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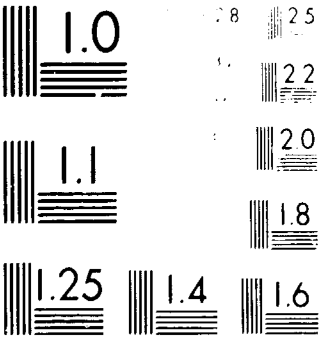

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APPLICATION OF LIGHTER-THAN-AIR TECHNOLOGY IN DEVELOPING COUNTRIES*

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SECTION I

INTRODUCTION AND OVERVIEW

OBJECTIVE

1. The objective of this paper is to provide a survey and assessment of emerging technological breakthroughs and their implications for industrial development of developing countries in the field of lighter than air (LTA) technology, with particular reference to the types and systems most appropriate to conditions prevailing in the developing countries.

APPROACH

2. The approach taken is first to summarize and to delineate the categories of LTA platform types in a generic manner. Three basic platform types that appear to be most suitable for immediate or near term application to the needs of developing countries are then selected. For each selected type of LTA platform, a brief overview is then presented that includes its general characteristics, mission applicability and relative estimate of economic feasibility. An examination is then made of a number of general considerations applying to all of the selected LTA platforms when operating in developing countries. Finally, a detailed presentation is given of each of the three types of selected platforms: conventional airships, heavy-lift airships and tethered aerostats. A section of the paper is devoted to each of these and includes a description of the vehicle type, performance capabilities, potential missions and applications, gross estimates of costs and availability to developing countries.

CATEGORIZATION OF LTA PLATFORMS

Balloons

3. Free floating unpowered balloons are the oldest type of LTA vehicle and represent man's first successful attempt to achieve flight. The initial lifting medium was hot air, but natural gas, hydrogen and helium have also been used as the lifting gas. The basic sub-categories of balloons currently in use are as follows:

- Scientific Balloons. Since the early 1960s scientific balloons constructed of lightweight plastic materials have been used to explore the atmosphere. Balloons as large as 1.49 million cu m (52,000,000 cu ft) have been launched with scientific measurement packages to altitudes in excess of 45 km (150,000 ft). Universities have found these balloons to be an inexpensive means of conducting high altitude research.

- Sports Balloons. The use of gas balloons for sports has been popular for many years and is still popular in Europe. More recently hot air ballooning has become very popular in the U.S.A. It is estimated that there are more than 3,000 hot air balloons being used for sporting purposes throughout the world. The recent transatlantic flight of the helium-filled balloon, "Double Eagle II," was a remarkable demonstration of modern free balloon technology.

Conventional Airships

4. The next evolutionary steps beyond the free balloon was the "conventional" airship, which is powered and can be steered. In the early 1900s considerable effort was expended by the European countries and the U.S.A. in developing conventional airship designs and more than 600 were constructed. The U.S. Navy continued to use airships until 1962. Conventional airships may be categorized as pressure (nonrigid) and rigid airships.

- Rigid Airships. Rigid airships maintain their shape by a basic metal girder structure. The lifting gas is contained in multiple cells within the structure. Conventional rigid airships must be relatively large in volume in order to achieve suitable flight efficiency. Probably the best known and largest rigid airship was the German airship Hindenburg having a gas volume of nearly 200,000 cu m (7,060,000 cu ft).

- Pressure Airships. This type of conventional airship maintains its shape by the pressure of the gas contained in its hull (or envelope). Generally, the envelope is a single gas cell that also contains air ballonets for the purpose of compensating for changes in pressure and temperature. Pressure airships are considerably smaller in volume than the rigid type. The largest pressure airships (ZPG-3W) were operated by the U.S. Navy in the early 1960s and had a volume of 41,500 cu m (1,465,000 cu ft). There are several sub-categories of pressure airships as follows:

  -- Nonrigid Airships. For purposes of this paper the nonrigid airship is considered to have a fabric envelope and no rigid structure other than the control car and the empennage. All of the U.S. Navy "blimps" were of this type, and it also characterizes the Goodyear commercial advertising airships as well as the current British (AD-500) and German developments. A more detailed description of nonrigid airships is given in a following section on conventional airships.

  -- Semi-Rigid Airships. This type of pressure airship also has a fabric envelope but is constructed with a rigid keel along the bottom of the envelope. The Italian airships Norge and Italia, built in the 1920s for Arctic exploration, are the best known examples of this type of construction. More modern airships have not utilized the semi-rigid construction.

-- Metalclad Airships. This type of airship utilizes a very thin aluminum skin in construction of the envelope rather than fabric material. Internal pressure is still required to maintain the shape of the envelope. The U.S. Navy airship ZMC-2 was operated very successfully in the 1930s and is a well known example of this type of construction. Although no other airships of this type have been built since that time, the metalclad airship is considered to be a viable design technique for a modern airship and is being studied by interested groups in the U.S.A. and England.

Hybrid Airships

5. Hybrid airships span a wide variety of proposed design concepts and generally attempt to combine the aerodynamic properties of fixed wing or rotary wing aircraft with the aerostatic characteristics of airships. Major subcategories consist of the following:

- Semi-Buoyant Airships. The objective of this type of design is to improve airship performance by increasing aerodynamic lift through modifications of the hull planform. Lifting body technology has been applied in designs having a deltoid hull configuration as demonstrated by the U.S. designed "Aereon III" in the 1970s. Other semi-buoyant airship designs have been proposed having multiple hulls or configurations with lenticular or ellipsoidal hulls. It does not appear that practical semi-buoyant airships are feasible in the near-term period.

- Heavy-Lift Airships. For the purposes of this paper, heavy lift airships are defined as those concepts that generally represent a merging of helicopter and airship technologies. The primary objective of these concepts is to haul very heavy payloads, far in excess of the capability of current helicopter technology, over relatively short distances. The following concepts have been proposed:

  -- Helistat. This concept consists of a nonrigid airship hull with four modified helicopters attached to it. The static lift of the airship is sufficient to counter the weight of the helicopters and associated structure, thus leaving the full lifting capacity of the helicopter rotors to accommodate the payload. A full scale version of the Helistat, having a payload capacity of about 25 tons, is under construction in the U.S. by the Piasicki Aircraft Corporation. Similar concepts have been proposed in the French Helicostat design, and in concepts proposed by the Goodyear Aerospace Corporation. A detailed description of the Goodyear design is presented later in this paper.

-- Aerocrane. This heavy-lift airship concept consists of a spherical aerostat having rotor blades attached at the equator. Engines are located in each rotor which cause the vehicle to rotate when power is applied. The rotors generate the lift required for the payload and control is attained by the application of collective and cyclic pitch. Flying models of the Aerocrane concept have been demonstrated. There is no current project for construction of a man-rated Aerocrane heavy-lifter although the simplicity of the concept appears promising.

-- Cyclocrane. This concept is somewhat similar to the Aerocrane except that rotation is around the horizontal axis and the aerostat is aerodynamically shaped rather than spherical. Canadian interests are currently funding the construction of a man-rated reduced scale vehicle (having a 2 ton payload) that is intended to demonstrate the proof of concept.

Tethered Aerostats

6. Tethered aerostats are an outgrowth of captive military observation balloons that were used as early as the U.S. Civil War. Aerodynamically shaped observation balloons and barrage balloons were employed in World War I and World War II. In the early 1970s the U.S. sponsored a project to optimize the aerodynamic design of tethered aerostats. This resulted in the Family II design having significantly improved flight characteristics over previous designs. There are two basic categories of tethered aerostats (both unmanned) as follows:

- Fixed Aerostat Systems. The modern version of these tethered aerostats employ the Family II design noted above or derivations thereof. They have been constructed in sizes up to 11,300 cu m (400,000 cu ft) with altitude capability up to about 6 km (20,000 ft) depending on payload and size. A detailed presentation of fixed aerostat systems is given later in this paper.

- Traversing Aerostat Systems. These systems are very low altitude aerostats or balloons meant to haul heavy loads over very short distances. They are attached to a cable that permit the aerostat and its suspended payload to be winched back and forth over a distance generally less than 2 km. Both shaped aerostats and balloons have been used in this application although current logging operations in the U.S. employ only the "natural shape" balloon.

Remotely Piloted Aerostats

7. Small, low altitude piloted aerostats have been constructed for specialized missions mostly of a military nature. These have been designed as nonrigid airships with control systems functioning by telemetry command from a ground station. Much larger remotely piloted aerostats, capable of high altitude flight, have been proposed and are currently being evaluated by the U.S. The HI-SPOT project would employ an aerostat having a volume on the order of 85,000 cu m (3,000,000 cu ft) and an operational altitude of about 21 km (70,000 ft). A similar high altitude project (HAPP) is being evaluated by NASA employing a novel source of power -- microwave energy beamed up to the aerostat from the ground control station.

LTA PLATFORMS APPROPRIATE TO DEVELOPING COUNTRIES

8. From the preceding summary of LTA platform categories, it is considered that there are three platform types that are most appropriate to the needs of developing countries: conventional airships (relatively small nonrigid types), heavy-lift airships, and tethered aerostats. For these selected types an overview of potential missions/applications and economic viability is given below and discussed in detail in the following sections of this report.

Conventional Airships

9. The small nonrigid airship could be extremely useful to developing countries in a number of different applications. The fuel efficiency and long endurance capability of such airships make them ideal candidates for operating in offshore approaches and coastal waters. The following types of missions could be conducted:

- surveillance and policing of territorial waters,
- search and rescue operations,
- marine environmental protection,
- geophysical survey,
- fishing support, and
- port safety and security.

10. While the small nonrigid airship normally operates most effectively in over-water missions, it could also be used for interior applications such as:

- limited logistics support to remote areas,
- exploration and survey of remote areas, and
- search and rescue operations.

11. From the economic viewpoint, small nonrigid airships can be built with existing technology using proven designs. They are relatively inexpensive to operate and require modest ground support equipment.

Heavy-Lift Airships

12. Heavy-lift airships having a payload capacity of 50-100 tons could also be applied to a variety of missions. For offshore applications these include:

- construction and resupply of oil rigs and
- off-loading of containerships when adequate shore facilities are not available.

13. For interior applications the following missions are suggested:

- heavy logistics support to remote areas,
- harvesting timber, and
- limited support in mining, agriculture and heavy construction.

14. Economically, heavy-lift airships require additional developmental efforts with some attendant technical risks. This will result in higher initial acquisition costs. Operating costs can also be expected to be somewhat higher than the conventional airship. Ground support requirements would be little more than that required for nonrigid airships.

Tethered Aerostats

15. Fixed tethered aerostat systems already have demonstrated successfully their usefulness in developing countries. The primary mission for such systems is to provide a wide-coverage communications network to remote areas that include:

- radio and television broadcast and
- telephone microwave relay.

Traversing tethered aerostats could also be usefully employed in developing countries for such missions as:

- logging operations and
- off-loading of containerships.

16. From an economic viewpoint, tethered aerostats of proven design are currently available. Operational costs are modest with little ground support equipment required. A significant cost savings for these systems results from the fact that flight crew training is avoided since they are unmanned.

CONSIDERATIONS IN LTA OPERATIONS

17. In examining the potential use of LTA platforms in developing countries there are a number of considerations that should be kept in mind. These considerations apply to all of the platforms selected as appropriate to the needs of developing countries and, in general, apply to all LTA operations.

Use and Availability of Helium

18. The use of nonflammable helium as a lifting gas is an essential factor in providing safe LTA operations. Helium has a somewhat lower lifting capacity than highly flammable hydrogen and is more costly. But the increase in safety afforded by the use of helium is well worth the slight penalty that must be paid in lift capability and cost. All modern airships constructed during and since World War II have used helium exclusively as their lifting gas (with the exception of hot air blimps employed for advertising and sporting purposes).

19. Natural gas is the primary source of helium where it occurs in varying degrees of concentration. There are adequate sources of helium in the U.S.A. for applications to greatly expanded LTA programs. Helium is also believed to be available in the U.S.S.R. and in Poland.

20. Helium may be purchased in either liquid or gaseous form. In the liquid form helium is transported in containerized dewars with capacities up to 42,000 liters (11,000 gallons). In the compressed gaseous form, which would probably be more practical for use in developing countries, helium is supplied in tube trailers, containerized tube modules or in separate tubes of various sizes. A tube trailer could provide up to 5,000 cu m (180,000 cu ft) of helium at a pressure of 185 kg/sq cm (2600 psi).

Ground Support Equipment

21. Aerostats and nonrigid airships of moderate size have been erected in the field. They have been operated and maintained from mobile or fixed mooring masts for long periods of time (in excess of one year) without availability of hangar facilities. Under these circumstances routine maintenance, repairs and engine changes were conducted using specially designed ground support equipment when necessary to permit access to difficult areas. For sustained operations in developing countries it would be desirable to construct a centrally located hangar for assembly, overhaul and protection from weather extremes. Simple, low-cost structures have been erected to accomplish this purpose to support commercial operations.

22. Airship operations require very little real estate compared to fixed wing requirements and can operate routinely from relatively unprepared areas. Basic ground support equipment consists of masting facilities, fuel and helium supplies, basic inventory of spare parts, and tools and supplies necessary to conduct routine maintenance.

All-Weather Capabilities

23. The capability of airships to operate in adverse weather conditions has often been questioned. The U.S. Navy has shown conclusively that the nonrigid airships can be flown in virtually all weather conditions -- rain, snow, sleet, icing, zero visibility, gale winds and thunderstorms. High wind conditions can often reduce the effectiveness of the airship in accomplishing its mission. Accumulation of wet snow on the envelope can become a problem when the airship is on the mast. Fast-moving thunderstorms and potential lightning strikes pose a problem to tethered aerostats which are fixed to a geographic site. But these weather-related problems can be met and the threat largely overcome by experienced operating personnel.

Technology Transfer

24. It is of interest to examine the possibility of establishing an airship industry in a developing country. This would involve the wherewithal to design, fabricate, assemble and operate LTA platforms for which proven requirements have been established.

25. Airship designers are a rare commodity in the modern world. There is still a considerable amount of "art" involved in design of a modern airship even in following proven prototypes. A few additional experienced LTA personnel would be needed to supervise the assembly and erection of a nonrigid airship, to conduct initial flight tests and to train necessary flight and ground personnel. Thus it would be necessary for a developing country wishing to establish a capability to manufacture airships or aerostats to assemble a small cadre of experienced LTA personnel. This expertise could be passed on to indigenous personnel during the first few formulative years.

26. With the exception of the envelope, the structural members of the airship are fabricated in accordance with accepted aircraft manufacturing techniques. It is likely that synthetic materials such as molded fiberglass would be used in some applications and this would require special expertise. It would undoubtedly be cost effective to import the required propulsion units and perhaps other items such as generators, blowers and instrumentation. For the envelope it would probably be necessary to import the material needed for its construction, and competently trained personnel would be needed to supervise and inspect the fabrication process.

27. A suitable hangar would be essential for assembly and erection of the airship. Ground handling and ground support equipment would be necessary as previously mentioned. It would also be desirable to construct a helium storage and purification facility to support continuing operations.

28. From the above considerations it appears feasible that an airship industry could be established in a developing country. It would require a substantial initial capital investment; a small nucleus of experienced LTA personnel during the beginning years; and initial import of many component parts. Before such an undertaking could be seriously considered, however, it must be shown that LTA platforms can be put to productive use in developing countries and that a real market exists for their application.

SECTION II

CONVENTIONAL AIRSHIPS

INTRODUCTION

29. This paper looks at modern conventional airships and the role they could play in developing countries. The use of the word conventional refers more to its role than its design. The traditional role of the airship is long endurance, long range, low speed flight. This makes it an ideal platform for surveillance operations and remote area transport. A modern airship builds upon traditional designs and incorporates modern technology in structural materials, propulsion systems and control techniques. Structural improvements will be obtained by using lighter high strength plastics and alloys. Most proposals for the propulsion systems for modern airships include vectored propulsion systems. A modern airship would also incorporate many of the advances made in microelectronics for avionic and control systems.

30. This paper looks at the nature of conventional airships and the missions that they are best suited for in the modern world.

WHY AIRSHIPS

31. Instead of using power, and the required energy, to generate lift, an airship takes advantage of the natural bouyancy of the lifting gas. There are, potentially, three types of lift that an airship can use; static lift, dynamic lift and powered lift. Static lift is derived from the fact that the lifting gas is lighter than air and therefore will rise like a bubble in the ocean of air, the atmosphere. Dynamic lift is derived from the flow of air over a curved surface. The resultant air pressure differences above and below the surface creates lift. This is the principle under which airplanes operate. Powered lift is created by vectoring the direction of force from the propellers or rotors. Traditionally airships have used static and dynamic lift. Modern airships will also incorporate powered lift.

32. Most of the lift of a conventional airship is provided by the static lift. Because of this, little fuel must be consumed to keep it aloft. This gives rise to the two major characteristics of an airship that make it attractive in the modern world, long endurance and low fuel consumption. These characteristics make airships attractive for surveillance operations and long distance logistic support.

33. Traditionally airships are operated slightly heavy to provide better aerodynamic control. Therefore, airships are usually operated as Short Takeoff and Landing (STOL) vehicles requiring a minimum amount of landing and takeoff facilities. The incorporation of powered lift and control technology could make an airship a Vertical Takeoff and Landing (VTOL) vehicle requiring little area for takeoffs and landing. A modern airship would be ideally suited for remote area operations where there are no facilities for handling heavier than air craft.

RIGID VS. NONRIGID AIRSHIPS

34. The lifting gas of an airship is lighter than air. This gas must be contained to be useful. There are basically two types of containers; a rigid airship and a nonrigid (pressure) airship. The rigid airship has a frame structure with a thin skin. Interior to the structure are gas cells that contain the lifting gas. In a nonrigid airship the shape is maintained by keeping the internal pressure of the envelope slightly greater than the external air pressure and through the use of stiffeners at strategic locations.

35. Due to the heaviness of the rigid structure, rigid airships must be large to provide enough lift for the structure and useful payload. The larger the structure, the greater the usable lift for payload. The maximum size of a rigid airship is only limited by the fabrication facilities and the ground facilities. The largest rigid airship ever built was the Hindenburg, 200,000 cu m (7,060,000 cu ft).

36. Nonrigid airships have much less weight associated with the craft and therefore economically feasible payloads can be obtained in much smaller airships. The maximum size of a nonrigid airship is limited by envelope technology and aerodynamic efficiency. The upper limit within current technology limits is considered to be about 85,000 cu m (3,000,000 cu ft). The largest nonrigid airship ever built was the ZPG-3W which was 41,500 cu m (1,465,000 cu ft).

RIGID AIRSHIPS

37. The age of rigid airships ended in 1940 with the scrapping of the U.S.S. Los Angeles. Probably the most famous rigid was the Hindenburg which was designed for helium, but due to political considerations, used hydrogen as its lifting gas. As was mentioned above, rigid airships are only feasible if they are relatively large.

38. Most rigid airships were used for long range applications. The U.S.S. MACON and U.S.S. AKRON were used as airplane carrier scouts by the U.S. Navy. Graf Zeppelin and the Hindenburg provided transatlantic transportation as a speedy alternative to ship voyage of that era. During its lifetime the Hindenburg made 63 flights and carried over 3,000 passengers.

39. In a modern world it is doubtful that rigid airships have an economically feasible role. The fabrication cost, ground facilities costs and slow speed make it a poor competitor to commercial aircraft. There have been proposals for supersized hybrid airships with enormous payload and range capabilities, but these would definitely not be suitable for developing countries and it is doubtful that they would be economical in any role.

NONRIGID AIRSHIPS

40. In recent years there has been considerable renewed interest in nonrigid airships. Because of the inherent fuel efficiency, long endurance and improved ground handling facilities, a modern nonrigid airship could be economically attractive.

41. Proposals for modern nonrigid airships run in size from 6000 cu m (210,000 cu ft) for advertising and short patrol to 42,500 cu m (1,5000,000 cu ft) for long distance patrol and surveillance. The U.S. Coast Guard has recently investigated the use of airships of 20,000 cu m (700,000 cu ft) to 30,000 cu m (1,000,000 cu ft) for maritime patrol. Most of these proposed designs incorporate vectored propulsion systems. These would allow greater controllability for hovering the airship and a VTOL capability. Trimotor, with two engines mounted adjacent to the car and a propulsion unit on the stern, and quadrotor, with four tiltable engines mounted to the car, have been proposed. The quadrotor design would have reversible thrust allowing the airship to operate light and essentially eliminating the need for ballasting.

42. These designs would incorporate light weight fabrics of synthetic yarns for the envelope, fuel efficient, light weight engines and advanced electronic controls and avionics. Thus a modern airship would have a greater useful payload than historic airships of comparable size.

AIRSHIP OPERATIONS

43. A number of concerns expressed about nonrigid airships are related to its vulnerability to puncture and weather. Since most, if not all, of the airship's lift is provided by the bouyancy of the lifting gas, it is less susceptible to catostrophic failure when there is loss of power or damage to an aerodynamic surface. Since the internal pressure of the envelope is only slightly greater than the ambient environment, 40-75 mm of water, when punctured the envelope does not burst. It takes a hole of a significant size to cause sufficient loss of lift to bring down an airship. Goodyear frequently has to patch bullet holes in its advertising airships.

44. The airship has proven itself in all types of adverse weather conditions. The three situations that most affect aircraft operations are high wind and turbulence associated with thunderstorms, ice and snow, and low ceilings and poor visibility. By far the most significant of these is thunderstorms. The severe wind shears, lightning and turbulence present a hazard to any aircraft. The preferred technique when confronted with thunderstorms is avoidance. When penetration is necessary, it is usually accomplished at the lowest possible altitude consistent with safe operation, usually between 500 to 1,000 m. Airships are at a disadvantage compared to large jetliners in that they cannot fly over moderate thunderstorms.

45. Snow and ice can also present problems to airships. Due to the large surface area of the airship, large amounts of snow and ice can accumulate on the envelope. Changes in altitude can usually prevent significant accumulation. Throughout its total period of operating airships, the U.S. Navy never lost an airship in the air due to snow or ice accumulation. When masted, however, snow and ice is a major problem. Too much accumulation can cause the collapse of the envelope. This problem can be eliminated through mechanical means or by heating of the gas. Probably the simplest method of clearing snow and ice from a masted airship is to throw a rope over the airship and walk it the length of the envelope.

46. Of the three weather conditions considered, an airship probably offers the greatest operational advantage for conditions of poor visibility and low ceilings. These conditions impact on both ground operations and flight operations. Insufficient sight distances preclude takeoffs and landings. The minimum acceptable sight distance is a function of the minimum operating speed of the platform. A VTOL airship can operate at zero velocity and therefore could operate in a situation of essentially zero visibility. A major consideration in takeoffs and landings is the ability to determine the clearance over obstacles. A true VTOL platform does not have to worry about obstacles once it has identified its landing area, assuming that adequate instrument landing equipment is available.

47. Another concern is the complexity and cost of ground handling and ground facilities. Although I know of no comparative studies, but given that there are no facilities available, it is probably cheaper to provide ground facilities for a modern airship than for a modern jetliner. In a benign environment all that is needed is a mast and apron for normal berthing and maintenance. In addition to a mast an airship would require fuel, maintenance and helium facilities. A hangar would be required for overhaul. In a harsh environment with frequent severe thunderstorms or heavy wet snow or ice, hangars would be desirable. During World War II the U.S. Navy operated blimps in South America, the Caribbean, and the Mediterranean without hangar facilites, only masts. In comparison, jetliners need large runway facilities.

48. Early airship operation required large ground crews for handling lines during launch and recovery. With the introduction of short masts and mobile winches, the U.S. Navy was using less than 20 men for manual operations when airship operations were terminated. Goodyear uses less than 10 in its airship operation. With the development of a VTOL capability in a modern airship, the number of ground handling personnel should be five or less.

49. In order to improve aerodynamic control conventional airships are maintained in a slightly heavy state. To replace the weight that is lost in the consumption of fuel the airship takes on ballast. The conventional way of doing this is to recover water from the ocean or other body of water. Late U.S. Navy rigid airships obtained ballast by condensing water out of the engine exhaust gases.
These condensers added weight to the airship, the anathema of airship designers. Proposals for modern airships have included vectored propulsion systems that could be used to generate reverse and transverse thrust to control the airship when operating light. This is an unproven design.

50. Because the easiest method of obtaining ballast remains lifting water from available sources, conventional airships are best suited for maritime operations or in areas where water is available for ballasting.

MODERN AIRSHIP MISSIONS

51. The most appealing missions for a modern conventional airship would be maritime patrol. The U.S. Coast Guard is in the process of obtaining a demonstration vehicle for its maritime partol missions. Because of the payload capacity and endurance, the airship is well suited for this role.

52. Figures 1 and 2 show the payload and endurance regime of an airship in relation to currently available aircraft and ships. From these figures it can be seen that airships fit in the gap between the traditional platforms used for maritime operations. Ships tend to be slow speed, long endurance, high payload platforms. Aircraft are high speed, low endurance, low payload platforms. Airships have significantly higher speed than ships and much greater endurance and a higher payload capacity than aircraft. The airship depicted in these figures is in the 20,000 cu m (700,000 cu ft) to 30,000 cu m (1,000,000 cu ft) size.

53. Potential maritime patrol missions identified for the U.S. Coast Guard are listed in Table 1. These can be categorized by three types of operation:

1. search and surveillance,
2. logistics support, and
3. command and control.

Search and Surveillance

54. Airships have been traditionally used and are ideally suited for search and surveillance missions in a maritime environment.

- They provide a stable, comfortable platform conducive to visual observation and sensor operation.
- They travel at a high enough speed to be able to sweep large areas in short times.
- They have a wide horizon, giving the observer a broad view from their operating altitude.
- They have long endurance so they can stay on station without requiring backup.
- They are able to ascend/descend rapidly to provide close observation.
- They provide a significant presence.

55. These capabilities can be used for:

- searching for ships in distress;
- policing functions, such as prevention of smuggling or illegal immigration;
- searching for oil spills or ice; and
- surveying and monitoring navigational buoys.

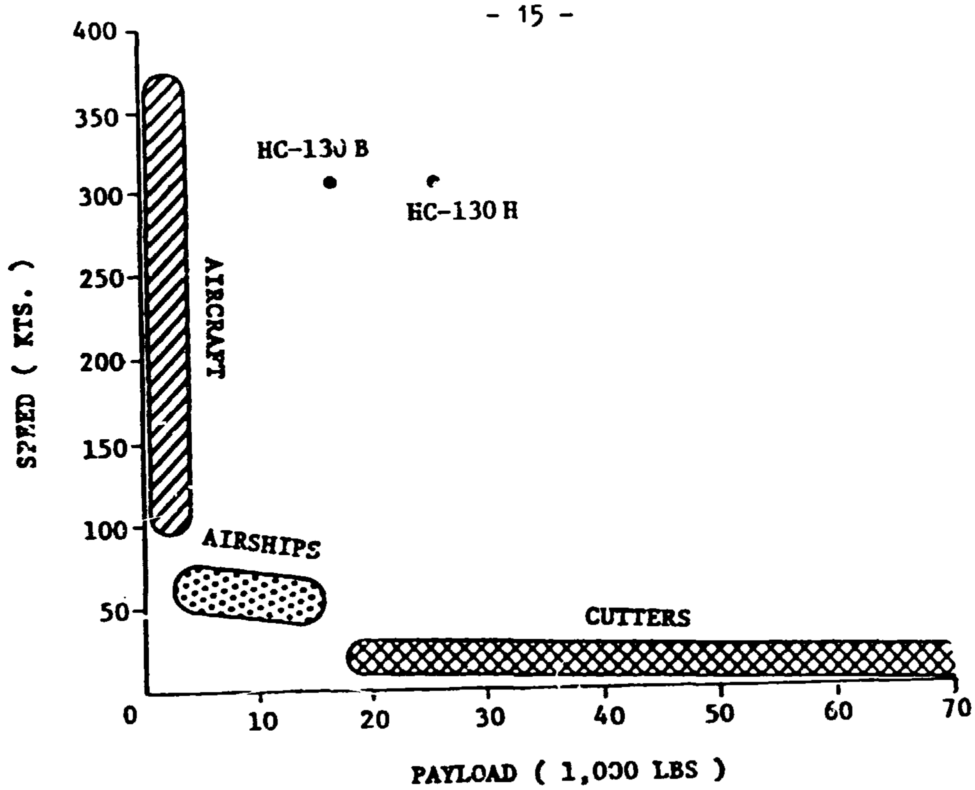

Figure 1 PLATFORM SPEED VS. PAYLOAD

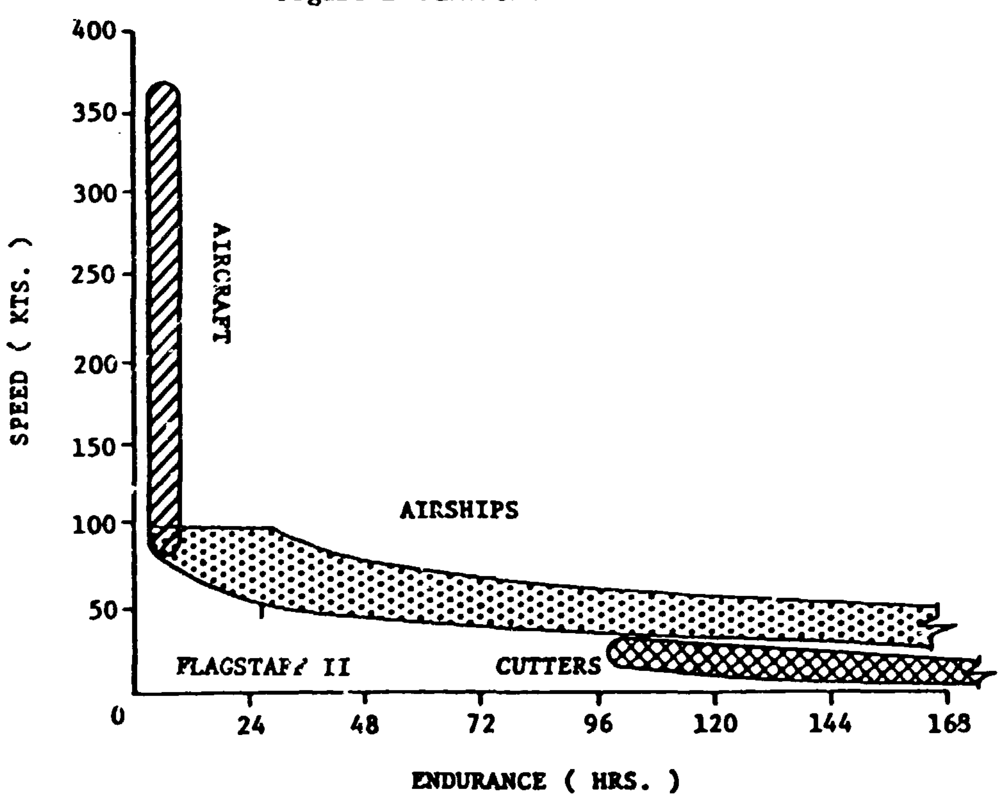

Figure 2 PLATFORM SPEED VS. ENDURANCE

Table 1 POTENTIAL AIRSHIP UTILIZATION IN COAST GUARD PROGRAMS

ENFORCEMENT OF LAWS AND TREATIES

- Surveillance, interdiction, and seizure of illicit fishing and drug traffic

SEARCH AND RESCUE

- Search, logistics and aid

MARINE ENVIRONMENTAL PROTECTION

- Search and surveillance of the marine environment
- Assist in the logistics and command, communication and control of cleanup operations

PORT SAFETY AND SECURITY

- Hazardous cargo traffic control
- Command, control and communication

MARINE SCIENCE ACTIVITIES

- Ice patrol
- Oceanographic survey
- Locating buoys

ICE OPERATIONS

- Surveillance of ice conditions

SHORT RANGE AIDS TO NAVIGATION

- Monitor buoys

Logistics Support

56. The airship in the proposed size range would have a reasonable payload capability. For short range operations, where the fuel load is limited, the maritime patrol airship is projected to have a payload capacity of up to 10 metric tons. A major aspect of the development of a maritime airship is the incorporation of vectored thrust to provide an adequate hover capability. With powered hover an airship would be able to deliver payloads without landing, lift people or goods from the deck of moderate sized ships, and lower a hoist to allow boarding of ships. As opposed to other high speed platforms, an airship can tow vessels in distress or delivery sleds. An airship could rapidly arrive on the scene and then provide towing service. In a maritime environment an airship could perform logistics support for the following situations:

- supply offshore facilities,
- provide fire fighting equipment,
- deliver oil pollution cleanup equipment, and
- assist in a search and rescue mission.

Command and Control

57. Because of its long endurance, ability to travel at very slow speeds and a payload capacity to carry communications equipment, an airship is also proposed for command and control operations. By flying over the scene at slow speeds the commander has an excellent view of the situation below. If something demands his immediate attention, the airship could descend to the point of interest. Command and control operations could be of importance in:

- fighting fires,
- controlling traffic in a port or harbour,
- cleaning up pollution incidents, and
- overseeing a major search and rescue operation.

NON-MARITIME OPERATIONS

58. Except for concerns about ballasting and the possibility of obstructions, there is little difference between operations over water and operations over land. Search and surveillance, logistics support, and command and control can be performed by airships over remote land areas. A hover capable airship could either deliver goods without landing or would require minimal amount of ground facilities or ground handling, making it ideal for remote area operations. Clearing of the land and delivery of a mast is all that would be needed at a remote landing site. More extensive facilities for maintenance, fuel, helium and reprovisioning would have to be available at a support base in a more developed area.

59. Typical applications of an airship for remote areas could include:

- geological survey,
- land survey,
- hydrologic survey,
- delivery of seismological sensors,
- supply of remote outposts,
- delivery of construction supplies,
- delivery of drilling or mining equipment, and
- fire fighting.

60. Overland operations are limited by the design altitude of the airship. If the design altitude is 2 km, the airships ceiling would be limited to 2 km. Therefore, high mountains can be an obstacle to airship operations. In addition, due to topographical features, increased air currents are encountered over land as opposed to over ocean operations. This can increase crew fatigue in long endurance operations.

61. The use of airships for short haul passenger transit is probably not economically feasible. A high passenger density is needed for any economically viable transportation system. This density only exists in populated, developed areas which usually have a developed air transportation system. It is difficult for airships to compete economically with existing air systems due to their relatively slow speed and need to build duplicate terminal and ground handling facilities.

REPRESENTATIVE MARITIME PATROL AIRSHIP DESIGN

62. Three point designs have been proposed for the U.S. Coast Guard's maritime missions based upon estimates of operational requirements. The three point designs were developed by Goodyear Aerospace Corporation, Bell Aerospace, Textron and the Naval Air Development Center (NADC). The NADC design was used to evaluate operational effectiveness and cost data. The design parameters for the NADC design are given in Table 2. Except for placement of the propulsion system this is a fairl_ conventional airship design. This is a trimotor airship with two engines on either side of the car and a propulser at the stern. It is representative of the type of maritime patrol airship that could be applied to the needs of developing countries.

COSTS OF AIRSHIP OPERATIONS

63. The cost of a maritime patrol airship of about 22,000 cu m (775,000 cu ft) has been analyzed. It is estimated that it would cost about $35 million (1980$) for research and development and an equivalent amount for the first unit. For a buy of 50, the unit cost including R&D is approximately $6 million (1980$). The total life cycle cost, prorated on a flight hour basis, is in the

Table 2 MARITIME PATROL AIRSHIP CONCEPTUAL POINT DESIGN

ITEM	NADC ZP-X	
Envelope Volume	22,192 cu m	(783,696 cu ft)
Length	93 m	(305 ft)
Diameter	21.1 m	(69.3 ft)
Static Lift @609.6 m (2,000 ft)	20,068 kg	(44,243 lbs)
Dynamic Lift	3,464.5 kg	(7,638 lbs)
Horsepower Required	1,927	
Gross Weight	24,745.2 kg	(54,554 lbs)
Empty Weight	12,552.7 kg	(27,674 lbs)
Useful Load	12,192.6 kg	(26,880 lbs)
Buoyancy Ratio	.86	
Maximum Altitude	3,048 m	(10,000 ft)
Maximum Speed	90 kts	

range of $900/FH to $1375. This estimate is based upon U.S. Coast Guard pay scales, an FAA restriction on the flight crew to 800 flight hours annually, and the availability of existing facilities in the U.S. Obviously in other countries these numbers will vary considerably dependent on salary structure, available facilities and flight restrictions.

SECTION III

HEAVY LIFT AIRSHIPS

INTRODUCTION

64. There is a growing need for an economical air vehicle which performs like a helicoper and can lift vertically large and/or heavy payloads in the range of 25 to 150 tons. In response to this requirement, Goodyear Aerospace Corporation is currently examining a concept called the Heavy Lift Airship (HLA). The HLA is a hybrid vehicle marrying the state-of-the-art in rotorcraft and lighter than air technologies. While providing a quantum increase in vertical lift capability, the HLA appears to show improved operating economics over that of the helicopter. This section of the paper defines the concept, gives the results of preliminary analyses and estimates the performance of a 75-ton point design. Results of market analyses, operating economics, and economic case studies are also discussed.

THE CONCEPT

65. The basic principle behind the Heavy Lift Airship is to combine the static lift of the airship with the dynamic lift of the rotorcraft. The objective is to use existing technology to provide a quantum increase in current and projected helicopter lifting capabilities at substantial reductions in vertical lift costs.

66. Of course, such a marriage can assume many forms, including variations in Aerostat configuration, buoyancy ratio, propulsion configuration, thrust modulation, and control force management. The work at Goodyear Aerospace has considered and traded all these options as rigorously as possible, but has placed emphasis on those which minimize development risk and maximize benefits to the user. These benefits invariably boil down to cost, productivity, and operational versatility.

RECOMMENDED CONFIGURATION

67. The conclusion that Goodyear Aerospace has drawn from these many configuration studies is that a production HLA should be configured essentially as shown in Figure 3.

68. The Aerostat shown is sized essentially to offset the empty weight of the vehicle, and it has the aerodynamic properties of a conventional airship. The propulsion systems are packaged as dedicated units and contain both rotors for efficient vertical lift as well as propellers for efficient ferry (cruise) operations. Fly-by-wire flight controls are incorporated with computerized logic to integrate most effectively the many control mechanisms available from the combined systems. This concept, as shown, can be sized within available technology for payloads ranging from 25 to 150 tons.

69. Combining even higher-buoyancy ratios with a reverse-thrust rotor capability might yield even lower ton-mile costs. However, investigation shows that this is somewhat deceptive. Overall productivity is lower (considering turns

Figure 3 CONFIGURATION OF PRODUCTION HLA

per hour), and ferry costs and the ease of ground handling are substantially degraded because of the excess buoyancy. Thus, the net benefit to users is lower, and the resulting vehicle is less suitable to the applications of prime interest.

GENERAL DESCRIPTION

70. The 75-ton HLA described here carries 68,000 kg (150,000 lb) of useful payload at an altitude of 1525 m (5,000 ft). This requires an envelope volume of 73,600 cu m (2,600,000 cu ft) with four rotor modules capable of providing a maximum thrust of 24,00 kg (53,000 lb) each. Overall dimensions of the vehicle are as follows: a maximum length of 138 m (453 ft), an overall height of 38 m (125 ft), and a width of 70 m (231 ft). With the rotors folded aft, the width is reduced to 53 m (175 ft). Maximum diameter of the envelope is 32.7 m (107.2 ft) and length is 136.4 m (447.4 ft).

71. General arrangement of the vehicle is shown in Figure 4 and consists of an envelope with the conventional airship contours. At the stern, three fins and their movable surfaces are mounted in an inverted "Y" configuration. The bow stiffening is typical, consisting of a nose cone, mooring spindle, and battens that extend to ten percent of the envelope length.

72. A control car is located at the forward section of the envelope, about 33 m (108 ft) from the nose. A separate internal and external suspension system provides the support. Catenaries, starframe, and outrigger struts are positioned at the center of buoyancy on the airship. The four rotor modules in the concept are interchangeable. They house the engines, gearboxes, and shafting for the vertical thrust rotors and the horizontal thrust propellers. Four ballonets, with the two lateral center ballonets being interconnected to act as one, provide a total of 18,400 m (650,000 cu ft) of air volume.

73. The HLA also projects extremely good operating economics for three main reasons. First, buoyancy lifts empty weight of the air vehicle, thereby allowing the rotors to support approximately twice as much payload for the same amount of fuel. Second, only a small penalty is paid to increase empty weight; therefore, rotor systems can be designed to minimize acquisition and maintenance costs rather than weight, which generally has the opposite effect. Third, centralized control operations have certain additional cost benefits.

74. These influences are illustrated in Figure 5, where the total operating cost of an S64 helicopter is compared with an HLA with four modern-technology dedicated rotor systems designed specifically for the HLA with low acquisition and maintenance cost features. The end result is operating costs midway between those of helicopter and of fixed-wing aircraft, as shown in Figure 6.

MISSIONS/APPLICATIONS

75. The applications most suited to enhancement by use of the HLA are resource development and remote construction projects. The HLA is not intended to compete with existing transportation systems. It is a cost-effective cargo carrier partially by virtue of being able to eliminate costly road, railway, or airport construction. If the infrastructure is already in place, little savings can be realized.

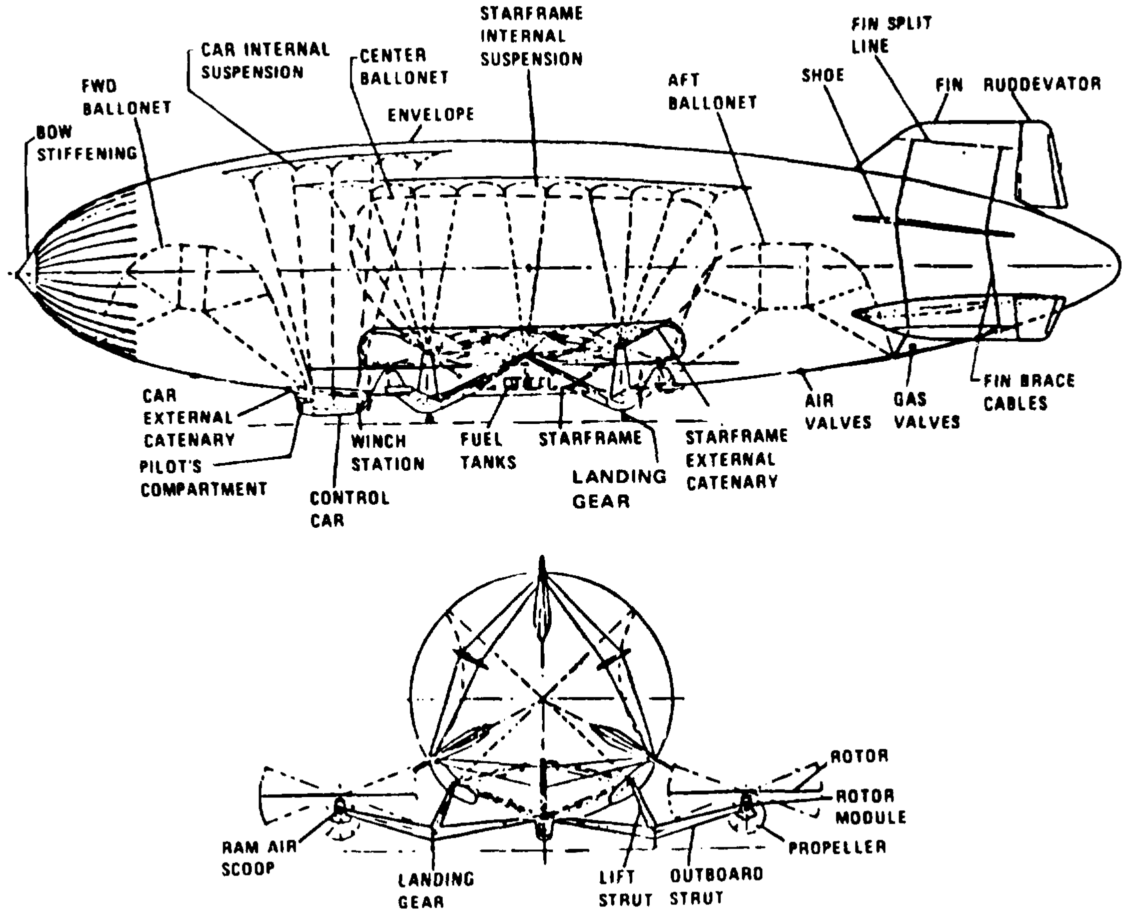

Figure 4 GENERAL ARRANGEMENT HEAVY LIFT AIRSHIP

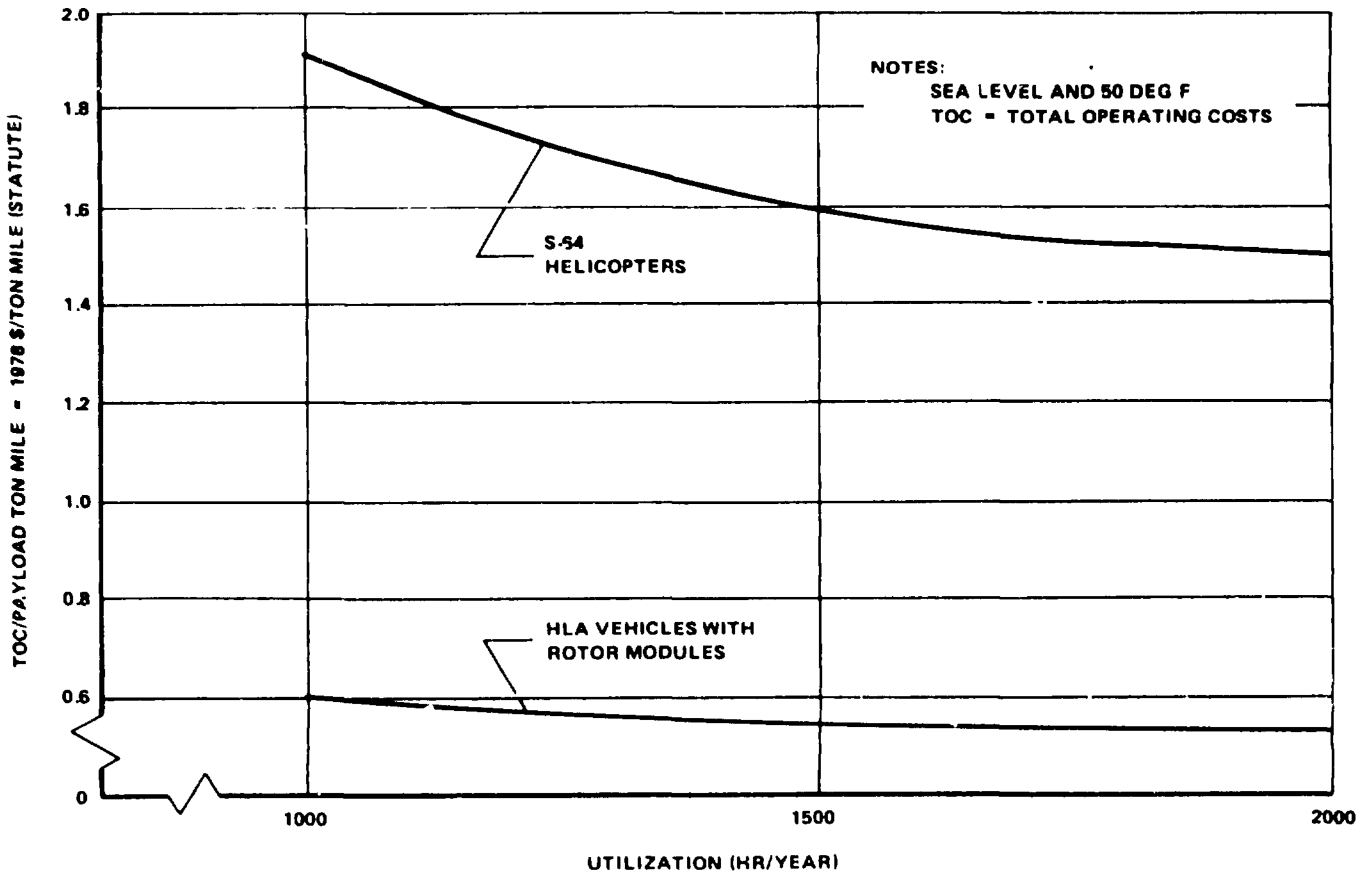

Figure 5 HLA OPERATING COSTS

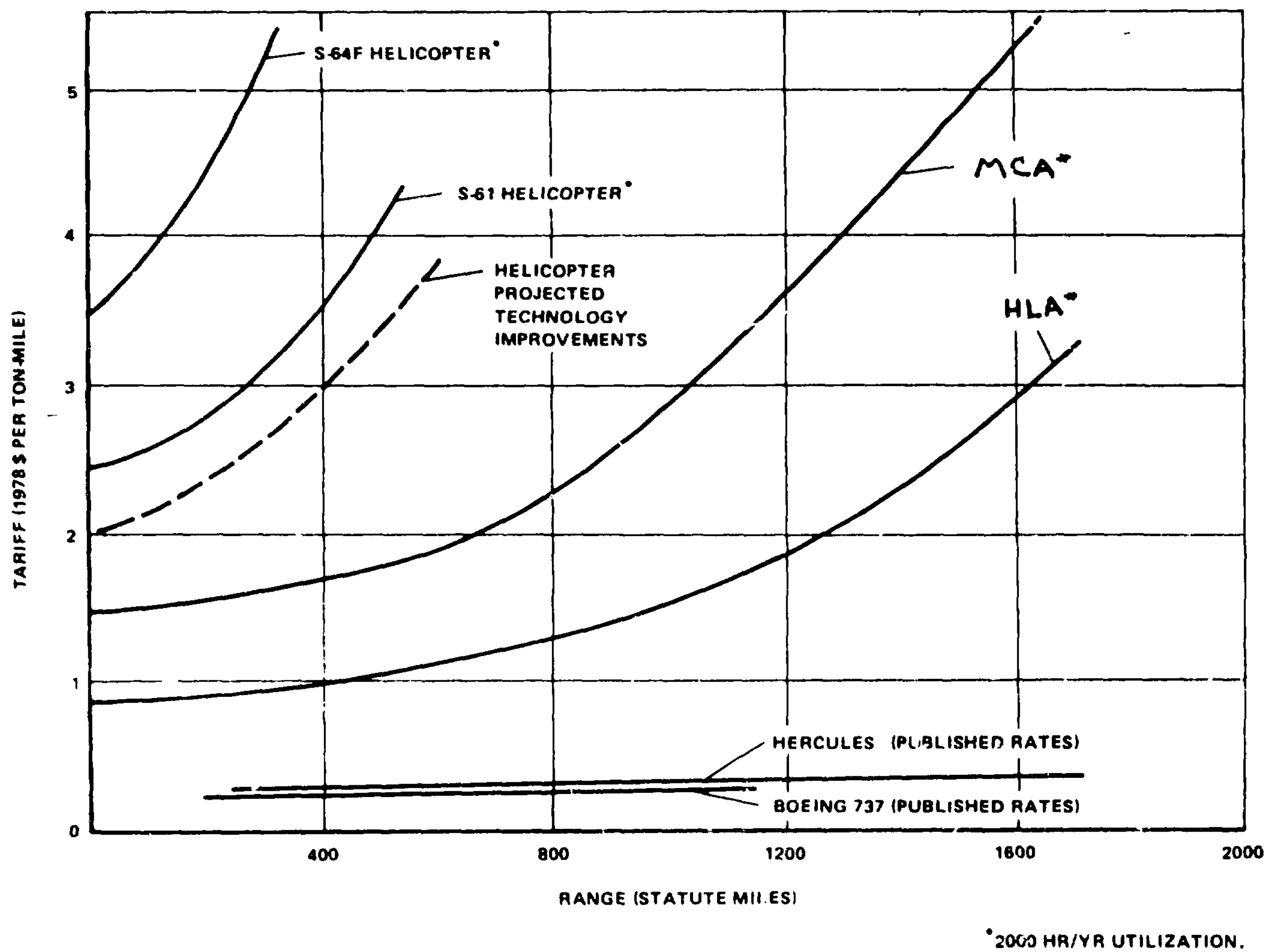

Figure 6 COMPARISON OF TARIFFS FOR VARIOUS AIRCRAFT

76. Figure 7 lists some of the potential industries having an interest in the HLA. In a study performed for NASA Ames by Booz-Allen and in independent studies performed by Goodyear, many representative companies from these industries were interviewed. It was the intent of these case studies to examine, in detail, current transportation problems and their associated costs. The problems were then reassessed, taking advantage of the projected operating performance and economics of the HLA.

77. As can be seen in Figure 8, an average of 45 percent cost savings could be realized by various projects with the introduction of the heavy lifter.

78. The final portion of the study was to develop supportable selling prices of vehicles based on projected cost benefits. Figure 9 summarizes these results and also estimates the market potential for the vehicle.

PROJECTED COSTS

79. Not unlike the development of any new aircraft, the projected costs for the programme to design, develop, test, and certify a full scall HLA are high.

80. Preliminary estimates show that an excess of $150 million would be required to build the first vehicle. Included in this cost is a two-year Technology Development/Preliminary Design phase valued at approximately $20 million. Until the completion of this phase, the true value of the prototype's cost cannot be accurately determined.

81. An outline of the development plan is shown in Figure 10. As can be seen, a 5-6 year program is envisioned.

82. A 1978 study performed by Goodyear for the Ministry of Transportation in Alberta, Canada projected the total operating costs plus tariffs of the HLA to be $6,000/hr in lift mode and $4,800/hr in ferry. These numbers must be continually refined throughout the vehicle design phase.

83. Goodyear has established $30 million as a design-to-cost goal for any production vehicles.

CURRENT STATUS

84. It is not likely that the funding for prototype development will come from the private sector. Goodyear, however, is continuing its research and development activity.

85. There are some technical risks associated with the programme. These risks can be overcome with time and money.

86. The largest area of risk is in the area of economics. There is some concern that if the development costs were to become too high, the market could not support the resultant sell price of the vehicle.

87. If the government sponsored the prototype development, the non-recurring costs would not have to be amortized over the production vehicles. This would result in a sell price which would better match the market as we understand it today.

INDUSTRIES EVALUATED HAVING HIGH HLA POTENTIAL

- LOGGING (HARVESTING SAWTIMBER)
- FORESTRY (FIRE FIGHTING)
- SHIP OFF-LOADING (PORT CONGESTION)
- POWER GENERATION AND TRANSMISSION (CONSTRUCTION)
- PIPELINE (CONSTRUCTION AND MAINTENANCE)
- PREFABRICATED STRUCTURE (TRANSPORT AND EMPLACEMENT)
- REMOTE CONSTRUCTION PROJECTS
- GENERAL HEAVY LIFT TRANSPORTATION
- OFF-SHORE PLATFORM (SUPPORT AND CONSTRUCTION)
- PETRO-CHEMICAL (SITE CONSTRUCTION)
- HIGH RISE AND BRIDGE (CONSTRUCTION)
- MILITARY APPLICATIONS
- PEOPLE/CARGO SHUTTLE (DEVELOPING NATIONS)

Figure 7

ECONOMIC BENEFITS TO USERS (TYPICAL CASE STUDIES)

HEAVY LIFT APPLICATION	TOTAL PROJECT COST ($ MILLIONS)		REDUCTION (PERCENT)
	WITHOUT HLA	WITH HLA	
POWERLINE TOWER CONSTRUCTION	48	36.2	25
MOVEMENT OF HEAVY EQUIPMENT (FIRE BREAKS)	8	0.05	99
LOGGING	18.65 (ANNUAL)	10.3 (ANNUAL)	45
PREFABRICATED STRUCTURES ACROSS RIVERS	10 (ANNUAL)	3.2 (ANNUAL)	68
PIPELINE REPAIR			
LOST COMPRESSOR STATION	0.3	0.1	66
LINE BREAK	12	6	50
EXTENSION TO WINTER SEASON (PIPELINE)			
CASE I – 48-INCH PIPE	143	138	3
CASE II – 56-INCH PIPE	167	139.5	16
OIL AND GAS DRILLING	0.56	0.15	73
MOVEMENT OF EQUIPMENT ACROSS RIVERS (PIPELINE)			
USE PUBLIC ROADS	3.7	2.6	30
CONSTRUCT TEMPORARY ROADS (10% OF DISTANCE)	5.2	2.6	50
EXTENSION OF WINTER SEASON (GENERAL)	200	190	5

Figure 8

HLA MARKET POTENTIAL ASSESSMENT

HIGH POTENTIAL INDUSTRIES	LONG-RANGE ESTIMATE		EARLY ORDERS	SUPPORTABLE SELLING PRICE ($ MILLION)
	NASA	GAC		
• SHUTTLE/GENERAL TRANSPORT	5	25	5	50
• PORT CONGESTION	80	40	5	148
• REMOTE CONSTRUCTION	25	15	5	100
• PREFABRICATED STRUCTURES	5	5	2	36
• OFF-SHORE PLATFORMS	←		TBD*	→
• BRIDGE AND HIGH-RISE	←		TBD	→
• POWER DISTRIBUTION	3	3	0	148
• RESOURCE DEVELOPMENT	←		TBD	→
• GAS AND OIL PIPELINE	←	TBD	→	138
• FORESTRY (FIRES, ETC.)	←		TBD	→
• MILITARY APPLICATION	←		TBD	→
TOTALS	118	88	17	NA

*TBD = TO BE DETERMINED AFTER OBTAINING WORLDWIDE PROJECT DENSITIES.

Figure 9

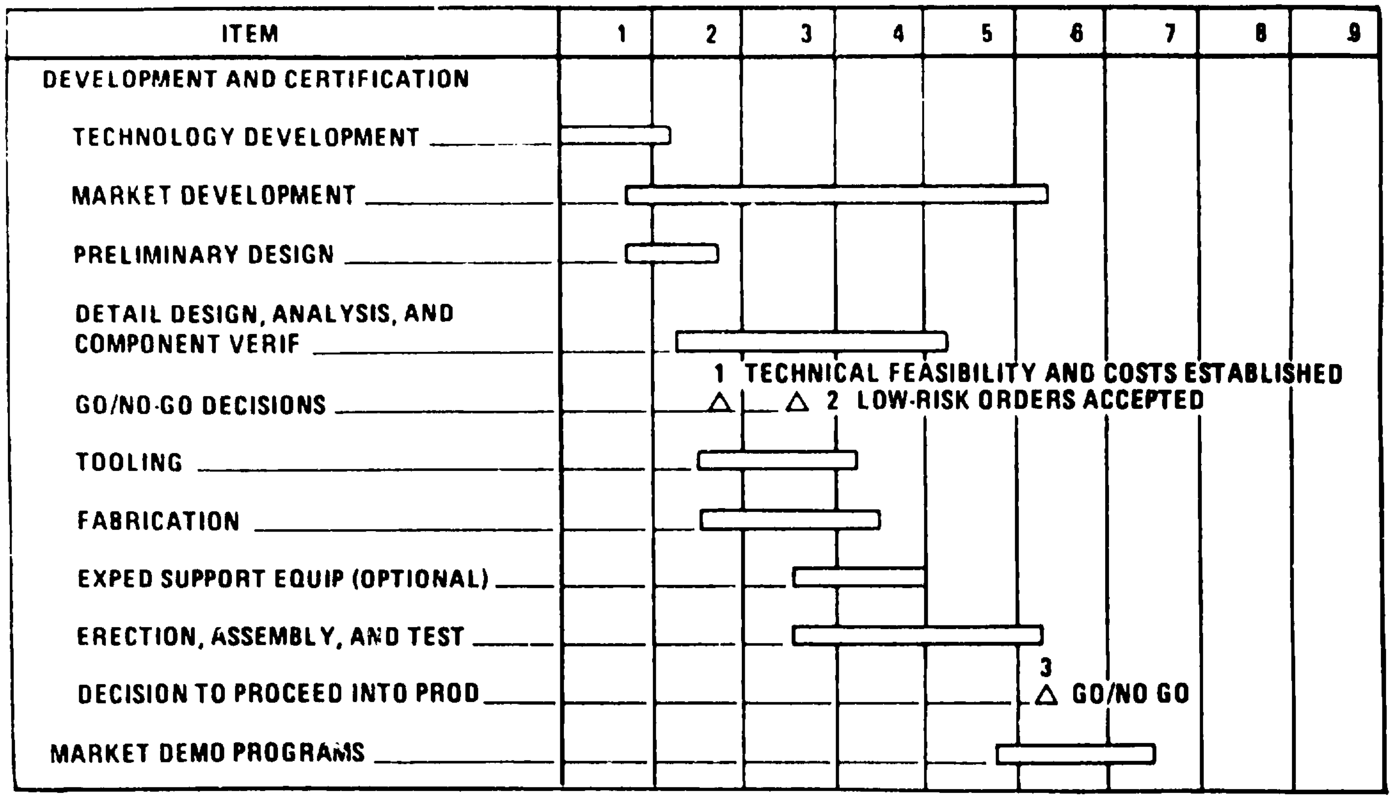

Figure 10 HLA DEVELOPMENT PROGRAM PLAN

88. The need to vertically lift and transport heavy cargo is growing. The state-of-the-art of helicopter technology will not develop vehicles with lift greater than 35-40 tons in the foreseeable future. The Heavy Lift Airship appears to be the only "near term" solution to the peculiar transportation problems associated with developing countries.

SECTION IV

TETHERED AEROSTATS

INTRODUCTION

89. It was in 17?3 that two Frenchmen, the Montgolfier brothers, made the first manned ascent in a hot-air free balloon, when the two men were carried over Paris and got this whole lighter than air (LTA) business "off the ground." In all likelihood the Montgolfier brothers made a few preliminary flights with their hot-air balloon tethered to the ground, so we can probably trace the beginnings of tethered aerostats to about the same time.

90. However, American history tells us that the first practical use of a tethered aerostat occurred during the Civil War in the United States in the 1860s when the Union Army constructed a balloon filled with flammable hydrogen and tethered it to the ground with a cable. The most interesting part of this application is the fact that the payload carried by this "spy" balloon was a man suspended in a basket beneath the balloon. From an altitude of only a few hundred feet he was able to look out across the battlefield and act as an artillery spotter.

91. The military again made extensive use of tethered aerostats in both World War I and World War II during the first half of this century -- particularly in the defense of the British Isles. The form of aerostat used was the barrage balloon -- which was a streamlined gas bag designed to lift a steel cable more than one thousand meters into the air to deter low-flying bomber aircraft. It was calculated that even a minor collison between an aircraft and the steel tether cable would be sufficient to destroy the aircraft.

92. Following World War II and until the late 1960's there was little or no activity in the tethered aerostat industry except for the continued use by the British of hydrogen-filled tethered aerostats for parachutist training. Up to six trainees can be carried aloft to about three hundred metres using the lift of the aerostat. They make their training jumps from this altitude and when all of the trainees have parachuted from the personnel support structure under the balloon, the craft is hauled back to the ground by its tether and another load is carried aloft. The cost of this LTA operation is only a fraction of the cost of other parachute training methods and has been in use more or less continuously since World War II until the present time.

93. In 1968 a research and development programme for tethered aerostats in the United States was instituted at the Range Measurement Laboratory (RML) at Cape Canaveral, Florida. The RML began to experiment with larger aerostats patterned after the old British barrage balloons. These balloons were designated BJ after the names of the inventors "Bateman and Jones." The volume of the BJ series balloons ranged from 600 cu m (21,200 cu ft) to as large as 2,500 cu m (88,000 cu ft). This series of balloons set an altitude record for tethered aerostats for the time period when a tandem series of two aerostats were flown to altitudes of 4,000 (13,000 ft) and 3,000 meters (9,800 ft), respectively. In this arrangement, the upper balloon was launched first and raised to an altitude of about 1,000 metres (3,280 ft) on an auxiliary tether. Upon reaching 1,000

metres altitude, it began to put tension on the main tether, which was rigged from the confluence point of the upper balloon to a lifting point on the top of the lower aerostat. The lower aerostat of the tandem pair was then launched and the pair of aerostats outhauled on a single tether to the maximum altitude.

94. In the latter part of 1968, a $6 million research and development programme for the generation of a new "family" of aerostats was begun. This programme lasted until 1972 and produced the Family II aerostat series. The first one of these aerostats, a 5,600 cu m (19,750 cu ft) version, first flew successfully in December of 1971. Since that time, there have been 35 Family II aerostat systems produced in the United States in sizes ranging from 5,600 cu m to nearly 12,000 cu m (424,000 cu ft). These aerostats have been used in a variety of military and commercial aplications including communications relay, long line telephone relay, community telephone service, mobile telephone service, radar surveillance, electronic surveillance and a variety of sensor demonstrations.

95. As always seems to be the case in LTA, the goals were continuously raised toward larger aerostats to carry larger payloads to higher altitudes. Recently, a modern record was established when a tethered aerostat demonstrated its capability to operate successfully at 5,500 metres (18,000 ft). However, of most importance is the fact that more than $200 million has been invested in tethered aerostat systems including aerostats, payloads, and ground handling systems, for military and commercial purposes over the past ten years. Perhaps another $200 million has been spent on civil works to accommodate the aerostat systems in various locations throughout the world.

96. A recent development in the world of tethered aerostats has been the application of a large natural shaped balloon which is held captive by a tether and used as a "skyhook" in logging operations. Fifteen large balloons have been built in two sizes, 15,000 cu m (530,000 cu ft) and 17,500 cu m (618,000 cu ft), which are used in connection with yarding and winching equipment to move heavy logs from the forest, lifting them up over hills, across valleys and finally lowering them to an accessible area for transport. These balloons save millions of dollars in road construction and equipment costs which would normally be required to drag the heavy timber from relatively inaccessible logging areas. Of even more importance is the conservation of the topsoil, small timber and natural environment of the forest areas as the logs are transported up and over their surroundings instead of being dragged across the ground.

DESCRIPTION

97. The construction of the basic modern-day tethered aerostat is quite similar to that of the late model nonrigid airships in use throughout the world. The aerostat hull is a single compartment gas envelope which is an aerodynamically shaped body of revolution with either three or four tail fins mounted on the aft secton of the hull. The aerostat is inflated with helium, an inert gas, to provide safe buoyant lift. The shape of the aircraft is maintained by keeping the pressure of the gas inside the hull slightly above the ambient atmospheric pressure. The superpressure normally used is between 50 (1.91 in) and 75 mm (2.95 in) of water. Within the single helium compartment there is a small balloon called a ballonet which is inflated with air. This airfilled compartment is formed by a flexible fabric diaphragm. As the aerostat ascends in the atmosphere and as the atmospheric pressure is reduced with altitude, air is vented from the ballonet through valves to allow the helium to

expand within the hull while maintaining a constant superpressure. As the aerostat is retrieved from altitude and the atmospheric pressure increases, the helium compresses and air is forced in to the ballonet compartment by electrically powered blowers. The totality of blowers, valves, air ducts, pressure sensors, switches and electrical controls which operate together to maintain the constant internal pressure of the aerostat and thereby its aerodynamic shape is called the aerostat pressurization system. Unlike manned aerostats which characteristically have two or more ballonets for pressure and trim control, all tethered aerostats up to the present time have been constructed with a single large ballonet. The size of the ballonet is selected to match the intended operating altitude of the aerostat system; a large ballonet volume (as a percentage of the total aerostat volume) is required for high altitude applications. For example, in order for an aerostat to reach an altitude of 5,500 meters (18,000 ft) where the atmospheric pressure is approximately one-half the pressure at sea level, the ballonet must be at least 50% of the total hull volume to allow for the expansion of the helium during the ascent from the surface to the operating altitude. The ballonet volume in modern aerostats has varied from as little as 25% of tne total aerostat volume to as much as 56% of the total aerostat volume.

98. The ballonet in a tethered aerostat must be designed to permit longitudinal stability at any fullness. An airship having a 50% ballonet volume can experience big fore and aft excursions in the center of buoyancy with the ballonet approximately half full of air as the aerostat pitch changes and the large air bubble shifts fore and aft. The large movement of the center of buoyancy is detrimental to the aerostat stability and must be carefully considered in the overall design of the system. The ballonet is built out of lightweight synthetic material (dacron or nylon) which is coated with highly flexible substances such as polyester or polyether urethane which is also resistant to helium permeation.

99. All of the loads that are supported by the aerostat as well as the aerostat suspension system which tethers it to the ground are externally attached to the aerostat hull and do not make use of an internal suspension system similar to those used on manned airshps. Another visible difference between the tethered aerostat and the manned aerostat is the use of air-inflated or helium-inflated fins. Characteristically, the fins on tethered aerostats are many times larger in area than the fixed and movable control surfaces on manned airshps.

100. The working payload (usually electronics) is normally housed within an inflated, streamlined windscreen which is attached to the belly of the aerostat. The windscreen is normally pressurized with air from the ballonet. Windscreen materials customarily have been similar to the ballonet fabrics except that the outer surface is coated with a white pigmented polyester urethane which is resistant to the environment.

101. Because the tethered aerostat does not have a structurally reinforced nose like manned airships to withstand the dynamic pressure of high velocity winds, the internal pressure in the aerostat is referenced to the dynamic pressure as measured at the aerostat. This differs from the manner in which manned airship pressure systems operate. Manned blimps always maintain a superpressure above the ambient <u>static</u> pressure; tethered aerostats operate at a superpressure

above the ambient dynamic pressure. Therefore, in very high wind velocities (up to 105 knots at 3,000 metres (9,800 ft)) the total superpressure within the aerostat hull may reach a value approaching 175 mm (6.9 in) of water in order to preclude dimpling of the nose by the wind forces.

102. The hull envelope for a nonrigid aerostat must possess high strength-to-weight and low permeability. Depending on anticipated hazards, it may be essential that the envelope resist the attacks of weather or that repeated handling not degrade other required properties. Minor damage should not lead to catastrophic failure. The cost of the hull envelope, although secondary to most other requirements, must remain within reason. Lastly, high-strength sealing techniques must be available to weld panels into a continuum that possesses all essential envelope characteristics. The hulls of tethered aerostats are constructed out of the most modern synthetic materials available today, i.e., all aerostat hulls use single or multiple ply dacron cloth that is either coated with a synthetic material such as polyurethane, or that is laminated to synthetic films such as myiar or tedlar. These materials achieve a very high degree of helium integrity. The strength of a present-day aerostat hull material is about equivalent to the strongest nonrigid airship hull material ever built yet the weight of the material used in the construction is on the order of 1/2 that of previous manned airships.

103. Although there are no active controls on a tethered aerostat in the form of rudders, elevators, thrustors, etc., the aerostat uses a telemetry system to relay to the ground the several parameters which accurately describe the status of the aerostat, particularly the operation of the pressurization system. Characteristically the helium hull presure, ballonet pressure, empennage pressure and the windscreen pressure are transmitted to the ground as well as the status of all of the pressure relief valves (OPEN or CLOSED) and the blowers (ON or OFF). There is also a command telemetry system operated from the ground console that can be used to command blowers ON or OFF and cause valves to OPEN or CLOSE. The command system is used in emergency situations to override the normal automatic operation of the aerostat pressurization system.

104. Although it is not intended that tethered aerostats be operated in thunderstorm conditions, precautions have been taken in the construction of the entire system to make each component sufficiently strong to permit the system to survive under moderate thunderstorm conditions in the event that such storm penetration cannot be avoided. As part of the system for those aerostats which are intended to operate in areas of high thunderstorm probability a lightning protection system has been added. Heavy gauge aluminum wires are suspended above and below the aerostat and along each side with all parts of the system bonded together and to the outer conductive jacket of the tether. Thus a form of Faraday Cage encloses the aerostat and intercepts lightning strikes which might otherwise damage or destroy the aerostat system. The conductive jacket on the tether is designed to conduct the heavy lightning currents safely to ground; in fact, the tether jacket is designed to withstand direct lightning strikes while protecting the strength elements of the tether from lightning damage.

105. The only visible link between the aerostat and the ground is the tether. This system element has been the subject of much research and development in recent years. Since aerostat performance is dependent almost entirely on the buoyancy of the lifting gas countered by the weight of the system, a considerable effort has been directed toward the development of a high strength,

low weight tether. Cables constructed of high tensile steel were used for many years and were particularly useful in the barrage balloon application. However, with the discovery of synthetic fibers having a greater strength to weight ratio than steel, new lightweight tethers with high elasticity were made from polyester fibers held together in an unplaited, untwisted bundle by an outer plastic jacket. This no-lay-rope, made of Dacron fibers has been called NOLARO and has been in wide use in tethered aerostat applications for more than ten years. Recently a new synthetic aramid fibre with the trade name Kevlar has been developed into a tether for aerostat application and has a strength to weight ratio several times that of steel cables.

106. Power systems for tethered aerostats were non-existent on operational barrage balloons; they required no obstruction lighting and internal hull pressure was maintained by capturing the ram air pressure of the wind in large scoops and directing it into the ballonet. Modern tethered systems carry sophisticated payloads and require a considerable quantity of electrical power to operate the aerostat pressurization system and the payload. System operational safety is derived from a large number of blowers that can be used in emergency conditions to permit high recovery (descent) rates for storm avoidance. The large blower capacity places additional demands on the power subsystem. At present two forms of power systems have been developed and are in operation today. The older of the two types employs an airborne lightweight internal combustion engine-generator combination. This device has been used successfully for many years with gasoline driven reciprocating engines, rotary drive gasoline engines (the Wankel engine) and most recently with a lightweight diesel engine. Power generating capability of up to 15 kva has been provided by this means. The disadvantage of the motor-generator system is the requirement to recover the aerostat frequently to replenish the fuel supply.

107. A relatively new development (in the past five years) has been the transmission of electrical power through the tether to operate the aerostat system. The original power tether made use of a contra-helical steel cable with the electrical conductors at the center of the cable. The latest versions of the power tether uses a Kevlar strength member and is capable of supplying up to 31 kva of electrical power to the aerostat system. The attractiveness of the power tether is its reliability in all climates at all altitudes and the inherent ability it provides for the aerostat system to remain aloft for relatively long periods of time.

108. With the development of the Family II aerostat, some very sophisticated ground handling equipment has emerged to assist in the inflation, handling and mooring of these big aerostats. First of all, due to the widely dispersed operating sites around the world, a means had to be developed to safely inflate the aerostats outdoors. The smaller aerostats in the 5,600 (19,750 cu ft) and 7,000 cu m (24,700 cu ft) class have been held firmly to the ground with their handling lines (called "closehaul" lines) and the hull inflated with helium during an extended quiescent period in the wind and weather -- usually at night. The inflated pressurized hull is relatively safe in modest winds, even crosswinds up to ten knots. The aerostat is held fast at the inflation pad until all of the rigging and essential payloads are mounted, then the fins are inflated, the airship is allowed to rise up until it is flying on its single tether and it is transferred the short distance to its permanent mooring system. The larger aerostats, 10,000 cu m (353,000 cu ft) to 12,000 cu m (424,000 cu ft) class, are inflated under a double net. The lower net drapes over the

airship hull and is weighted down along the edges with a few hundred sandbags. The upper net, which is attached along its centreline to the lower net, is drawn taut at seven strong points around the periphery. As the helium is flowed into the hull, the sandbags are moved on the lower net and the restraining lines are adjusted on the upper net to control the location of the expanding helium bubble and to counter adverse wind forces. Unexpected winds in excess of 30 knots broadside to a large aerostat have been sustained without damage to the aerostat or ground equipment.

109. Once the aerostat hull is pressurized it can be held virtually indefinitey under the net while rigging and payloads are attached provided, of course, that excessively high winds are not encountered. When the rigging is complete, the fins are inflated simultaneously while allowing the aerostat to rise up on its tether. The aerostat with the net still draped over it is transferred to the nearby mooring system after which the net is removed.

110. The mooring systems have varied widely but contain basically a mooring tower or mast to which the nose of the aerostat is moored. A circular monorail located with the mooring tower at its center, is used to tether the aerostat to the ground in the moored configuration. The suspension lines are either attached to a mooring trolley or fastened to the end of a mooring boom which rotates freely on the monorail. Separate winches are provided to control each of the aerostat handling lines, the nose line and the main tether.

111. The mooring system most widely used to date employs the rotating boom system with two closehaul winches mounted near the end of the boom, the nose line winch mounted at the bottom of the mooring tower and the entire mechanism attached to a rotating machinery enclosure which houses the main tether winch, the prime power system (diesel/hydraulic) and the control station. Five men are required for launch or recovery -- one supervisor directs the operation, three men observe the three handling winches primarily to remove or attach the lines on the winches, and one man does all the work as he controls the nose latch, the three closehaul winches, the main tether winch and the diesel engine operation. Figure 11 is a drawing showing the major components of the rotating boom type mooring system.

112. The logging operation requires an extensive array of ground handling equipment consisting of a system of cables, anchors and winches that allow the aerostat to rise up in the air and translate from one location to another laterally and then be lowered to the ground at a second location. In addition to the winch and cable system, a heavy transporter system is required to move the balloon to the bedding down area where it is stored during periods when it is not being operated or during periods of high winds. In the bedding area, the large balloon is winched down and held tightly against the ground using its own rigging and auxiliary rigging specially designed for this purpose.

PERFORMANCE CAPABILITIES OF ALTERNATIVE PLATFORMS

113. In general the objective of a tethered aerostat system is to carry as large a useful payload (including the tether) to as high an altitude as possible and operate it for as long as possible for a minimum cost. Therefore, it can be expected that the performance capabilities of the various aerostat systems are directly related to the total lifting gas volume of the aerostat system. Performance curves for four different aerostat systems are plotted in Figure 12.

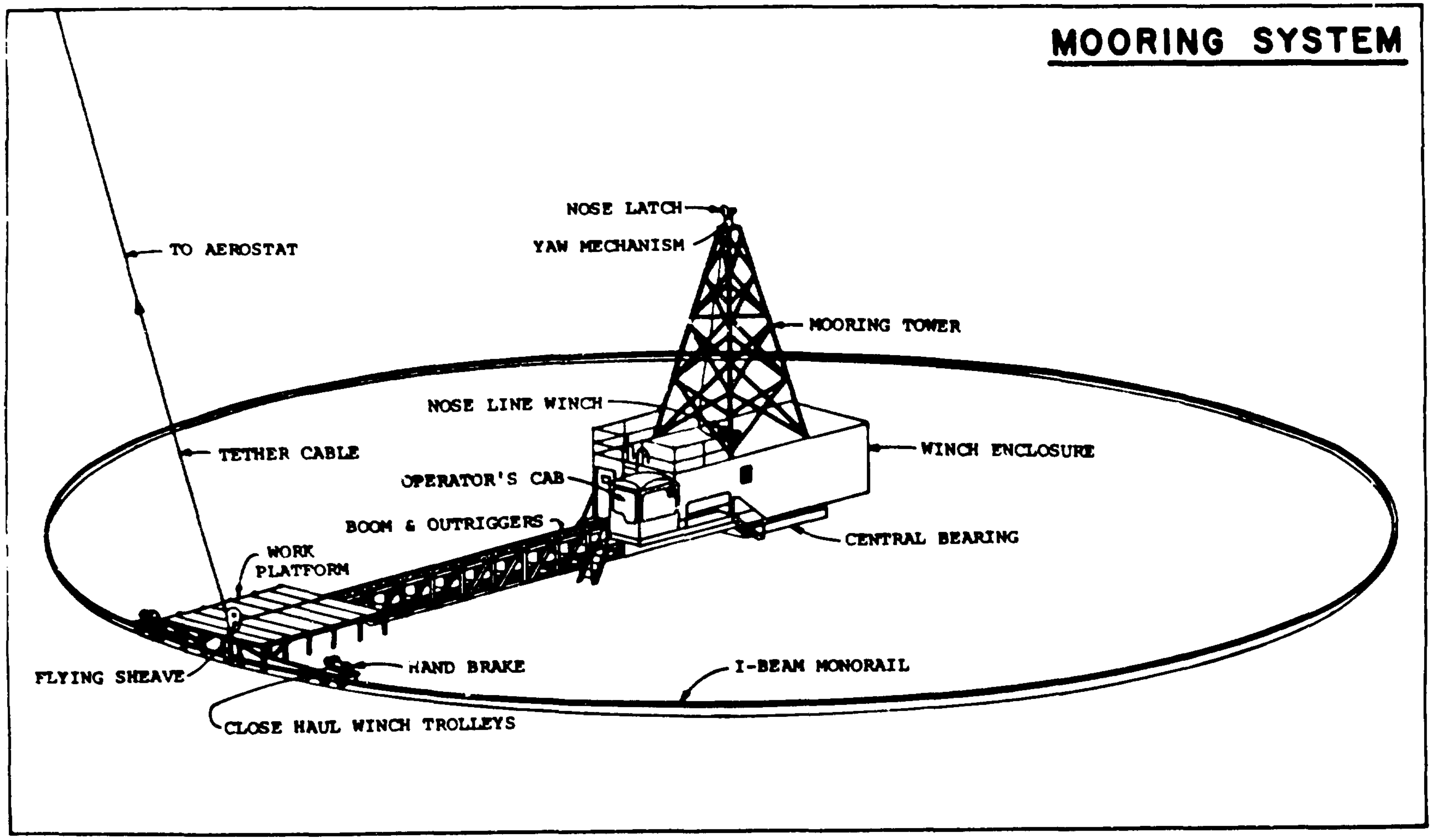
MOORING SYSTEM
NOSE LATCH
YAW MECHANISM
TO AEROSTAT
MOORING TOWER
NOSE LINE WINCH
TETHER CABLE
WINCH ENCLOSURE
OPERATOR'S CAB
BOOM & OUTRIGGERS
CENTRAL BEARING
WORK PLATFORM
FLYING SHEAVE
HAND BRAKE
I-BEAM MONORAIL
CLOSE HAUL WINCH TROLLEYS

Figure 11

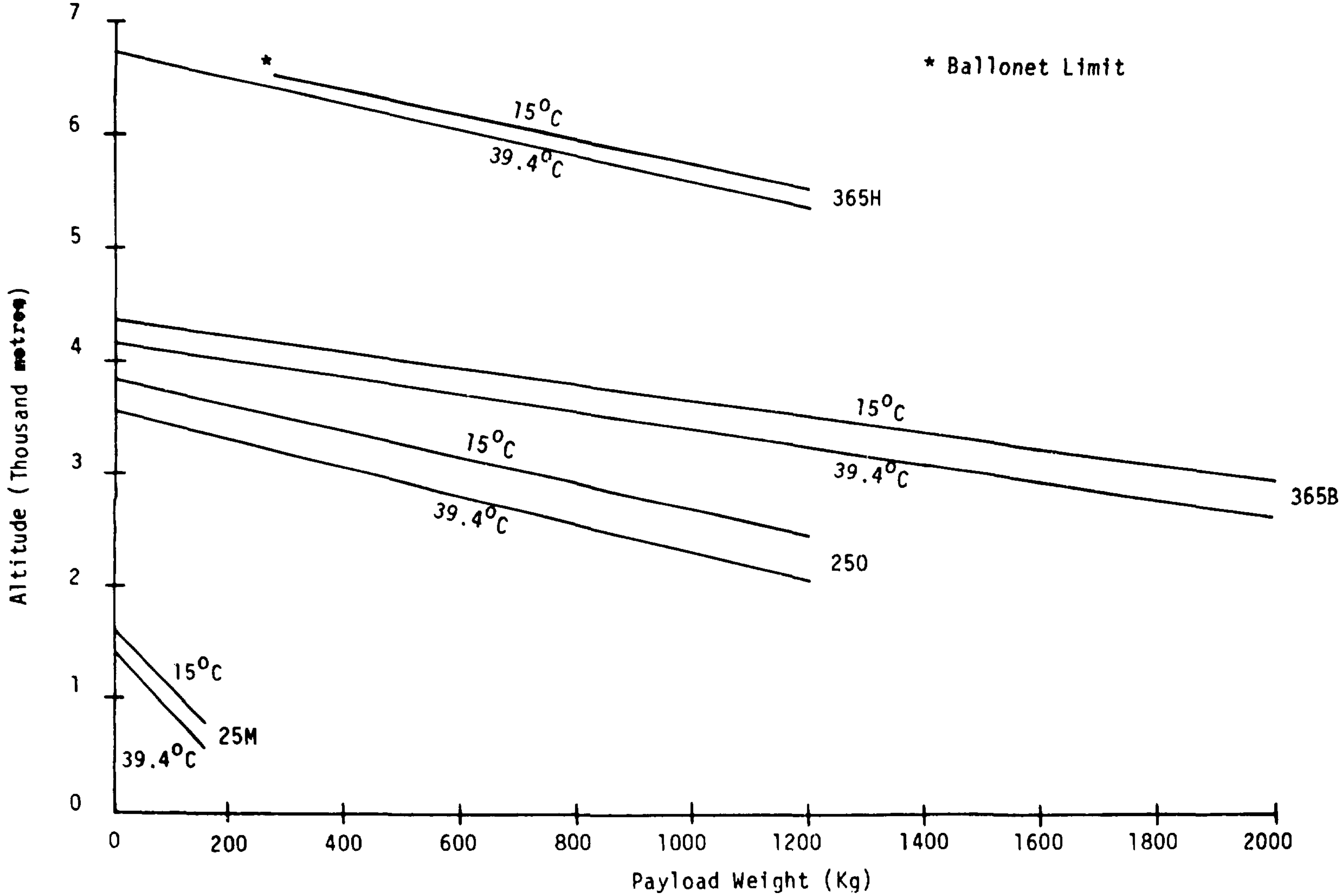

Figure 12 AEROSTAT PERFORMANCE FOR TYPICAL AEROSTAT SIZES

The four systems selected are actual operating models and are typical of what the industry offers today. The smallest of these systems is designated "25M" by the manufacturer and corresponds to a hull length of 25 metres (82 ft); it has a volume of slightly over 700 cu m (25,000 cu ft). This system is designed to be highly mobile and readily relocatable, operating from a mobile mooring system. From the performance curve it can be seen that the system can carry a modest payload to an operating altitude of about 1000 metres (3280 ft).

114. The next larger system is designated the model 250 which corresponds to the volume in English Units of 250,000 cu ft -- a metric volume of about 7,000 cu m. This aerostat system designed to operate with a payload weight of 700 kg (318 lbs) at an altitude of 3,000 metres (9,800 ft). The third system described in Figure 12 is the model 365B which was designed to have a volume of 365,000 cu ft, about 10,300 cu m, using air to inflate the fins. However, with helium employed in three fins to generate additional lift the actual total volume is nearly 12,000 cu m (424,000 cu ft). This system was designed to operate with a payload of 1,900 kg (4,180 lbs) at an altitude of 3,000 metres (9,800 ft). Both the 250 and 365B systems are designed with a lightning protection system on the aerostat and a lightning protection jacket on the tether. Both systems are designed for use with a power tether, but could employ other forms of power systems.

115. The 365H system is designed for high altitude operation in a climate where the probability of thunderstorms is very low and the likelihood of damage from a lightning strike virtually non-existent. The 365H aerostat is the same size and volume as the 365B but contains no lightning protection, uses a lighter weight tether with no lightning protection and fewer blowers in the pressurization system. The lighter weight 365H system is designed to carry a payload of 1,200 kg (2,640 lbs), to an altitude of 5,500 metres (18,000 ft) with a very much reduced operational safety factor.

116. In Figure 12 two performance curves are shown for each aerostat system to show the effect that the surface temperature has on the performance of the system. In each case, of course, the systems perform better in cold weather.

117. Figure 13 is a pictorial representation of the aerostats described in Figure 12. Figure 13 shows the relative sizes of the systems and relates them to the size of the familiar Boeing 747 jumbo jet.

POTENTIAL MISSIONS AND APPLICATIONS

118. A typical tethered aerostat payload can include up to two tons of communications equipment to be lifted to an altitude of 3 km (9,800 ft) with a significant loading safety margin. This payload may include commerical and educational television, a.m. and f.m. radio broadcasting equipment; off-the-air receivers; radar surveillance equipment; translating equipment; high-density wideband communications equipment for multichannel voice and data transmission; mobile and maritime networks, and equipment performing numerous other functions such as: wide area paging, emegency radio broadcasting, wide area data collection, remote area meteorological observation, optical scanning and monitoring.

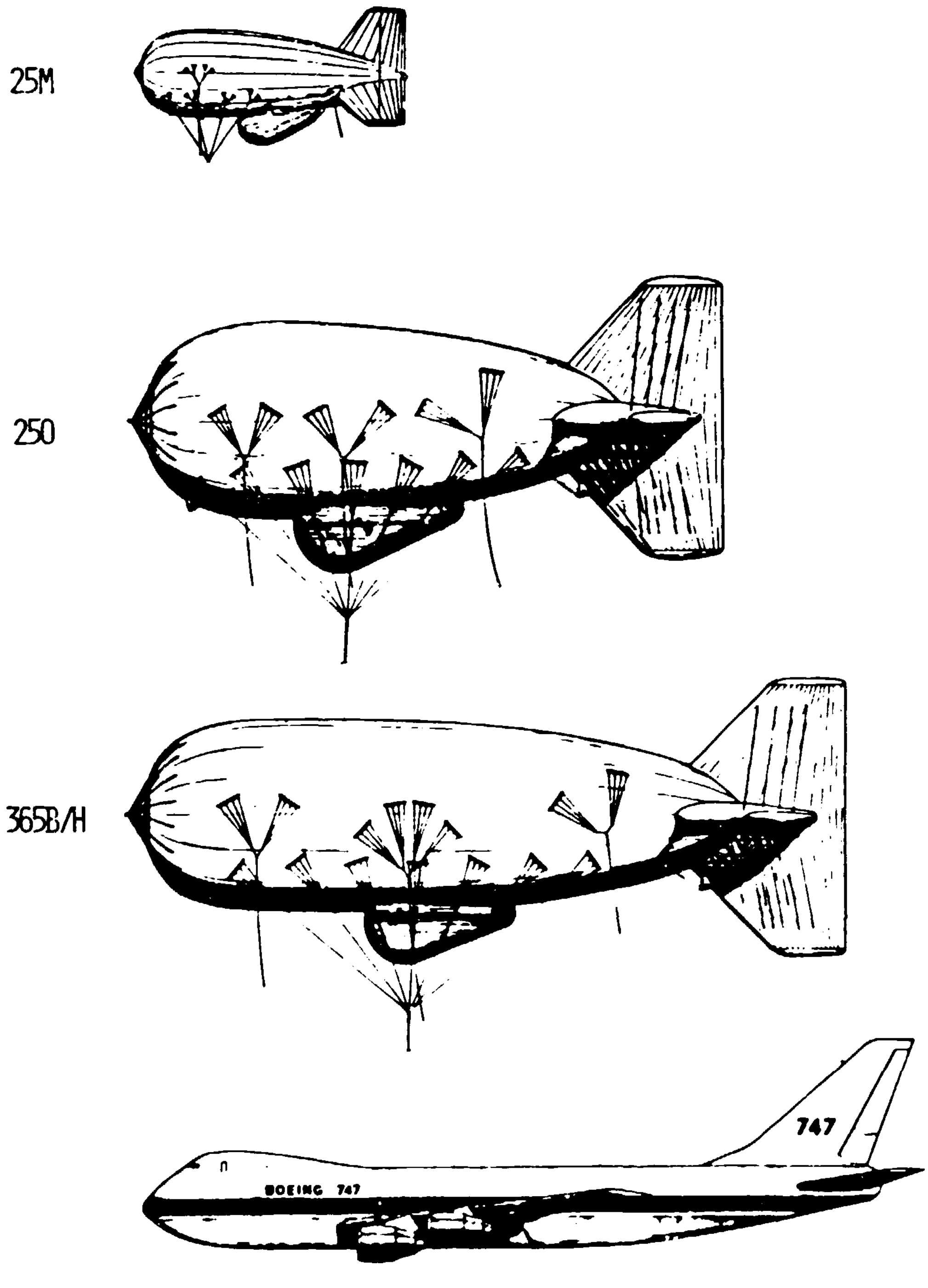

Figure 13 COMPARATIVE SIZES OF AEROSTATS

119. An aerostat TV broadcasting system has an inherent advantage over conventional broadcasting systems in its ability to cover a vastly greater area with a single transmission system. Lower costs. frequency conservation and performance improvement are the ultimate results. Since broadcasting in the United States is regulated by the FCC (Federal Communications Commission) the regulations of that body are used as a basis for comparing the performance of a typical TV system with that of conventional broadcasting systems. The FCC describes coverage in terms of field strength leading to Grade A or B picture quality. Considering the lower v.h.f. band, the median field strengths required for channels 2-6 are 2,500 μV/m for Grade A, and 225 μV/m for Grade B service. The factors affecting the actual received field strength are so numerous and difficult to predict that a statistical approach is used. This approach predicts field strength present in the best 50% of receiving locations for 50% of the time. Using these field strength predictions the chart of Figure 14 has been developed which shows the obvious advantages of the tethered aerostat system over conventional broadcasting. Conventional transmission is normally restricted, by practical considerations, to an effective tower height of 300 meters (1,000 ft); a tethered aerostat antenna is nominally at an altitude of 3,000 metres (9,800 ft). The aerostat system, with a lower effective radiated power (e.r.p.) of 2.5 kW, provides a much larger and superior coverage than a conventional terrestrial system would provide with an e.r.p. of 10 kW. FCC signal quality is based on a typical receiver with a noise figure of 12 dB for v.h.f. and 15 dB for u.h.f. and antenna gains of 6 dB for v.h.f. and 13 dB for u.h.f. Low-cost receivers with 6 dB noise figure for v.h.f. and 8 dB for u.h.f. and antennas with 13 dB gain at v.h.f. and 18 dB at u.h.f. are now available which can be utilized to provide still further improvements. Similar statistical techniques are used to estimate f.m. broadcasting service quality on a 50-50% basis. The objective field strength on this basis is 1,000 μV/m for urban areas, and 50 μV/m for rural areas. Figure 15 compares conventional and tethered aerostat systems for f.m. radio broadcast coverage at frequencies of 88 to 108 MHz.

120. Similar performance analyses can be applied to many of the other forms of communications relay missions fulfilled by tethered aerostat. Of equal importance with technical performance is the "cost performance" of aerostat systems where it can be shown quite easily that in most areas of the world the initial cost of the system, its installation and, in particular, its operating cost in comparison with conventional terrestrial communication systems, the tethered aerostat system enjoys a significant advantage.

GROSS ESTIMATE OF COSTS

121. Budgetary estimate for a 25M aerostat system excluding the electronic payload is approximately U.S. $850,000 which includes the following equipment:

Aerostat

122. One 25M aerostat configured to mount an electronics payload and including the following components:

A. Power distribution unit
B. Emergency descent battery
C. Pressure control unit

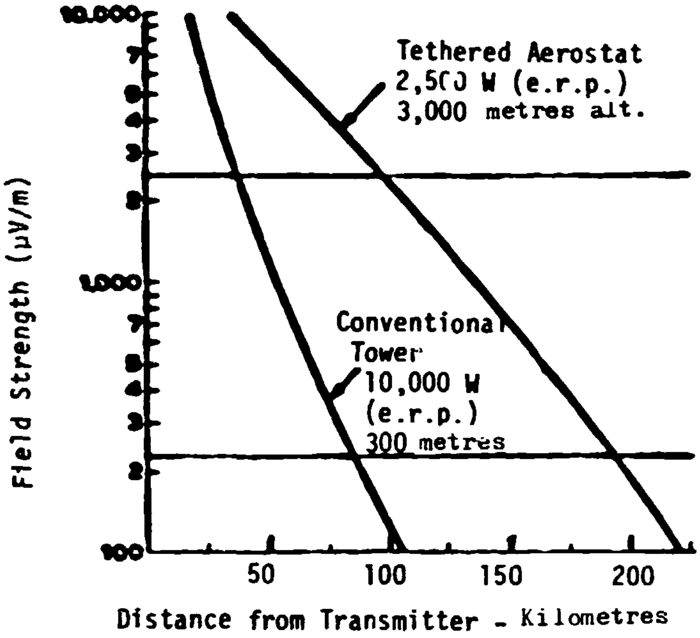

Figure 14 COMPARISON OF TETHERED AEROSTAT & CONVENTIONAL TV

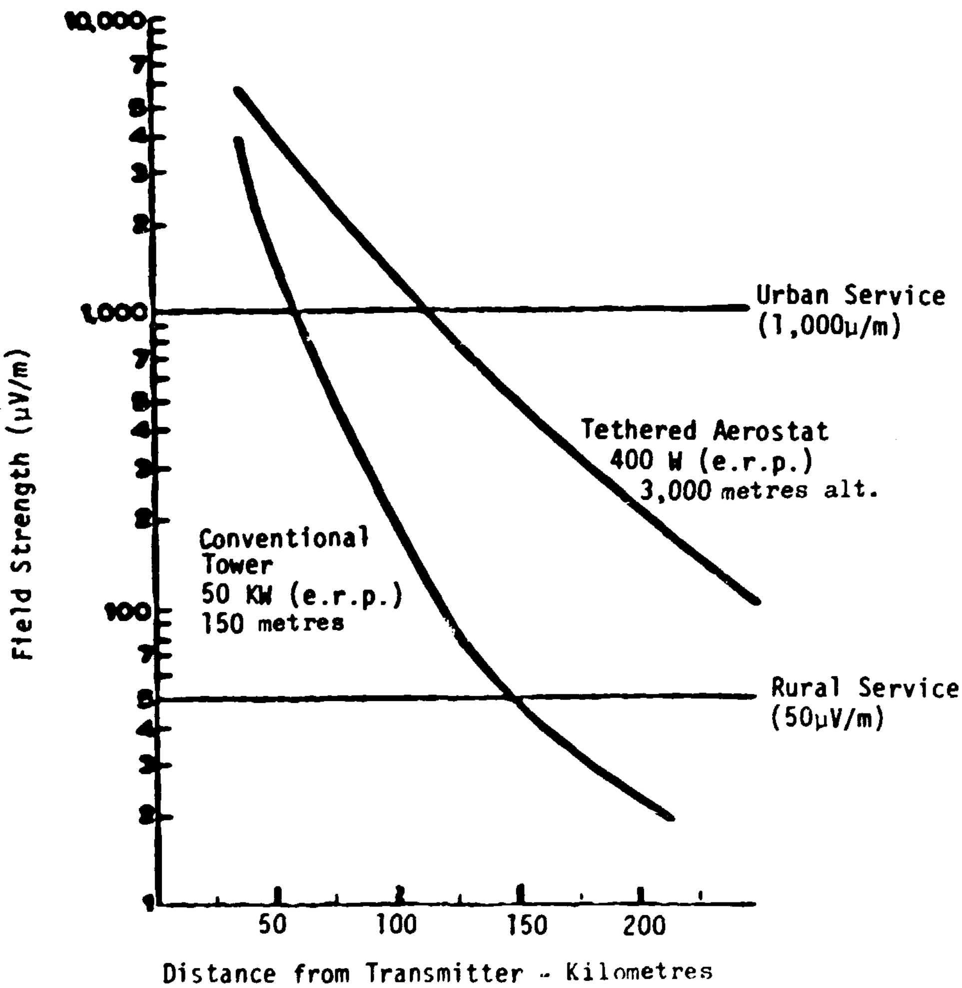

Figure 15 COMPARISON OF TETHERED AEROSTAT & CONVENTIONAL FM BROADCAST

D. Nose mooring assembly
E. Windscreen
F. Lightning protection cage
G. Valves and blowers
H. Lines and hardware

Airborne Electronics

The airborne electronic and mechanical components required to suspend the payload and monitor aerostat functions including:

A. Attachment truss
B. Payload support structure
C. Azimuth positioning system
D. Telemetry, command and data link equipment

The airborne electronics do not include the payload electronics.

Mooring Trailer

One complete transportable mooring system installed on a flatbed trailer and including:

A. Rotek bearing
B. Boom and tower assemblies
C. Flying sheave
D. Tether winch and drum
E. Closehaul and nose line winches
F. Hydraulic system
G. Electrical motors
H. Operator's control station
I. Ground installation anchors

Tether

Complete power tether system including:

A. 1050 metres of steel cable with power conductors
B. Tether transmission and sliprings
C. All power conversion equipment including motor-generators, control panel and transformers

Operations Trailer

One flatbed trailer for command, control and support, including:

A. Two diesel generators
B. Fuel tank
C. Operations shelter with temperature control
D. Telemetry, command and data link equipment
E. Mounting provisions for helium containers

Ancillary Equipment

Aerostat and ground station equipment used to transport and deploy the system including:

A. Aerostat and payload storage boxes
B. Aerostat inflation ground cloth
C. Auxiliary blower
D. Intertrailer cabling, helium inflation hose and inflation blower duct

The budgetary price estimate for a complete model 365B/H aerostat system in single unit quantity, excluding the payload, is $5,400,000 FOB, Baltimore, Maryland U.S.A. Included in the estimate are all aerostat-borne subsystems normally furnished by the manufacturer as well as the aerostat site ground control subsystem. Other items such as spare parts, training, test and site support equipment, shipping, site preparation and civil works, installation and operation and maintenance are not included at this time. The estimated payload cost would be an additional one to three million dollars depending on type, quantity, and complexity of the services required.

Aerostat System

One (1) model 365B or H Aerostat System completely equipped for flight operations configured to mount an airborne electronics payload. The aerostat includes one each of the following subsystems:

A. Power distribution and control subsystem
B Emergency descent subsystem
C. Mooring assembly including probe, nose battens and nose mooring cone
D. Windscreen
E. Strobe light subsystem
F. Lightning protection subsystem (not on 365H)
G. Helium pressure relief valves
H. Air pressure relief valves
I. Blower subsystem
J. Aerostat telemetry and command subsystem
K. Closehaul and confluence lines
L. Confluence point hardware
M. Wiring harness

Mooring System

One (1) Mooring System for the model 365 aerostat including one each of the following subsystems which form a part of the standard Mooring System:

A. Hydraulic main tether winch with capstan and drum
B. Two closehaul winches
C. One nose line winch
D. Auxiliary power unit
E. Mooring tower and main tether winch housing structure
F. Operator's cab and control unit