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But rather than advocate a development program at this time, the working group felt that useful studies could be directed toward examining potential markets for LTA in the existing transportation world. By analyzing competition, cost and performance requirements can be derived at which LTA's would be economically successful. By "working backwards" in this way, the airship designer has a specification that must be met if LTA is to become a viable form of transportation. If that specification cannot be met, there is no need for a development program.

## Operations

The working group addressed both ground and air operations of conventional airships. Hybrids were not discussed. The general conclusions were that the equipment developed for handling large blimps on the ground in the late 50's could be directly applied to modern blimps and rigids up to 3 million cubic feet capacity. Such equipment, primarily for mooring airships in the open, has been proven in 90 knot winds. For larger airships, the same technology and techniques could be used, but larger equipment would be needed.

One area for further research was identified - de-icing while moored out on the ground. Another problem area was the preservation of existing airship hangars. Although a modern airship would only have to be docked once a year for major overhauls, several hangars will be needed to service an airship fleet. Therefore, hangars in existence should be preserved to eliminate the cost of reconstructing them in the future.

The working group's paramount consideration for all flight operations was safety. Many problems of the past, such as weather and turbulence, can be greatly lessened applying modern technology. In fact, most of the technology and research needed to operate modern airships is in hand. Those areas requiring further technical research

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are new density control systems to alleviate problems of pressure altitude and thermal layer penetration, and in-flight body constraint and safety systems to prevent injury to crew or passengers while walking around. New in-flight monitoring and control systems would also improve flight operations.

Non-technical, institutional areas requiring further research are air traffic control (including possible creation of dedicated airspace), specifications for crash worthiness, use of non-flammable materials, evacuation procedures, training requirements and guides for proficiency checks and maintenance procedures.

Although most of the needed technology and procedures are in hand, the operations group felt that a flight research airship would be invaluable for regining techniques to commercial standards. This airship should be at least as large as the Navy's ZPG-3W blimps (approximately 400 feet long with an 85 foot diameter, have a top speed of 100 knots, a pressure height of 10,000 feet, range in excess of 10,000 miles and a useful load of 50,000 pounds).

### Technology

The technology group set up four subgroups to study overall design/configuration/mission related problems; materials, structures and manufacturing problems; aerodynamics, propulsion and performance problems; and stability, control and handling problems. The general conclusion of each subgroup was that most of the technology needed to develop modern airships already exists, but further work is needed to apply it to LTA.

Design/Configuration/Mission Related Problems - This subgroup reviewed past and present LTA concepts, classified them into configuration categories, related their performance to possible missions and then reviewed the mission-related problems that arose. The approach



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was similar to that of the Market Analysis working group, but it started from a technical perspective rather than from a mission/market perspective. Their results were very similar to those of the Market Analysis working group.

One major problem identified by this subgroup was mission-related. For ASW or geophysical prospecting missions, electromagnetic disturbance and vibration must be minimized. This may require the use of non-ferrous materials, sparkless engines and similar devices and techniques not normally used in LTA vehicles.

A second area of concern was design-related problems for hybrid airships. In general, more needs to be known about distributing large concentrated loads from wings, propellers, thrusters, rotors and large load frames over the very light, low density structure of the buoyant shell.

Materials, Structures and Manufacturing - This group found that major improvements could be made over old airship elements. New flexible envelope materials have been proven in current aerostat operations. New rigid materials offer greater rigidity and less weight. Modern aerospace manufacturing techniques, such as diffusion bonding and isotherm forging, can be applied to airship structures. Computerized analysis and design techniques used in the aerospace industry are also available.

Major areas defined as needing further research were:

1. Seaming techniques for modern fabrics and their tolerance of other inflation gases and super heat.
2. handling techniques to prevent structural damage during manufacturing or in service.
3. Non-linear and viscoelastic material and structural behavior, large deflection analysis and contact and discontinuity problems.
4. Random gust loading and response.
5. Preparation of a modern design manual with the latest information on loading, design factors, materials, gases and fuels.

Aerodynamics, Propulsion and Performance - This subgroup considered cruising performance, maneuvering performance and performance in turbulence or other adverse weather conditions. They felt that much useful research already has been done, but is hard to find. Therefore, they recommended that a central collection point should be established to house references on airship design work and useful information from related fields such as underwater vehicles, wind effects on buildings and so on. A compilation of useful computer programs would also be helpful as would turbulence spectrum analysis and information on wind-sensing techniques.

For classical airships, further work is necessary as the effects of L/D ratio, the housing of installations within the hull profile, the drag of various control surfaces, the effects of surface texture and rigidity on overall drag coefficients and the flow around a body of revolution in pitched flight. Research is also needed on LTA boundary control, particularly on fins and control surfaces.

In the propulsion area, propellers are still the optimal propulsive instrument for buoyant airships. Research is still needed, however, to develop large, low-speed, low-noise units, on the possible advantages of wake-immersed and ducted propellers, and the optimum location of the propellers on the airship's planks to minimize interference effects. The possible use of cycloidal propellers for low speed maneuvering should also be studied.

Maneuvering problems fall into two categories - those associated with low-speed flight and station keeping, and those in response to meteorological turbulence. Research is needed on the use of large vectored thrust in all three axes, the size of the thrust units themselves, gust sensing techniques and airflow in the region of an airship flying close to the ground.

Major areas of research identified for hybrid airships were take-off and landing performance, gust response in cruising flight and the interaction between aerostatic, aerodynamic and propulsive

forces in maneuvering flight.

Stability, Control and Handling Characteristics - This subgroup attempted to identify the current state-of-the-art, problem areas, suggested approaches and new technology requirements for LTA stability and control. The largest research need is the development of the equations of motion for an airship, which would include terms either ignored in airplane analyses such as the action of air on the hull, or unique to airships, such as gas lag motions. Modeling and wind tunnel testing may be required to develop the coefficients. These equations of motion would then be used to analyze the pilot-airship system dynamic response, perform stability analysis and develop stability and control criteria. Structural flexibility could also be analyzed once the equations are developed. Automatic flight control systems, adapted from airplanes, will have to be modified for airship applications. A unique need is automatic trimming to compensate for variations in mass distribution, center-of-buoyance shifts, gas density and temperature changes, and atmospheric pressure gradients.

Finally, the subgroup identified a need for general research projects on the violence of turbulence, techniques for rapid altitude control, other than ballast and gas venting, a way to condition gas to vary density and alternatives to pure tail control.

### Summary and Analysis

LTA does offer great potential as transport vehicles for both civilian and military applications. Although further research is needed to develop advanced LTA vehicles, the technology is in hand to build and operate modern airships today that would be considerably better than those of the past. The key question is whether these modern airships make sense economically.

It is clear that unmanned LTA lifting devices can be produced

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and operated economically. But the viability of large manned airships is still uncertain. Because there is no real economic data on costs and performance, estimates of airship economics vary widely. Ultimately, an airship must be built and operated to provide hard data.

But before actual development and construction, rigorous market analysis should be performed to determine what groups would use airships under what conditions. By looking at potential airship applications and determining what cost and performance characteristics are needed for the airship either to capture a role now performed by another vehicle or to carve out new, unique applications, a design specification can be evolved. With this as a guide, designers can estimate whether or not airship can be built to meet that specification. If not, there is no need to build an operational vehicle.

Because of the potential national benefits of airships for both civilian and military applications, the federal government as well as private industry should fund this market analysis (as well as be ready to support development if the market analysis is positive). The basic market analysis would be relatively inexpensive, probably less than one million dollars, and is the next logical step in developing a modern airship system.

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## POLICY

The major issues that were addressed by the working group in the area of general policy were the following:

1. Should the United States Government undertake development of a lighter than air vehicle?
2. Should the United States sponsor research and technology efforts in the area of lighter than air including the construction of an experimental LTA research vehicle?

The working group determined that in both the civilian sector and the military sector certain unique missions could be identified that LTA could perform, e.g. transporting heavy powerplant components to remote sites or loitering on station for long durations. In addition, certain competitive missions for which LTA is well suited were identified that are now being performed by other modes, such as carrying heavy cargo over water. The working group also identified possible export-import implications in LTA technology, as well as potential energy savings and improvements in the United States military posture. However, due to the unknown economic risks, the group concluded that it was premature to stress government development of an LTA vehicle at this time.

Rather the working group concluded that the appropriate agencies of the United States should encourage research and technology in the LTA area. It felt that NASA, particularly, as the lead agency in the field of aeronautics, should sponsor appropriate studies in LTA to better define the technical unknowns that were discussed during the course of the Workshop. The working group concluded that R & T efforts should not be confined to the governmental sector -- private industry and the universities were also encouraged to study the fundamental areas of uncertainty in further LTA development. Only after additional studies have put some bounds on some of the general uncertainties did the working group feel that it would be beneficial

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to proceed to the construction of an experimental LTA research vehicle.

In the area of implementation the following major items came under discussion:

1. What is the proper role, if any, of LTA in the transportation industry? In the military area?
2. Who should assume the costs of any required infrastructure?
3. What type of LTA vehicle is the most promising: nonrigid, semi-rigid, rigid, hybrid? Metal clad or traditional coverings?
4. What is the best way of estimating the economics of airship operations? The cost of construction?

The working group felt that the major role of LTA was for cargo rather than passenger transportation. The need for heavy lift capability was stressed as well as the movement of goods and commodities whose transportation requirements lay between the rates and speeds of truck/cargo ship/rail and those of cargo airplanes. The prime military missions identified were lifting goods from ship to shore and staying on station for long durations.

Infrastructure was one of the knottier problems faced by the working group. Although everyone supported the theory that the U.S. Government should assume responsibility for LTA air traffic control as it does for heavier than air vehicles, there was little support for federal funding of hangar and/or special airfield construction (although some felt that ADAP funds could be used for this purpose). The possibility of indirect subsidy through mail payments was raised, but the majority felt that the cost of running an airshipline should be borne largely by the investors in such a venture.

The special advantages and disadvantages of all types of all types of LTA vehicles were discussed at length, but no consensus as to which was best could be formed. Rather, each type of LTA vehicle seemed to have its own niche in the LTA spectrum.

There was almost universal agreement that only the actual

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building and operation of an airship would provide adequate answer to economic questions. Extrapolations from past LTA experience, while possible adequate in some areas, cannot be used to estimate today's operating or construction costs.

Having considered all these factors, the working group felt that a positive policy statement was necessary rather than listing possible policy options. They drew up the following statement which was endorsed by a majority of the Workshop's participants:

### POLICY STATEMENT

The Workshop considered the application of LTA systems as a solution to critical national and international problems.

The Workshop reached the consensus that these needs include the following:

1. Access to heretofore inaccessible natural resources with minimal environmental impact.
2. On site delivery of large power plant components.
3. Monitoring of the environment on a worldwide basis.
4. Fulfillment of various military missions critical to the national defense.
5. Improvement of the balance of payments.

The Workshop felt that the operational characteristics which make LTA responsive to these problems are:

1. Unique and singular suitability to the transport of large indivisible loads.
2. Unequaled airborne endurance on station and en route.
3. Favorable transportational and environmental impact.
4. Smaller dependance then other modes on prepared surface transportation facilities and arteries.

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The Workshop recognized that a program of LTA system development and implementation could provide enormous benefits to the U.S. and the world. The cost of such a project, however, may involve expenditures of hundreds of millions of dollars. To minimize the technological and economic uncertainties prior to committing such large sums, and to stimulate private investment, the following series of actions are recommended by the Workshop. These efforts, if successful, would logically lead to implementation of a program involving experimental flight research vehicles. The Workshop therefore urges:

- that appropriate professional organizations develop programs of stimulating LTA related studies for inclusion into academic curricula, and that private industry encourage such studies through financial aid.
- that appropriate government agencies include an LTA element in all future transportation studies.
- that appropriate international organizations consider the potential benefits of LTA systems for developing countries, and examine means by which such technology might be made available.
- that a survey be made of efforts in LTA development being conducted and contemplated by foreign countries and companies, with emphasis on identifying areas for international cooperation between governments or private industry.
- that appropriate agencies develop incentives that will stimulate a broad interest in LTA in the private sector. Such incentives could include a program of initial government grants at modest levels for concept development and elaboration; mechanisms for exchange of information between potential users and potential manufacturers; and examination of possible cost sharing programs between government and industry.



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-- that NASA develop a program to survey current technology and specify those areas of knowledge that are directly transferable to LTA concept development and implementation.

-- that appropriate agencies conduct studies to establish, for a range of LTA applications, cost and volume parameters based on existing non LTA modes of transportation in order to identify those areas where LTA may be competitive and where LTA may perform unique missions.

-- that appropriate agencies conduct programs of technology assessment in LTA, addressed specifically to comparative analysis of energy consumption, land use, noise, air pollution and other environmental impacts, for a range of LTA applications. Appropriate agencies are also urged to verify and categorize possible additional needs throughout the areas of civil and military applications.

-- that certification and licensing rules and regulations applicable to LTA operations be reviewed and promulgated by appropriate government agencies to provide a climate suitable for rapid development of LTA systems by the private sector.

-- that since helium is a rare element essential to technological progress in areas including but not limited to LTA, the government should commit itself to a renewal of a helium conservation program.

## MARKET ANALYSIS

Commercial success is measured by sales; military by effectiveness at satisfying mission requirements. But before success can be predicted, the missions or markets must be identified and the vehicle characteristics specified. Then the number of vehicles that might eventually be needed can be estimated. This is important because the number of vehicles greatly affects the purchase price. Research and development costs must be amortized over the expected sales. Therefore, the more units, the lower the R & D costs per unit. The number of vehicles also affects production costs. Large production runs offer economics of scale and opportunities to reduce costs through learning, again reducing the cost per unit.

Thus, identifying potential markets and missions is important not only as a mechanism for identifying the type of vehicle and its important features but also as the first step in determining its economics.

### Market Analysis Objectives

The objectives of the working group were to:

1. Identify possible missions and market opportunities for Lighter Than Air Craft,
2. Evaluate relative value of mission/market applications,
3. Indicate primary areas for Lighter Than Air vehicle development and application.

### Market Analysis Method

The steps taken to reach the defined objectives of the working group were to:

- 1) Establish mission/market categories,

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- 2) Detail the missions and markets in each category,
- 3) List the commodity and transport attributes which should be evaluated for each category,
- 4) Identify major LTA vehicle types,
- 5) Select the LTA vehicle types which could be used for each mission,
- 6) Identify high potential applications,
- 7) Use the above to select major missions/markets for each of the four major LTA vehicle types.

### Major Mission/Market Categories

The working group reviewed the possible commercial, military, and public service uses for LTA vehicles. Major mission/market categories were then established and possible missions identified. Those major market categories were:

1. Heavy-lift, large-size unit movements.
2. Agricultural applications (harvesting crops, transportation from the field and other services).
3. Passenger transportation.
4. General cargo transportation.
5. Bulk transportation (dry, liquid, and gaseous).

The more specialized, non-market oriented missions identified were:

1. Military missions (anti-submarine warfare, logistics support, etc.)
2. Special missions (public service, non-load carrying applications, traffic control, communications, etc.).
3. Environmental surveillance.

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## The Mission/Market Matrix.

The mission/market matrix developed is presented in Table 1. The missions are representative of those which could be performed by LTA systems and are grouped into the categories discussed in the previous section. Within each category the missions are listed in order of decreasing potential based both on the size of the market and its suitability to performance by LTA.

The matrix indicates that four separate types of LTA craft may be needed. These are:

1. Tethered balloons.
2. Heavy-lift, short range, VTOL airships,
3. Fully buoyant airships,
4. Hybrid airships.

A fifth type of airship not considered in detail, was a surveillance craft. This is actually a small airship or hybrid not capable of long range or heavy lift but used instead as a platform. It was eliminated because it was not fundamentally a different type of craft although it does pose entirely different problems in its development and costs.

The matrix indicates that each type of vehicle has potential for a wide variety of applications. The amount LTA can penetrate these markets will depend on LTA performance and costs in competition with other systems. In many of the missions, LTA would capture only a small portion of the total market. Examples are the transportation of dry bulk goods and agricultural commodities. LTA could, however, capture large shares of local markets in these goods, particularly in regions where alternate modes of transportation are underdeveloped.

Most of the potential LTA applications require vehicles of large size and payload capability. These will be expensive to develop. On the other hand some applications for relatively small

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TABLE 1  
POTENTIAL LTA MISSIONS/MARKETS

	<u>Tethered Balloon</u>	<u>Heavy Lift Short Range VTOL</u>	<u>Fully Buoyant Airships</u>	<u>Hybrid Airships</u>
<b>I. <u>MILITARY</u></b>				
1. Anti-submarine warfare			X	X
2. Logistics over the shore	X	X		
3. Command control center			X	X
4. Strategic lift			X	X
5. Communication			X	X
6. Surveillance	X		X	X
7. Mine Sweeping		X	X	
8. Missile launching platform			X	X
9. Heavy lift tactical support	X	X		
10. Sea control			X	X
11. Rescue and recovery			X	X
12. Ship repair	X	X		
13. Navigational aid - maintenance		X	X	X
14. Aircraft and RPV carrier			X	X
<b>II. <u>HEAVY LIFT OR LARGE SIZE</u></b>				
1. Prefabricated buildings	X	X		
2. Power generation and <b>transmission equipment</b>		X	X	X
3. Construction services	X	X		
4. Industrial equipment	X	X	X	X
5. Refineries, tanks			X	X
6. Aerospace vehicles & components		X	X	X
7. Construction equipment		X	X	X
8. Mining equipment	X	X	X	X
9. Industrial duct works		X	X	X
10. Earthmoving	X	X		
11. Offshore platforms		<b>X</b>		
<b>III. <u>AGRICULTURE</u></b>				
1. Timber Harvesting and Transport	X	X		
2. Fresh fruits and vegetables especially perishables			X	X
3. Livestock		X	X	X
4. Fish surveillance harvesting, transport		X	X	X
5. Chemical application		X		
6. Agricultural machinery movement		X	X	X
7. Crop harvesting in difficult terrain	X	X		
8. Blight surveillance	X		X	X

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	Tethered Balloon	Heavy Lift Short Range VTOL	Fully Buoyant Airships	Hybrid Airships
<b>IV. <u>DRY BULK</u></b>				
1. Grain			X	X
2. Ore			X	X
3. Lumber			X	X
4. Coal			X	X
<b>V. <u>LIQUID BULK</u></b>				
1. Petroleum and derivatives			X	X
2. Industrial liquids			X	X
<b>VI. <u>GASEOUS BULK</u></b>				
1. Natural Gas (Methane)			X	X
2. Ammonia			X	X
<b>VII. <u>GENERAL CARGO</u></b>				
1. Low density freight			X	X
2. Freight all kinds unitized origin to destination service			X	X
3. Vehicles (autos, trucks, etc.)			X	X
4. Warehousing logistic support			X	X
<b>VIII. <u>PERSON MOVEMENT</u></b>				
1. Intracity rapid transit		X		X
2. Ambulance and wrecker		X		
3. Individual (recreational) vehicles			X	X
4. Auto ferry		X	X	X
5. Fire fighters	X	X	X	X
6. Cruise ships			X	X
7. Scheduled passenger service			X	X
8. Special work site access		X		

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vehicles are possible, such as patrol and surveillance for personal use. Development of these vehicles would be relatively inexpensive and may be a logical first step in re-introducing LTA.

### Commodity Market Attributes

The characteristics of the commodity to be moved influence the choice of vehicle and/or its design. The following have been selected as being the most pertinent:

1. Value per pound (market value of the commodity),
2. Density (weight per unit volume of the packaged commodity),
3. Size (overall dimensions of the unit to be transported),
4. Weight (weight of the indivisible unit to be shipped),
5. Environment (environmental requirements for the commodity during transport),
6. Shelf life (permissible transport time under the environmental conditions in the vehicle),
7. Fragility (as packaged vulnerability of the commodity to damage).

In addition to the characteristics of the commodity itself, other factors influence a shipper's modal choice. The most important of these are:

1. Annual use volume (predicted yearly volume moving from the point of origin to its point of use),
2. Inventory control (warehousing and delivery requirements),
3. Transport margin (difference between the production cost and market price which cannot be exceeded by transport cost),
4. Accessibility to transportation (the need for door-to-door pickup and delivery)
5. Security requirements (the need for security relative to pilferage or outside access).

In a complete market analysis these factors must be evaluated

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for each potential market.

## Required Transport Attributes

To match missions/markets with LTA capabilities, vehicle and system characteristics must also be defined. The major factors to consider are:

1. Vehicle performance parameters (payload weight, cruise speed, range, altitude, endurance, ability to hover/loiter, take-off and landing characteristics).
2. Cargo capability (dimensions of largest indivisible component that can be handled, weight of largest indivisible component, ability to provide refrigerated environment, ability to provide low G environment).
3. Transport system effectiveness parameters (time reliability, dependability of schedule, security from pilferage, need for terminal support facilities and manning, door-to-door capability, frequency of service, cost of transit).
4. Environmental impact considerations (noise, air pollution, energy efficiency).
5. Sensitivity to the external environment (vulnerability to snipers or military actions, weather sensitivity, radar signature).

## The Analysis Procedure

It is now possible to match vehicle types and possible markets and to identify those with the highest potential for development. The working group did this qualitatively as a first attempt at market analysis. A much more detailed study is required for definitive answers. Each market must be addressed individually to assess the degree of market penetration and estimate the number of vehicles



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needed. This is an iterative process because vehicle costs, which are a major factor in estimating market potential, are dependent on the capital and operating costs which are, in turn, dependent on the number of markets where the vehicles can be used.

For missions and markets not now being served, the estimation of the number of vehicles required is essentially a guess based on a knowledge of the production process and how it might be changed by LTA vehicles with the right characteristics. For existing markets the analysis is based on tradeoffs between the costs and performance of the existing mode and the new LTA service.

### Mission/Market Analysis Results

The following sections discuss the types of missions and markets each type of LTA vehicle might serve in the future.

Tethered Balloons - The market analysis shown in Table 1 indicates that tethered balloons would have particular applications as heavy lift devices in the ten to four or five hundred ton payload range. The present state-of-the-art in hot air sport balloons is directly applicable except that helium or hydrogen is used as the lifting gas. Balloons are presently being built in the U.S. by several companies and were discussed in a number of the papers presented at the Workshop. Balloon systems are currently being operated in the Bahamas as a communications platform and in the Pacific northwest by the Bohemia Lumber Co. and Alaska Lumber Co. for logging. The four logging balloons have 500,000 cu. ft. capacity and the aerial communication platform, 250,000 cu. ft. Payload is roughly 6.5 tons per 250,000 cu. ft. The balloon can be tethered and winches and various other equipment attached in several ways depending on the application. The units are inexpensive and require very little research and development for new applications. The cost of the communication platform operated in

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the Bahamas is estimated at one million dollars, including the all-weather Aerostat, winches and accessories. The logging systems cost four hundred to seven hundred fifty thousand dollars.

Tethered balloons could be used in the future to spot-lift industrial and mining equipment, and to move and set up prefabricated buildings and systems in lieu of a crane. They could be used as an earth moving tool and have special applications in fire fighting as a lighting platform. Equipment movement over rough terrain is another possible application, as is service as a platform for aerial photography. As an agricultural tool, heavy lift tethered balloons could be used for blight surveillance, crop harvesting in difficult terrain and moving crops in and out of large fields. Another application could be in pipeline and transmission line construction where LTA can be used over difficult terrain with minimum disturbance.

Tethered balloons have various military applications as well: logistics over the shore, moving heavy military equipment, ship repair at sea or on shore where other facilities are not available, a military communication and surveillance platform and heavy lift tactical support. The tethered balloon has been used in military applications for many years, serving as look out platforms as early as the Civil War.

The United States government recently has spent a great deal of money on tethered balloon applications. The Range Measurements Laboratory at Patric Air Force Base has spent about eight million dollars to develop a balloon system that could survive 90 knot winds. The resulting design has successfully flown in 85 knot winds and in all weather conditions. This work is a major advancement in balloon design and engineering and could lead to other industrial applications and missions, including adapting this new balloon to logging systems.

Heavy Lift VTOL - A major market exists for a heavy lift VTOL aircraft

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to transport and place heavy or bulky loads for a wide range of applications from power plant construction to mass transit. In many cases, the existence of an economical heavy lift VTOL aircraft would open up new market areas such as mass production of prefabricated housing by offering a transportation service not currently available. Lighter Than Air could be the answer. LTA VTOL could also be used in many military missions where existing methods do not offer adequate service. An example is the off-loading of containerships. With the replacement of break bulk cargo freighter by container ships, some new method must be found to unload the materials needed to support amphibious assault operations, either offshore or in ports where cranes are not available.

Table 2 outlines potential markets for VTOL LTA vehicles. None of the specific configurations presented at the Workshop were endorsed but general vehicle characteristics developed. The aircraft needed must have vectorable thrust substantially in excess of conventional airships, vertical take off and landing capabilities and payloads ranging from 50 to 1000 tons. Low forward speeds are adequate for economic performance considering the short range normally associated with these missions.

Table 2

## POSSIBLE MISSIONS FOR VTOL LTA VEHICLES

### MILITARY MISSIONS

#### Primary

Over-the-shore logistic support

Support of amphibious operations

#### Secondary

Marine navigational aid maintenance

Mine sweeping

Missile launch platform

Heavy lift tactical support

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## COMMERCIAL HEAVY LIFT MISSIONS

### Primary

Transport and implacement of power generating equipment

Transmission and pipeline construction

Transport and implacement of industrial equipment such as cracking towers and large tanks

Transport of construction or mining equipment to remote or normally inaccessible sites

Transport and emplacement of mass produced, full sized homes and buildings

General construction services such as mechanical equipment emplacement, bridge and overpass construction, etc.

Transport of oversized aerospace vehicles and components

### Secondary

Transport and emplacement of industrial duct work

Earth moving, overburden removal and dredging

Construction and supply of offshore oil and gas platforms

## PASSENGER TRANSPORTATION

### Primary

Urban mass transit

### Secondary

Transport of fire fighting personnel and equipment

Ambulance and wrecker service

Aerial 'auto ferry' service

Transportation of workers to remote work sites

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## AGRICULTURE

### Primary

Timber harvesting

Livestock transportation

### Secondary

Chemical application

Fishing

## SPECIAL MARKET AREAS

Forest fire fighting

Disaster relief

In summary, a major market exists for heavy lift, VTOL services for payloads that only LTA can lift economically. Several design concepts have been analyzed in detail. The results indicate that financially successful operational vehicles can be produced for these missions. In fact, they may be able to compete for some missions currently performed by other modes. The next step in these programs should be actual vehicle development rather than further study.

Fully Buoyant Airships - Different sizes of fully buoyant airships would be needed for different missions. Modern versions of past airships, small as compared to those suggested today, would satisfy most military applications such as sea control, anti-submarine warfare and detection and command and control. These missions require the long duration, medium speed and loiter capabilities associated with shaped buoyant airships. Present technologies in materials, propulsion and controls should lead to significant improvements over past design.

Agricultural missions in regions with undeveloped infrastructures may also be satisfied by "small" airships. Possible missions

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include the movement of farm products, including animals, from remote areas to transportation centers or directly to market. However, it is not clear that all of the design problems associated with this type of application can be overcome today.

Other applications require large LTA vehicles. Airships of 10 to 50 million cu. ft. or larger could carry large payloads such as containerized general cargo or bulk cargos. The key question is the cost per ton mile for this service. The largest portion of that cost will be the amortized capital costs. Therefore, a low initial cost vehicle must be developed if the concept is to be viable.

The carriers who would use large airships can be subdivided into scheduled carriers and nonscheduled or chartered carriers. The scheduled carriers would develop adequate ground support services for mooring, fueling and loading at the points it regularly serves. However, the air charter or nonscheduled carrier must operate with minimum ground support services and will have to carry much of the equipment on-board. The resulting lower payload would have to be off-set by premium rates for these special services.

Further market research is needed to define the market potential of all sizes to fully buoyant airships before prototype development is undertaken.

Hybrid Airships - Hybrid airships are vehicles which combine substantial aerodynamic lift with buoyant lift. These vehicles must either make a short take off run to generate airfoil lift or use vectored thrust and/or a rotary wing configuration to achieve vertical take off capability. Like fully buoyant airships, hybrids come in all sizes.

Several primary missions were foreseen for hybrids. The first was bulk commodity movement, principally in regions lacking a developed transportation infrastructure. This application includes the transport of petroleum, natural gas, dry bulk (ores, grains, lumber), livestock and fresh fruits and produce.

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A second application is the transport of heavy, outsized loads such as power generation equipment, industrial and agricultural equipment and aerospace vehicles and components.

General heavy cargo applications in the industrialized world were identified as the third major use of hybrids. This would require penetration of surface-freight markets like feeder line container movements to or from long haul carriers; unitized origin-destination freight; low-density, high volume manufactured products such as plastics; automotive equipment and automobile components; and breeder livestock.

Military missions where a hybrid could be used include long-endurance flights requiring both high-speed rapid deployment and low-speed maneuvering. Examples are anti-submarine warfare and the strategic deployment of personnel, weapons, and support equipment.

Finally, hybrids could perform surveillance missions involving long loiter such as environmental monitoring, and border, police, coastal, and pipeline patrol.

With from 60-80% aerodynamic or powered lift, the hybrid can perform many short or medium range airplane missions, but with fewer constraints on payload weight, volume, energy and runway requirements. Similarly, with 20-40% buoyant lift, the hybrid can also perform most long distance airship transportation and long endurance missions without being subject to the general wind and terminal-area operational constraints of fully buoyant vehicles.

However, even less is really known about hybrids than about fully buoyant airships. Therefore, further market analysis will have to be performed before commitment to an actual development program.

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## ECONOMICS

The working group attempted to formulate costing techniques for LTA vehicles. It found that in general the costing and economic frameworks developed for fixed wing aircraft or other transportation systems are applicable to LTA. Statistical methods used by other modes are available to develop cost formulas from operating data as are sensitivity analysis techniques to examine different alternatives and assumptions. Unfortunately no LTA vehicles have been designed and built for many years and no modern operating experience is available. Therefore, there is no data base to which the costing techniques can be applied.

The following example illustrates the problem. The Air Transport Association's 1967 formula (ATA67) for estimating comparative direct operating costs of turbine powered transport airplanes uses the equation

$$C = a(\text{TOGW}_{\text{max}}/b) + c \quad 1/V_b$$

to estimate flight crew costs, where

$$\begin{aligned} \text{TOGW}_{\text{max}} &= \text{Maximum Gross Take-Off Weight of the Aircraft} \\ V_b &= \text{Block Speed} \end{aligned}$$

a, b and c are constants derived from actual crew contracts.

To estimate flight crew costs for a proposed aircraft, one inserts the  $\text{TOGW}_{\text{max}}$  and the estimated block speed, which can be computed from aircraft speed. By varying  $\text{TOGW}_{\text{max}}$  and  $V_b$ , parametric studies of crew cost versus aircraft weight and speed can be performed.

Applying this approach to airships, however, is impossible. Even if size and speed are given for a particular design, there is



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no data base that can be used to derive a, b and c, so they must be assumed.

Applying different sets of assumptions as to crew cost and other costs as well, all of which were quite reasonable, the working group derived LTA costs that ranged between 2 and 30 cents per ton-mile. In one case, the airship would be highly competitive. In the other, there would be little market for its services.

The group was able to decide, however, that the basic ATA 67 costing approach could be applied to airships if and when data is developed. The only major change was the addition of a gas replenishment term, unique to airships.

For most transportation modes, the annual capital costs represents a large per cent of total cost. Vehicle price, based on construction and development costs is the main factor that determines annual capital cost. But this is an area where the working group encountered the largest variations in cost estimates.

These differences arose from

1. Inadequate information on the economic conditions under which early dirigibles were developed as compared to the present economic situation.

2. Lack of experience with LTA craft under modern certification regulations.

3. Inability to define the complexity of a modern airship structure relative to current airframe experience.

The latter factor is critical because aircraft manufacturing costs vary from \$10/lb. of airframe weight for simple, austere, "light" aircraft structures, to over \$100/lb. for sophisticated transport aircraft.

Present estimates of LTA construction costs vary by orders of magnitude. It was possible to narrow this range to between \$25 and \$100 per pound of airframe weight although not without dissent. These estimates were not particularly sensitive to the

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number of airships produced -- that is, there would be a relatively flat learning curve. To determine total cost, the research and development costs and the costs of prototype construction, testing and certification must be pro-rated over the total number of units. Vehicle cost also influences costs of insurance, direct airframe maintenance, and general and administration costs.

The calculation of annual capital cost per ton-mile is also influenced by useful LTA life, utilization, financing conditions, opportunity cost of capital and tax shelter considerations. Given the lack of hard data in most if not all of these categories, the difficulties in estimating annual capital cost became obvious. (It should be noted that while the state of knowledge of airship costs is poor, the situation concerning hybrid LTA vehicles is even worse.)

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.

In conclusion, the group identified a need to establish a hard data base for modern LTA's, with particular emphasis on construction and development costs. Given this data base, a set of equations can be derived and used to calculate cost and performance characteristics for various missions. However, actual operational experience may be needed to obtain this hard data base.

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## OPERATIONS

The working group concentrated on operational problems of conventional airships and did not discuss hybrids. Ground operations and flight operations were treated separately although any given mission includes both.

### Ground Operations

Ground operations were conducted in two sub-categories: those incident to flight such as take-off, landing and mooring; and those not related to flight such as servicing, maintenance, loading and unloading. The general conclusion was that sufficient experience and technology exists to handle a large, non-rigid such as the 1,500,000 cubic foot ZPG-3W blimp flown by the U.S. Navy from 1958 to 1961. This technology and applicable procedures would also be adequate to handle a small rigid up to perhaps 3,000,000 cubic feet, but beyond that size new methods and devices might be required.

Although the technology and procedure developed for the ZPG-3W were adequate, the group felt that a flight research airship would be an invaluable tool for refining operations to commercial standards. Such a vehicle would also be of great use in refining flight operations and investigating possible solutions to in-flight operational problems.

To get meaningful experience, the flight research airship should be at least as large as the ZPG-3W (approximately 400 feet long with an 85 foot diameter), have a top speed of 100 knots, a pressure height of 10,000 feet, range in excess of 10,000 miles and a useful load of 50,000 pounds.

Two types of mooring masts could be used to accomodate this

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airship, the type V mobile mast or the type VS transportable stick or expeditionary type mast. The stick-type are less expensive.

Mechanical ground handling would be done with the Navy's MC-3 mobile winch, used **with** the ZPG-3W, which also could serve as the towing tractor of the mobile mast. In pairs, the MC-3 mobile winches would be used for docking and undocking, masting and un-masting and landing and launching, reducing ground crew requirements to eight to ten men. Ground crew requirements for any size ship would **not** exceed this number.

At a mooring out circle, a jacked and dogged down Type V Mobile Mast with a ZPG-3W moored to it could hold in winds of up to ninety knots. Although docking and undocking of this size airship could not be done if cross hager winds exceeded 14 knots, all routine servicing and maintenance including engine changes can be done at the mooring out circle. Therefore, the airship need only be docked and undocked for major maintenance for which delays due to unfavorable winds are more easily tolerated.

In addition to the proposed LTA research vehicle, the operations group also discussed the ground handling problems of a large rigid airship. A 15,000,000 cubic foot vehicle was assumed because it is the largest size that could be built in existing construction hangars. (See Table 3.)

Large conventional rigid and metal clad airships would operate primarily in the VTOL mode using static lift and vectored thrust. Takeoffs could be made heavy from either mobile or stick-type low masts with vectored thrust providing the extra lift. VTOL landings would be made with the ship light, using vectored thrust to hold it down. It would be pulled into the mooring cup by the main wire and winch from the mobile or stick-mast.

Two yaw lines would be used to steady the ship's nose from undesirable lateral movement and to prevent the airship from

Table 3  
EXISTING AIRSHIP HANGARS

		Maximum Size Airship that can be Housed (Cu. Ft.)	No. of Cu. Ft. Can be F
ron, Ohio	1 1175' x 325' x 200'	15,000,000	4
ffett Field	1 1170' x 231' x 124'	14,000,000	4
" "	2 1000' x 220' x 160'	10,000,000	2
eksville, NC	1 958' x 258' x 180'	10,000,000	4
" "	1 1000' x 220' x 160'	10,000,000	2
kehurst, NJ	1 807' x 258' x 172'	7,000,000	3
" "	2 1000' x 220' x 160'	10,000,000	2
ita Ana, CA	2 1000' x 220' x 160'	10,000,000	2
.llamook, OR	2 1000' x 220' x 160'	10,000,000	2

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is 13 large hangars

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overriding the mast. These lines could be operated by three different systems:

1. Mobile winches similar to the MC-3 type, but heavier and larger.

2. At infrequently used sites, an 800 foot radius circular smooth path would be prepared for a landing wheel on the aft fin. Deadmen anchored in the ground just inside the path would be used for the yaw line control, with mooring points every 15 degrees along the perimeter of the circle.

3. Regularly used bases would have a circular railroad track, yaw guy-cars and a railroad rideout car to prevent kiting.

All loading and unloading would be done while the airship is moored out as would all servicing. In the past, engines were changed and even new gas cells installed while a rigid airship was moored out.

Any future large rigid airship, except for emergencies, would dock only once a year for major overhaul.

There are problems associated with mooring out any size airship, predominantly icing and high winds. Although dry snow blows off, wet snow, freezing rain or other icing conditions can cause trouble. Several procedures have been tried with varying degrees of success: high pressure fire hoses to wash off snow and ice, passing a line or belt over the top of the airship to pull off the snow and ice, or heating the helium in non-rigids. This is one area where further research is needed.

The ZPG-3W, properly moored to a mobile mast can withstand a 90 knot wind. Research is needed, however, on the effectiveness of the various mooring techniques for large rigids in high wind conditions.

For cross country flights overland, a number of ground bases or landing areas will be required at intervals well within the

the normal cruising range of all planned types of airships. In addition to normal airport supplies such as aviation fuels, airship bases should have at least small supplies of helium for emergency "top-ups"

Designated mooring out areas or bases should be reasonably level and smooth with a landing wheel roll-on circle and have an expeditionary or stick mooring mast as described earlier. The areas adjacent to these bases should be reasonably free of tall trees, buildings, electric and telephone lines and poles within the limits of normal airship take-off and landing approaches.

Bases for large rigid airships will be more extensive and elaborate. In addition to the requirements already described, they will need greater approach and take-off clearance, water supplies for ballast replenishment, a suitable mooring mast and stern hold-down facilities. Table 4 summarizes some of the equipment required at airship bases for non-hangar operations.

## Flight Operations

The paramount consideration of all flight operations must be safety. Airships must be safe, reliable vehicles if they are to serve a useful transportation role. Several topics were discussed that have a direct impact on flight safety.

Weather - The airship faces the same weather problems as other aircraft -- turbulence, icing and high winds. But because of the airship's slow speed and altitude restrictions, these problems are more serious. Long airship journeys may take several days. This increases the need for accurate long term forecasts enroute and at the destination.

Table 4

GROUND EQUIPMENT FOR NON-HANGAR OPERATIONS

Equipment	Non-Rigid	Rigid
Mules	Proven (in ZPG-2 and 3W Operations)	Adaptable
Light Weight Quick Assembly Portable Mast	Proven	Adaptable
Mobile Mast	Proven	Adaptable
Mobile Fuel and Ballast Equipment	Proven	Adaptable
Electrical Power Provided Through Mast	Proven	Adaptable
Gas Replenishment- Mobile or through Mast	Proven	Adaptable
Snow and Ice Removal Equipment	Proven	Adaptable
Helicopter Maintenance Vehicle for Upper Envelope and Surface Problems and Ice Removal	Proven	Adaptable
Portable Helium Purification Units	Proven	Adaptable
Railroad Tie-Down	Not Required	Proven (in earlier U.S. Rigid Operations)



Prior to takeoff, initial flight planning must consider the locations and probable paths of weather systems and associated frontal passages, winds, precipitation, visibility, icing and the like. The flight planner will then select a route and altitude profile that minimizes conditions adverse to the airship and maximizes favorable tail-winds.

Once the flight is underway, the airship crew must be particularly attentive to weather changes. Aside from the more obvious adverse conditions to be avoided, strength and direction of winds must be closely watched because of their impact on performance. Fortunately, weather satellite updates, broadcast several times an hour, and reports from other aircraft and ground stations provide adequate information for major on-board flight plan modification.

The quality of modern airborne radar allows early detection of storm centers, heavy precipitation and associated turbulence. Where possible, these areas would be avoided. When the limited speed of the airship prevents circumnavigation, radar can indicate the path of least turbulence.

In summary, weather does present special problems for airship operations. But with modern weather information, and on-board electronic equipment, a trained airship crew should be able to attain a high level of safe, regular service.

Altitude/Payload Management - Pure airships are displacement vehicles. That is, most of their lift is generated aerostatically rather than aerodynamically. The airship will rise when it weighs less than the air it displaces. It will sink when it weighs more than the air it displaces. The buoyancy of an airship results from the density differential between the vehicle and the surrounding atmosphere.

Atmospheric density is a function of altitude, temperature and humidity. Airship density is a function of its mass and

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volume. Combining these factors, two major problems of airship operation can be identified. First, as an airship rises, atmospheric pressure decreases. But at some point, the cells are full and gas must be vented if the airship is to go higher. This is called the pressure altitude. If less gas is used from the beginning, the airship can go to a higher pressure altitude without rupturing. But decreasing the original amount of gas also decreases volume and increases density. To compensate, the airship must lower its mass, which in practice means decreased fuel or payload or both. Pressure altitude restrictions could place a great limitation on the use of airships in undeveloped or inaccessible regions which are often mountainous.

The second problem occurs when the airship passes through temperature gradients. Because cold air is more dense than warm air, an airship in equilibrium with cold air may not be able to climb through a warm layer, which provides less lift. Likewise, if it descends through warm air, it will fall faster than expected. Conversely, if a warm airship tries to descend through cold air, it may bob on top of the layer and be unable to descend further. Under temperature gradient conditions, the airship was often forced to idle either in the air or on the ground until conditions changed, or its gas temperature changed through heat loss or absorption.

One way of coping with these problems is varying the mass of the LTA vehicle. The traditional method, introduced by Professor J.A.C. Charles in 1783, is to use disposable ballast to gain altitude and the valving of some of the lifting gas to lose altitude. It is still the most direct method.

With modern technology, it may be possible to control density by varying volume instead of mass. This could be done by

1. Expansion/contraction of the LTA gas mechanically.
2. Liquification/evaporation of the LTA gas.

3. Addition and subtraction of heat to the gas.

The weight penalty of the equipment needed for 1 and 2 seems to be prohibitive. Although hull insulation and heat exchangers may be required for 3, it appears the most likely to succeed given today's materials and technology.

In summary, new density control systems may be needed for operation over ranges of temperature and altitude. Aerodynamic lift would be used to correct for small variations in altitude and gas valving and ballast systems would still be needed for emergency density control.

Air Traffic Control - The size, speed and maneuverability of airships may dictate airspace allocations. Therefore it will be necessary for airship operations to be compatible with the operation of other aircraft that might occupy the same altitude/route/terminal regime. Compatibility may be achieved by such means as:

1. Allocation of special airship routes, terminal areas and altitudes.
2. Air traffic control time and space separation.

Either of these methods may well meet strong objection from general aviation, the normal users of low altitude airspace.

In addition, alternate bases with associated routings must be available to avoid airspace congestion at primary terminal areas when surface conditions are not conducive to landing.

Other than these special requirements due to the airship's large size and low speed, airships should be compatible with the normal ATC system.

In summary, the airship operating regime, both terminal and enroute, may require specific airspace/time allocations. This will involve trade-offs with other airspace users and may induce institutional and/or political problems, but no other problems are foreseen.

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Emergency Considerations - In addition to the normal and routine operating procedures which can be developed for a given vehicle and a given mission, there are emergency procedures used by flight crews in emergency conditions. Such procedures are highly dependent on the vehicle type and mission. However, a few general comments can be made. Careful consideration must be given to the ballast management program in LTA vehicles. The flight crew must be able to cope with adverse ballast conditions. These adverse conditions must be easily and rapidly identified and at least one way of rectifying these conditions be provided such as rapid release of water.

Because some LTA's will be large vehicles, adequate crew communications must be provided during emergency conditions including loss of primary electrical power.

In general, redundancy of vital systems necessary for flight operations alleviates the need for lengthy and complicated emergency procedures, but redundancy is expensive. Therefore the decision to design redundancy into a vehicle should be made on the basis of trade-off studies of the appropriate costs and benefits including operational alternatives.

There are several areas which require special attention:

1. Body restraining systems
2. Non-flammable materials
3. Evacuation procedures
4. Appropriate crash worthiness
5. Easy ingress/egress

The size of an airship requires movement of the crew for inspections and maintenance. It offers greater freedom for passenger movement, a necessity on long endurance flights. Long endurance flights will also require beds for crew as well as passengers. Past experience from airship operations shows that airship motion occasionally can be so violent that a man would be thrown off his feet.

Therefore, some body restraint system will be necessary.

In addition to aircraft type seat belts, the accommodations and furnishing must be shaped and designed to prevent bodily injury when the airship experiences a violent motion from a gust. Special beds will be required, preferably not requiring safety belts to confine the body. Passageways and areas must be furnished with body-restraining systems to protect passengers and crew members if gusts are encountered while they are moving about.

Existing regulations for flammable materials in airplanes would still apply. In addition, new standards would be required for skin fabrics, gas cell materials and the like.

Special attention must be given to the problem of an emergency evacuation. The huge size of the airship envelope in combination with the comparatively diminutive crew and passenger cabin poses a problem unique to airships.

An airship is a low speed aircraft. Therefore, existing crash worthiness requirements would have to be met. Further, the size of airships would allow a design with high crash attenuation capability, giving additional crew/passenger protection.

The access to gondolas and the interior of the airship could become an operational problem if not properly considered in the configuration of the airship. General requirements have to be analyzed and established as a guide for the design of specific configurations.

In summary, safety procedures must be developed for airships as they have been for airplanes. Special attention must be given to the large size and potentially long duration missions of airships that may be different from airplane experience.

Training Requirements - Safe operation of the airship must be the paramount consideration at all times. Therefore, today's airship will require training to the same high standards required in aircraft operation. Some system of certification for the entire crew

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must be established. Periodic revalidation of proficiency should be an integral part of this certification system. There is every reason to believe that the use of simulators for initial and periodic follow-up training can be employed as a valuable, and probably even essential, training resource.

Safe maintenance practices peculiar to the airship must be established and continually checked through a training and proficiency demonstration program. All areas pertaining to the safe operation of the airship both while airborne and on the ground must become an instinctive part of the habits of all personnel associated with airship maintenance and operation.

In-Flight Monitoring and Control Systems - Past airships have had to compromise their controllability by limiting the amount or rate at which elevator or rudder could be applied, to protect the structural integrity of the hull. As a result, they were sometimes uncontrollable during periods of several side or vertical gusts. This situation can be corrected in three ways:

1. Better structural techniques
2. Better materials
3. Automatic flight controls

The latter would use sensors mounted on critical parts of the hull and fin structure to measure the amount or strain caused by control movements or gusts. This would be fed back to the autopilot to reduce the control movement before the strength of any part of the structure was exceeded. Therefore, the maximum safe degree of control could always be applied without endangering the safety of the airship.

To increase the margin of safety of airships, improvements in stability and control are necessary, particularly at low speeds under 20 miles per hour. Lack of control response at these speeds has complicated landing and hovering and also loading and unloading

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when performed in the open while hovering or at the mast. Improvement in airship stability and control at low speed is a necessity.

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## TECHNOLOGY

For each area of technology, the problems of designing both conventional and hybrid LTA aircraft were reviewed by the working group to answer the following questions:

1. What is the current state of applicable technology?
2. What improvements over past LTA designs would result from application of current technology to LTA concepts?
3. Where do gaps exist in technology needed for future designs?
4. Can we assign priorities for future R & D to fill those gaps?

The technology working group split into subgroups, each to address specific areas of technology. The reports of each subgroup follow.

### Overall Design/Configurations/Mission Related Problems

This subgroup reviewed a variety of past and present concepts for LTA aircraft, classified them into configuration categories, related their performance to missions and then reviewed mission-related technology problems. The subgroup also defined various design-related problems for hybrid configurations. The approach was similar to that of the Market Analysis working group, but it started from a technical perspective rather than from a mission/market perspective.

Characteristics of Airships - A wide variety of airship concepts have been



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explored and, in some cases, developed to exploit the unique characteristics of fully and semi-buoyant aircraft. The most significant characteristic of the fully buoyant airship is its ability to lift a load aerostatically without the expenditure of power. However, it pays for this free lift when it tries to move its large volume and size at even moderate speeds. Because of the high drag from the large surface area and displacement of the buoyant envelope, high speeds require very high expenditures of power. Therefore buoyant lift vehicles are best suited for large loads, low speed, long endurance missions. Conventional winged aircraft are more suitable for smaller, higher density loads, high speeds, limited endurance missions.

For intermediate missions it may be advantageous to combine buoyant lift with auxiliary lift from wings during cruise, or from rotors during hover (propellers during cruise) or perhaps from both wings and rotors. These configurations have given rise to a large number of hybrid LTA concepts. Some are shown in Figure 1. By combining wing, rotor and buoyant lift it may be possible to tailor aircraft design to mission requirements in terms of load size, hover requirements and speed, producing a smaller and more efficient vehicle.

For example, conventional airships can perform long endurance, loiter missions for days at low speeds, low fuel expenditure, and hopefully with low noise and pollution levels. The conventional airship can also be used to lift large loads if an equivalent ballast (perhaps water) can be dropped at the origin and is available at destination. If ballast problems make pure LTA operations impossible then limited buoyant lift might be used to offset the empty weight of Vertical/Short Take-Off and Landing (VSTOL) vehicles. The available wing or rotor lift can then be totally devoted to lifting payload.

Projected advances in both helicopters and conventional airplanes do not appear to provide the large payload capabilities required for certain missions

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currently envisioned. While no large airships having these large payload capabilities have been built either, LTA appears to have the potential to perform these missions with the proper application of modern technology.

Classification of LTA Configurations - In addition to the conventional classification of airships as rigid, semi-rigid or non-rigid, recent work has suggested an expanded classification to cover the new hybrid concepts which combine aerostatic, wing and rotor components.

Table 5 classifies the various aircraft concepts and designs presented at the Workshop by their take-off capability, buoyant state, construction and auxiliary lift systems. This method of classification more fully describes vehicle characteristics than the older, rigid, semi-rigid, non-rigid, and hybrid classifications.

Table 5

CLASSIFICATIONS OF LTA CONCEPTS/DESIGNS

<u>Concept/Design</u>	<u>T/O Capability</u>	<u>Buoyancy</u>	<u>Envelope</u>	<u>Auxiliary Lift</u>
Aerostat	VTOL	Buoyant	Nonrigid	None
HASPA	VTOL	Buoyant	Nonrigid	None
Raven Logging Balloon	VTOL	Buoyant	Nonrigid	None
Raven Hot-airship	V/STOL	Buoyant	Nonrigid	None
Airfloat Heavylift Transport	VTOL	Buoyant	Semirigid	None
Dynapod	V/STOL	Buoyant	Semirigid	None
Aerospace Develop- ment Airship	V/STOL	Buoyant	Semirigid	None
Papst-DAL	V/STOL	Buoyant	Semirigid	None
SCACI Concepts	V/STOL	Buoyant	Rigid	None
Canadian Airship Development	V/STOL	Buoyant	Nonrigid	Aerodynamic
Helistat	V/STOL	Semibuoyant	Nonrigid	Propeller
Aerocrane	VTOL	Semibuoyant	Nonrigid	Propeller
Goodyear ZPG-3W	STOL	Semibuoyant	Nonrigid	Aerodynamic
Goodyear BLC	STOL	Semibuoyant	Semirigid	Aerodynamic
Aereon Dynairship	STOL	Semibuoyant	Rigid	Aerodynamic
Lifting Body M2/F2	STOL	Semibuoyant	Rigid	Aerodynamic

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Classification of LTA Missions - The following mission areas were examined for possible applications of LTA technology:

1. Transportation of heavy, indivisible loads
2. Transportation of passengers, containers or break-bulk freight
3. Low altitude surveillance
4. High altitude surveillance
5. General Purpose

Under the transportation of heavy, indivisible loads category, the subgroup discussed the movement of large indivisible loads that exceed the capacity of surface transportation systems because of size constraints, interface constraints (over-the-beach) or roadbed capacity. Included in this category were the transportation of large machinery, factory fabricated structures and specialized equipment for whole-tree logging in rough terrain. The distances involved may be long or short range. Both repeated and one-time missions were considered.

In considering the transportation of passengers, containers or break-bulk freight, the subgroup concentrated on the classical requirement to move people or goods between two points. In this context, the LTA technology will be competing in specific scenarios with appropriate other forms of transportation. Because of its unique characteristics, LTA may be more economical in some of these scenarios when total costs are considered. Ranges of interest included from very short distances (inter-urban transports) to the very long trans-oceanic distances.

The low altitude surveillance category basically covered the low altitude (less than 20,000 ft.), long endurance and high payload requirements mission. Possible applications include ASW and ocean surveillance operations for the Navy, high resolution geographic mapping, broad atmospheric/oceanographic sampling

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or similar activities. Another application would be the relay of electromagnetic signals for communications.

In contrast, high altitude surveillance missions were those using high altitude, line-of-sight sensors where large area coverage is required from a moving platform. Long endurance is required and payload requirements must be limited, but the cost of the LTA vehicle is relatively low.

Finally, those miscellaneous LTA missions that do not have a significant common demoninator were grouped together. Included were such things as sport ballooning and police surveillance of urban areas.

Matching Concepts to Mission - The requirements for vehicle performance which are associated with these missions were then derived and are summarized in Table 6. Payload requirements, altitude, endurance, and control authority vary quite widely, but the speed requirements for most missions are below 100 knots and most missions require very short takeoff distances.

The final step in the analysis was to match some of the vehicle concepts and designs presented at the workshop with the vehicle requirements developed. This is summarized in Table 7.

From this analysis, the subgroup decided that there was at least one match between mission and vehicle for each vehicular type. And in some cases, a vehicular type might be appropriate for several missions.

Table 6

TYPICAL MISSION PERFORMANCE REQUIREMENTS

Mission/ Requirements	Heavy Lift Indivisible Load		Transportation of Passengers and Break-Bulk Freight		Low Alti- tude Surveil- lance	High Alti- tude Surveil- lance	General Purpose
	Long Range	Short Range	Long Range	Short Range			
Take-Off Capability	V/STOL	VTOL	V/STOL	VTOL	VTOL	VTOL	V/STOL
Speed (knots)	50-100 <sub>+</sub>	25-50 <sub>+</sub>	50-100 <sub>+</sub>	50-100 <sub>+</sub>	25-100	0-50	25-100
Range (miles)	100 <sub>+</sub>	1-50	500-3,000 <sub>+</sub>	1-500 <sub>+</sub>	Limited	Limited	50 <sub>+</sub>
Endurance	Medium	Short	Medium	Short	Long	Long	Wide Range
Payloads (tons)	200-800	50-400	100-500	50-400	Wide Range	Small	Small
Altitude (feet)	0-5,000	0-5,000	Terrain Dependent	0-5,000	0-20,000	20,000- 80,000	0-3,000
Control Authority	High	H. gh	High	High	Med. High	Low	Wide Range

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Table 7

MATCHING CONCEPTS TO MISSIONS

Mission/ Concept	Heavy Lift Indivisible Load		Transportation of Passengers and Break-Bulk Freight		Low Alti- tude Surveil- lance	High Alti- tude Surveil- lance	General Purpose
	Long Range	Short Range	Long Range	Short Range			
Aerocrane	Possible Application	Primary Application			Possible Application		Possible Applications
Helistat	Primary Application	Possible Application		Possible Application			Possible Applications
Tethered Systems		Primary Application			Primary Application		Possible Applications
Lifting Body	Possible Application		Primary Application	Primary Application	Primary Application		Possible Applications
Conventional Airship	Possible Application	Possible Application	Primary Application	Primary Application	Primary Application		Primary Applications
High Altitude Balloon						Primary Application	

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Special Mission-Related Technology Requirements - To accommodate special instrumentation needed for ASW or geophysical prospecting, special attention may be necessary to minimize interference with the sensors or to insure a favorable environment for them. For example, in geophysical prospecting using sensitive magnetometers, electromagnetic disturbance and vibration must be minimized. This may require the use of non-ferrous sparkless engines, plastic rather than metallic structures, adequate grounding of all conduction elements, shielding of electrical systems, physical separation of sensors from machinery and extremely low resonant frequency mounting systems if low frequency signals are to be sensed.

For sensors towed in the water, adequate velocity and direction control is needed. Provision must be made to tow heavy systems with large tow forces. Comfortable, vibration free spaces for sensor operators will maximize their performance. If on-board acoustic sensing arrays are used, low self-noise from machinery and low flow noise in the vicinity of the sensor is necessary.

Hybrid Design Problems - Hybrid vehicles pose several problems that need more study. For example, there has been little analysis of the aero-elastic behavior of hybrid configurations that combine rotor/propellers with large semirigid or flexible envelopes. Until the dynamic stability coefficients of hybrids are determined, it is impossible to develop automatic stabilization and control systems. In some configurations large directional thrust rotors are placed around the periphery of the buoyant envelope. The resulting induced flows could exert large aerodynamic forces on the envelope, making hover control and cruise stabilization difficult. Is there one optimal shape for a lifting body LTA configuration or does it change with cruise speed? In configurations that combine wings and buoyant envelopes, the



aerodynamic forces on the envelope are unknown where large downwash flows occur on the wings. There may also be a danger of hull flow separation in crosswinds at low forward speeds and a resulting loss of lift on the relatively small wing.

In general, more needs to be known about distributing large concentrated loads from wings, propellers, thrusters, rotors and large load frames over the very light, low density structure of the buoyant shell.

## Materials, Structures and Manufacturing

There is no fundamental distinction between buoyant and hybrid airships with regard to materials, structures, or manufacturing techniques. Most available or new technologies may be applied to either type of vehicle with differences only in detailed design. Therefore, the sub-group discussions applied to both types of airship except where noted.

Materials - Progress has been made in the past several years to improve flexible aerostat envelope materials. This pliant materials technology can be applied from present balloon developments to the design of gas cells and envelopes. Among the newer materials are combinations of polyester and Kevlar fibers which offer greatly improved strength and tear resistance. Fabrics capable of transmitting planar shear stresses by virtue of tri-axial weaves have also been developed. These newer fabrics using improved fibers display reduced permeability characteristics. However, further development is required in seaming techniques, the effects of other inflation gases and the effect of high super heat on these new materials.

A wealth of possibilities exists for the use of rigid materials, such as fiber or laminated composites, metal or otherwise. Their principal value is less in improved strength than in the improved rigidity offered. However, the

pay-off for each and every structural material can only be fully explored through an internal configuration design making the maximum use of that material. The combinations and permutations are consequently large and as yet unmapped.

Manufacturing - Most of the recent fabrication and manufacturing techniques developed in the aerospace industry can be applied to airship structures, including:

1. Diffusion bonding
2. Ultrasonic assist in fabrication
3. Laser techniques, electron beam and weld bonding
4. High energy sheet metal forming
5. Isotherm forging
6. Premium quality high strength casting
7. Bonded structures
8. Rivet bonding
9. Improved adhesives

Special design and handling concepts for minimum gage, light weight structures may be needed to prevent structural damage during manufacturing or in service. Economic fabrication concepts and methods particularly suited to airship construction need to be developed to build low cost airframes.

Structural Design - Structural design must synthesize material characteristics with structural concepts. Large capacity, high-speed computers are an invaluable tool for this synthesis. At the conceptual design stage, numerous configurations may be evaluated. The computer can determine design loading conditions and perform structural analyses of promising configurations. Graphic displays of lines,

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structural members and plumbing and wiring can be prepared by computer, as well as line drawings and lofting data. Finally, the computer can convert these designs into numerical control tapes for automated die and template cutting. Similar programs have been developed and are currently being used to develop surface and undersea vehicles.

In spite of the sophistication in computerized design/analysis, there are deficiencies pertinent, but not unique, to airship applications. More work is needed in non-linear and viscoelastic material and structural behavior, large-deflection analysis, and contact and discontinuity problems.

Computer programs have been written specifically to treat these problems. However, they have not been incorporated into large-scale general purpose programs such as Nastran, Solid Sap, or others.

These problems are not unique to airship developments. It is not the responsibility of the LTA community alone to solve them. However, the LTA community should promote, cooperate, and assist in their solution.

Loads - Loads on conventional airship configurations are fairly well defined for the quasi-static conditions associated with discrete gusts, maneuvering, empennage loads and landing contact velocities. However, the random gust condition has not been explored nor the condition where multiple gusts act simultaneously in various magnitudes and directions on large bodies.

The situation becomes increasingly difficult when hybrids are considered. The dynamics associated with the airplane must be combined with those peculiar to the airship. Because these conditions are dynamic, a method of interfacing the buoyant mass and structural response with those of the HTA augmented components is needed in order to assess gust alleviation factors. Criteria must be established to determine what hybrid landing contact velocities will be. (Probably between those of LTA landings and the higher values of HTA.)

Criteria - LTA load, performance and design criteria need updating and a current standard design manual should be prepared to be used as a reference for the fundamentals of aerostatic design. These documents should include chapters on the following:

1. Loading - Ground conditions and criteria, flight conditions, including steady state and transient.
2. Design Factors - To be used for specific loads and stresses and limit load factors.
3. Materials - Physical properties, as complete and detailed as possible, of composites, metals and fabrics.
4. Gases - Complete physical properties, constants at uniform thermodynamic state, conversion factors for other states (possibly **graphs** and tables), standards of gas purity and standards for special lift of gases.
5. Fuels - Physical properties of liquid and gaseous fuels.

## Aerodynamics, Propulsion and Performance

To operate within the present-day transportation system, airships must operate in roles which differ from the traditional applications of these vehicles between the wars and operate under weather conditions and within a system of safety restrictions which demand a much higher performance than that attained by their predecessors. To analyze the overall performance of airships and ways of improving that performance the sub-group considered, cruising performance, maneuvering performance, performance in conditions of meteorological turbulence and performance in other adverse weather conditions. The sub-group then examined

the current state of the art, outstanding problems and made recommendations for further work. Hybrids were reviewed separately.

The investigation of these topics depends upon an integrated program of experimental and analytical work. The subgroup felt that much research may have already been completed, but is not widely known. Therefore participants in the Workshop were invited to submit any lists which they may have of references associated with airship design work, either from specific airship sources or from associated fields such as underwater vehicle research, wind effects on buildings, and so on. A similar listing of available computer programs which could be applied to any aspect of airship performance assessment would also be useful.

Wind tunnel work associated with earlier airship development was inhibited by the difficulty of achieving relevant Reynolds numbers. It appears, however, that high pressure tunnels may now be available which would allow meaningful measurements of aerodynamic derivatives and coefficients to be made in appropriate flow regimes. A search should be initiated for information on the existence and availability of such facilities.

Finally, the modern airship must operate in conditions of low-level turbulence which are inadequately documented. The collection of turbulence spectrum analyses and of information on wind sensing techniques must precede the establishment of an experimental program of wind measurement.

Cruising Performance - The general consensus of the subgroup was that buoyant airships, over long stage lengths, should have a cruising speed range of 80 to 100 knots, representing the relatively narrow margin between undesirable sensitivity to adverse winds and excessive fuel consumption. (Proposals for faster ships (200 to 300 kts.) were felt to be too specialized for study in this context.) This represents an increase of 20 to 40 knots over earlier designs, with corres-

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ponding increases in aerodynamic and structural loading and in propulsive power requirements. These lead in turn to a requirement for increased aerodynamic efficiency in cruising flight, which may be achieved by modifying airship geometry or by mechanical means, such as boundary layer control or propulsion system revision.

As far as cruising flight is concerned, it seems unlikely that geometric deviations from the traditional 'cigar' form will lead to significant reductions in drag. Further work is necessary on the effects of L/D ratio, on the housing of installations within the hull profile, on the drag of various control surface systems and on the effects of surface texture and rigidity on overall drag coefficients. The flow around a body of revolution in pitched flight also requires further investigation.

While the classical form remains most efficient for cruising operation, the increasing importance of maneuverability and control in turbulence at low speeds and altitudes may dictate an alternative geometry. Whether the penalty in cruising flight efficiency will be accepted will generally be decided by the mission for which the airship is designed.

Boundary layer control for airships has been proposed, in alternative forms, to reduce wake drag at the tail, reduce skin friction drag by delay of transition and to improve control surface performance by local flow control at the hinge break. There is little information on wake generation at typical flight values of Reynolds number. Therefore, further study is required on the application of boundary layer control in this context, particularly in view of the mechanical and structural problems involved. Effective reduction of skin friction requires suction over almost the whole envelope area. The weight and power requirements would appear to neutralize any aerodynamic advantage which may be achieved. More investigation is required, however, to quantify this qualitative reaction. Control surface blowing is already in use on some aircraft with great effect, and its adaptation to airship fins clearly merits further study.

Any revisions to the propulsion system will probably use propellers because they are still the optimum propulsive instrument for the buoyant airship. There is a need for the further development of large, low-speed, low-noise units. Aerodynamic advantages are attainable through the use of wake-immersed propellers and of ducted propellers, but each system involves weight penalties which must be evaluated in the context of the vehicle's mission.

The optimum location of tandem propeller units mounted on the airship flanks must be investigated. The interference effects of these propellers on each other and on the airflow over the hull have never been fully analyzed.

It appears that cycloidal propellers may have advantages in low-speed maneuvering, though they become extremely inefficient with increasing speed.

A wide power-plant choice is possible if all potential long-term developments are taken into account. A realistic approach must confine itself, however, to the actual and potential performance of units already in use. Because an emergent airship industry will be unable to support a specific program of engine development, such development will be controlled by demand in other industries. Therefore, the lightweight diesel engine probably will not achieve a development rate comparable with that of the gas turbine. The latter becomes more attractive for airship applications as its specific fuel consumption declines.

The airship would be more readily adaptable to nuclear propulsion than would any heavier-than-air vehicle. However, this is a long term prospect and its development will depend on the level of petroleum fuels available in the future.

Maneuvering - Maneuver capability in any modern airship will be of more importance at very low speed and altitude than in cruising flight. It is in the former regime that improvements in current performance are particularly necessary. Pressure airship experience has indicated an almost total loss in aerodynamic control effectiveness at speeds below about 17 knots. A significant degree of control at lower

speeds can be achieved only by the use of vectored thrust in all three directions. Effective design of such a system requires simulation based on aerodynamic data including second and higher order derivatives. But this information is not available even for traditional geometries. It can only be obtained through wind tunnel experiments over a relevant range of Reynolds numbers.

On certain missions, the low-speed control requirement may require either a total departure from traditional geometries or the application of very large thrust (as in the case of a tilting-rotor helistat). The associated penalty in cruising performance must be reduced to an acceptable level for the mission.

Meteorological Turbulence - In cruising flight, the problems of structural loading and controllability under gusting conditions are increased by the size and speed projected for future airships. It is probable that present-day knowledge of gust structure will permit a far more accurate estimate of the conditions airships will be required to meet than has previously been possible.

The necessary improvement in gust resistance may be achieved either by an increase in structural effectiveness (possibly involving a geometry change) or by some form of gust alleviation. Alleviation can be a control function involving moving surfaces or vectored thrust, but alternative possibilities may emerge from the study of flexible structures.

In the low-speed maneuvering and hovering regime, station-keeping becomes more important than structural loading. But the size of the thrust units needed for station keeping may in itself produce significant loading problems. Other problems which require further study include gust sensing techniques, including the use of radar; the dynamic characteristics of an airship in tethered conditions; and airflow in the region of an airship flying close to the ground.



Hybrid Performance - A general analysis of hybrid aircraft is inhibited by the wide range of hybrid configurations which have been proposed. All such concepts require further investigation. The degree of analysis depends upon their divergence from configurations for which information already exists. Certain hybrid designs can profit immediately from research on lifting bodies of various forms, including aircraft of low wing loading.

Most of the problems are related to the hybrid's large bulk and low mass.

Particular study fields include:

1. Take-off and landing performance, with particular reference to the vehicles' sensitivity to changes in wind direction, to the rapid decrease of ground effect forces with height, and to its slow response.
2. The problems of gust response in cruising flight which in many ways resemble those discussed for the buoyant airship.
3. Interaction between aerostatic, aerodynamic and propulsive forces in maneuvering flight.

It seems clear, however, that hybrids offer advantages on certain missions and that further research would be justified.

## Stability, Control and Handling Characteristics

This subgroup discussed stability, control and handling characteristics to establish 1. the current state-of-the-art, 2. identification of problem areas, 3. suggested approaches to solutions, and 4. identification of new technology required (as opposed to an adaptation of established technologies).

Equations of Motion - The rigid body equations of motion for the airship must include the action of air on the hull, a term usually ignored in airplane analysis. A useful approach is to formulate Kirchoff's equations and determine the energy of the airship and the fluid medium in terms of the airship's motion and geometric shape. Other forces and moments in the equations of motion include body forces such as weight and buoyancy; aerodynamic forces on the hull, empennage and gondola; control forces, both static and aerodynamic, and all the corresponding moments. Additional terms which must be included are gas lag motions in rigid airships and meteorological effects. These include adverse weather conditions (winds, gusts, snow accumulation) as well as changing ambient conditions in temperature and pressure.

Some of these inputs can be determined easily. Others pose serious problems. Most difficult to estimate are the aerodynamic drag and lift forces on the hull and their variation with angle of attack. To solve for these terms analytically, skin friction, pressure and induced drag need to be accurately predicted. Aerodynamic lift estimates based on the pressure distribution in real flow, boundary layer characteristics, separation point, and downstream flow properties must also be accurate. Lack of reliable analytic solutions in airplane studies has led to extensive use of experimental techniques to solve the relevant flow equations. Model experiments may be required for airship analysis as well.

An additional aerodynamic problem is the prediction of rudder and elevator effectiveness because there is little knowledge about flows around the empennage including downwash, sidewash and hull blockage effects.

Once the equations of motion are determined and kinematic effects included, the motion of the airship's center of mass and the airship's attitude response can be predicted. This permits trajectory analyses for linear and curvilinear flight paths as well as estimates of open loop response to the various inputs described.

Pilot-Airship Dynamic Systems Analysis - This is a recent technological development which mathematically models the pilot as well as the vehicle and external forces. Conventional automatic control theory is then applied to analyze the behavior of the entire system, including the pilot. The results indicate dynamic incompatibilities and the limitations of both man and vehicle. Although these techniques are now developed and applied to heavier than air vehicles, they were not available to airship designers of the past.

The ability to model the dynamics of the airship, its pilot and atmospheric disturbances can be used to predict the limits of unaugmented stability and control and the specifications of the automatic control systems required. The need for flight-active cockpit displays, flight-director displays and flight instruments in general can also be specified. Therefore, the adaptation of these techniques to airship design should significantly improve the stability, control and handling characteristics of modern airships.

Stability Analysis - With the equations of motion formulated, small perturbations can be analyzed to determine the stability of steady state flight by expressing the perturbational forces and moments in terms of the corresponding perturbational state variables and introducing suitable stability deviations. But there are several problems. The first is whether the Bryson expansion can be used for the airship as it is for the airplane. Even if it can, truncation errors must be analyzed. The second problem area is the determination of the derivatives. Analytical predictions of the derivatives with respect to linear or angular accelerations can be based on potential flow theory. However, those with respect to the linear and angular rates arise from real flow properties, and therefore are very difficult to predict analytically. In the past, only derivatives which could be determined experimentally were considered, while the others were ignored.

But this often led to only very approximate stability criteria. Clearly new analytical and numerical procedures or suitable experimental techniques must be developed to determine these real flow derivatives. The sensitivity of the stability criteria to the various stability derivatives can then be studied to determine which derivatives must be known accurately, and which ones need only be approximated.

Structural Flexibility - Airships, as flexible structures, resonate if forced at the appropriate frequencies by turbulence, motion in storms or even active attitude controls. This resonance could lead to structural failure, and may have been the cause of several rigid airship accidents in the past. To design around this problem, one must analyze the first few flexible modes of the structure, the operating environment and the interaction of the active attitude control system with the structure. This flexibility analysis, when incorporated into the rigid body equations of motion, would provide a realistic model of airship performance never available in the past.

There are many analytical and experimental problems, however, particularly the modeling of the hull as an elastic structure and the flexibility corrections to the stability derivatives. In addition, the coupling between the lateral and longitudinal motions caused by the effect of the fluid on the airship prevents the decomposition of the stability equations into two separate sets of lateral and longitudinal equations as done in airplane analyses. As a result, the stability analysis and the development of stability criteria are greatly complicated.

Automatic Flight Control Systems and Computer Controls Management - Automatic flight controls systems were not used on airships of the past. Consequently,

although modern automatic flight control systems exist, they are not designed for airship applications, and will have to be modified to provide:

1. Automatic trimming to compensate for variations in mass distribution, center-of-buoyancy shifts, gas density and temperature changes and atmospheric pressure gradients.
2. Stability augmentation.
3. Altitude and attitude hold functions.
4. Load/gust alleviation.
5. Flight-director displays.
6. Flight-crew station monitoring.
7. Specific flight-path control programming.

To perform these functions, the flight control system will need data on airship motion, structural loads, fuel states, atmospheric conditions, gust direction and magnitude, amount and distribution of ballast, buoyant gas state, control and thrust settings, and the like. Although available aircraft instruments can provide much of this information, new sensors must be designed or adapted from other uses to provide the additional data. The resulting flight control and computerized flight management systems will, however, provide greatly improved handling, both in route and for takeoff and landing and consequently improve overall airship reliability and effectiveness.

Stability and Control Criteria - Because of the inadequacies in past airship analyses, little is of use today. New criteria must be developed, particularly in the areas of:

1. Static longitudinal stability.

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2. Directional stability.
3. Control power about all axes.
4. Vertical control power, accelerations and decelerations.
5. Control required for trim about all axes.
6. Cross-control ranges of acceptability.
7. Ground proximity phenomena.
8. Limits of automatic control commands.
9. Margins of control available for maneuvering.
10. Dynamic stability about all axes.
11. Speed stability as a function of angle-of-attack and flight path angle.
12. Propulsive moments.

Both emperical and theoretical studies are needed to provide these criteria for airships. Systems analysis based on sound aerodynamic information can supply the theoretical base, but simulation will be needed to provide emperical data.

Requirements and Specifications - There are no general military or commercial requirements or specifications for airships. These should be developed to provide airship designers with much needed guidance.

Simulation - Simulation as we know it today was unknown to the airship designers of the past, but can be applied to both identify and solve major problem areas. Some uses would be to provide:

1. Clear identification of the dynamic interface between vehicle, pilot, and guidance and control systems.
2. Identification of unsuspected dynamic problems.

3. Aid in training pilots and flight crews.
4. Aid in establishing requirements.

Very little new technology is required because airship simulation can take advantage of techniques developed for airplane simulation and are available today.

Research Projects - The stability and control subgroup identified several other problem areas where further research is needed:

1. The violence of turbulence.
2. Techniques other than ballasting and gas venting for rapid altitude control.
3. A means of conditioning gas to vary density.
4. Alternatives to pure tail control.

Overall Technology Summary

In general, most of the technology needed to develop and operate modern airships is in hand. Research areas identified would apply to improved airships of the future.

(The following represents the preliminary views of the editor, and not necessarily those of the workshop as a whole.)

LTA does offer great potential as transport vehicles for both civilian and military applications. Although further research is needed to develop advanced LTA vehicles, the technology is in hand to build and operate modern airships today. that would be considerably better than those of the past. The key question is whether these modern airships make sense economically.

It is clear that unmanned LTA lifting devices can be produced and operated economically. But the viability of large manned airships is still uncertain. Because there is no real economic data on costs and performance, estimates of airship economics vary widely. Ultimately, an airship must be built and operated to provide hard data.

But before actual development and constructive, rigorous market analysis should be performed to determine what groups would use airships under what conditions. By looking at potential airship applications and determining what cost and performance characteristics are needed for the airship either to capture a role now performed by another vehicle or to carve out new unique applications, a design specification can be evolved. With this as a guide, designers can estimate whether or not an airship can be built to meet that specification. If not, there is no need to build an operational vehicle.

Because of the potential national benefits of airships for both civilian and military applications, the federal government as well as private industry should find this market analysis (as well as be ready to support development if the market analysis is positive). The basic market analysis would be relatively inexpensive, probably less than one million dollars, and is the next logical step in developing a modern airship system.